OLD-TIME TELEPHONES

Third Edition

Ralph O. Meyer

History, Design, Technology, Restoration

Front Cover Image

The Western Electric No. 701 "Princess" telephone was introduced in the Bell System in 1959. Designed by Henry Dreyfuss and Robert Hose, this bedroom phone incorporated the same technical advances developed by Bell Telephone Laboratories for their standard post-war No. 500 telephone. ***Photo by Matthew Gay, Gregg Museum of Art & Design, North Carolina State University.***

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Old-time telephones : technology, restoration, and repair/ by Ralph O. Meyer.
First Edition

Published by TAB Books, a division of McGraw-Hill, Inc.
ISBN 0-07-041817-9 ISBN 0-07-041818-7 (pbk.)
TK6471.M49 1994
621 .386—dc20

Old-time telephones! : design, history, and restoration / by Ralph O. Meyer.
Second Edition

Published by Schiffer Publishing Ltd., Atglen, PA
ISBN 0-7643-2282-6 (pbk.)
TK6471.M48 2005
621.386——dc22

Old-time telephones / by Ralph O. Meyer.
Third Edition

Published by North Carolina State University, Raleigh
ISBN 978-0-692-11204-5 (electronic pdf)

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Preface

Since publication of the 2nd edition of Old-Time Telephones, some additional errors were found in the text but the errors were small and did not justify a revision. More recently, the author has been writing a technical column, based on this book, for a newsletter of Telephone Collectors International. In the newsletter, improvements were made in the description of many topics that are covered in Part One of the book. The author is also working with Prof. R. A. Flinchum at North Carolina State University on design topics related to Part Two of the book. The work with Flinchum uncovered major errors in the common understanding of the role of Henry Dreyfuss and others in the design of Bell System telephones.

Together, these improvements and errors prompted this revised 3rd edition. The main features of the 1st and 2nd editions are retained in the 3rd edition. All known errors are corrected. Improvements are made in technical descriptions of historical developments, including the addition of new diagrams. The role of Dreyfuss and others in the design of Bell System telephones is clarified, especially the role of George Lum, who seems to have been overlooked by historians. And a few other miscellaneous improvements and updates are included, such as addressing the compatibility of old telephones with internet and wireless telephone service.

To make this information available to the widest audience, it was decided to publish the 3rd edition electronically as a searchable pdf file, located on a prominent web site, and available for downloading free of charge. Because of the searchable nature of this file, an index is not included.

R. O. M.

The author in 2006 at Telephone Collectors International show in Pittsburgh.

Part One
History

Chapter 1
Early Developments and the Bell Patent

In 1875, the year before the all-important telephone patent was issued, two people were working separately on telegraph improvements that would lead to the development of the telephone. One was Elisha Gray and the other was Alexander Graham Bell.

The Ohio-born Gray, then 40-years old, had received his first telegraph-related patent eight years earlier for a non-sticking relay (Hounshell 1975). This and other Gray patents were sold to the Western Union Telegraph Company. Later, with financial backing from a Western Union executive, Gray purchased half interest in a telegraph instrument manufacturing shop in Cleveland and renamed the shop after its two owners. The firm was called Gray & Barton. In 1872, Western Union purchased a one-third interest in Gray & Barton and changed the name again, this time to the Western Electric Manufacturing Company, drawing on the telegraph company's own name.[1] Gray remained in a key position with Western Electric.

Bell, just 28 years of age in 1875, was born in Scotland.[2] He was the son and protégé of a distinguished professor of elocution, who had become well known for a written code that described speech patterns. Five years earlier, Bell had moved to Canada with his family and then relocated to Boston, where he gave lectures and private instruction in speech therapy for the deaf. He had recently been appointed professor of vocal physiology at Boston University. This appointment gave him the title, professor.

Bell was working part time on telegraph improvements with the financial backing of families and friends of his deaf students. One of his backers, Gardiner Hubbard, was a prominent lawyer in Boston who had a daughter named Mabel; she had become deaf at age four as the result of scarlet fever. Bell tutored Mabel, then in her middle teens, and later they were married.[3]

The science of electromagnetism was still very young in 1875. In 1819, Hans Oersted discovered that a magnetic needle is deflected by a wire carrying electric current. In 1820, Andre Ampere formulated a law to mathematically relate the strength of the magnetic field to the current producing it. Several years later, in 1824, William Sturgeon made the first electromagnet as we know it today. In 1827, Georg Ohm discovered the relationship between voltage, current, and resistance in a circuit. Then, Michael Faraday, in 1831, and Joseph Henry, at about the same time, independently discovered that a changing magnetic field induces an electric current in a nearby conducting circuit.[4]

These principles of electromagnetism were put to use shortly after their discovery, and by 1875, the telegraph had been in commercial operation for more than 35 years. The first successful telegraph was developed in England by William Cooke and Charles Wheatstone (Hubbard 1965, 58-86).[5] Like Oersted's experiments, their instruments used magnetized needles that were deflected by electric currents passing through nearby wires -- adjacent coils in this case.

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[1] In 1926, Western Electric, by then ironically the exclusive manufacturing arm of the Bell System, spun off another firm called the Graybar Electric Company (Hounshell 1975, 137). Named after the original partners, Gray and Barton, Graybar sold Western Electric manufactured hardware commercially -- that is, outside of the closed Bell System.

[2] A detailed account of Bell's personal life is given in Bruce (1973).

[3] Bell and his wife Mabel had two daughters, Elsie and Marian (Bruce 1973, 422-429). Elsie married Gilbert Grosvenor, president of the National Geographic Society, and Marian married David Fairchild, a noted botanist.

[4] Notice how many electrical units are named after these 19th Century physicists, who made their discoveries within a period of about a dozen years: magnetic field strength is measured in oersteds (also gauss), electric current is measured in amperes, resistance is measured in ohms, capacitance is measured in farads, and inductance is measured in henrys. See the Appendix for further information on these basic units and concepts.

[5] Wheatstone is noted more for the electrical bridge circuit that bears his name. See the Appendix for a description of the Wheatstone bridge.

In the United States, Samuel Morse reportedly knew little of the work of Cooke and Wheatstone (Thompson 1947, 8). Following Sturgeon's work with electromagnets, rather than using Oersted's deflecting needles, Morse developed an armature-type telegraph. In its early forms, the electromagnet moved an armature carrying a pencil or stylus, which in turn left a code of dots and dashes on a scrolling strip of paper (Morse code). Later, the stylus was left off and the coded signals were interpreted by ear.

Figure 1-1 shows a much later standard telegraph sounder of the Morse type, and Fig. 1-2 is a simplified diagram of the circuit of such a telegraph set. A spring held the heavy armature against an upper stop. When the key was closed, the electromagnet pulled the armature to a lower stop. The sound of the armature hitting the stops was used to communicate the audible Morse code signals.

Fig. 1-1. Typical Morse-type telegraph sounder of the late 19th century. The set shown was manufactured by Pennsylvania Railroad's Altoona Shops.

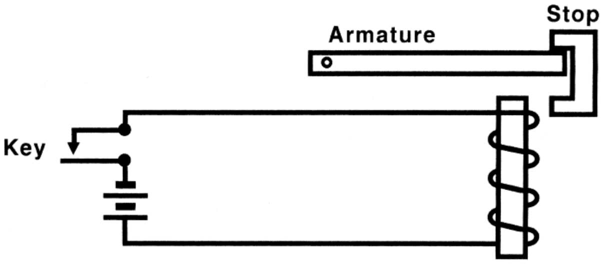

Fig. 1-2. Basic telegraph circuit with a Morse-type sounder.

Although the telegraph continued in use for a long time, the concept of a telephone emerged early. In 1854, a Frenchman named Charles Bourseul published the first known discussion on the transmission of the spoken word by electricity.[6] Bourseul, with reference to the Morse system of telegraphy, envisioned extensions of that technology. He spoke of the use of a flexible disk that would alternately make and break the connection with a battery to reproduce sound vibrations.

Philip Reis, a German physicist, constructed such an apparatus in 1861 and conducted well-publicized experiments. The operating principles of Reis's "telephone," as he called it, are illustrated in Fig. 1-3. The transmitter consisted of a vibrating diaphragm with platinum contacts at its center that were used to make and break the battery circuit. This closely followed Bourseul's descriptions. The receiver was a coil of wire wrapped around a knitting needle that had been fastened to a sounding board. The receiver was thus an electromagnet, but the magnetic field was not used to pull on a diaphragm as in a modern telephone receiver. Instead, the receiver made use of a phenomenon then called the Page effect and more recently known as magnetostriction (Wert and Thomson 1964, 379). In this phenomenon, the length dimension of a magnetic material is elongated when it is magnetized in one direction and the dimension is shortened when it is magnetized in another. When the direction of magnetization is rapidly changed, as in the alternating field of an electromagnet, the repeated lengthening and shortening causes the material to emit faint sounds. The frequency of the sound happens to be double that of the applied frequency.

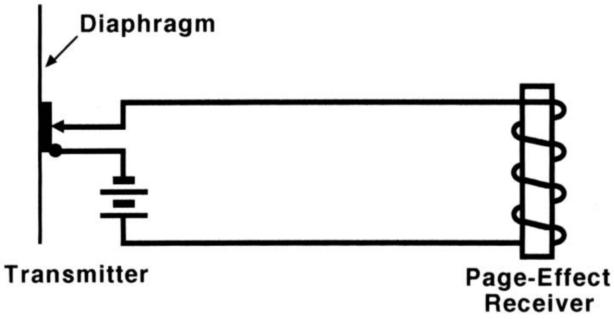

Fig. 1-3. Circuit of Reis's telephone of 1861 with make-and-break transmitter and Page-effect receiver.

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[6] A full translation of Bourseul's short paper and an excellent discussion of the Reis telephone are given in Miller (1930, 30-35).

The Reis telephone was not a success, and Kempster Miller summed up the situation like this (Miller 1930, 47):

> It is perfectly clear in the light of present knowledge why the methods of Bourseul and Reis could not succeed. The "make and break" principle was obviously all wrong. Furthermore, Reis' receiver, depending on the "Page Effect," would have been most inefficient even if it had been coupled with a transmitter based on the correct principle.

The telegraph thus continued in use as the sole means of electrical communication, and as demand increased, multiple telegraph lines had to be constructed. There was, therefore, an incentive to develop a means for sending many messages at one time over a single wire, and this multiplex capability was being worked on by Gray and Bell. The device under development was referred to by Bell as the harmonic telegraph because it used tuning forks or vibrating reeds, which produced musical tones, to generate the electrical signal frequencies.

Gray, by 1874, was experimenting with a single-tone telegraph transmitter, a two-tone transmitter, and an electromagnetic receiver (Hounshell 1975, 138-149). Figure 1-4 is a diagram that shows the operating principle of Gray's (and Bell's, as will be seen) single-tone transmitter. A thumbscrew, when properly adjusted, would make and break the electrical circuit, producing an intermittent current having the resonant frequency of the vibrating steel reed.

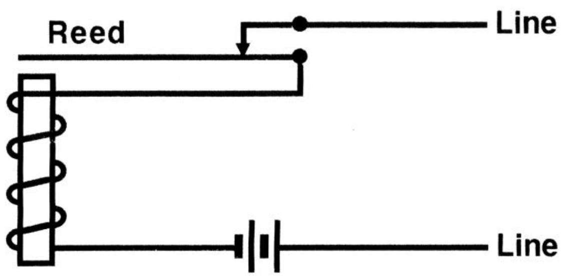

Fig. 1-4. Diagram of tuned vibrating-reed telegraph transmitter used by both Gray and Bell.

Figure 1-5, from a patent issued to Gray in July, 1875, shows Gray's electromagnetic receiver.[7] In the figure, F is the base, E are the electromagnets, and S is a hollow cylinder of metal, reportedly the lid of a shoe polish can, placed on the poles of the magnets as a resonator.

Gray described the operation of the receiver in his patent as follows:

> My invention . . . is based on the fact well known by electricians that an electromagnet elongates under the action of the electric current, and contracts again when the current ceases. Consequently a succession of impulses or interruptions will cause the magnet to vibrate, and if these vibrations be of sufficient frequency a musical tone will be produced, the pitch of which will depend upon the rapidity of the vibrations.

Thus, we see that Gray's receiver, like Reis's receiver, was based on the Page effect and was not likely to produce intelligible speech.

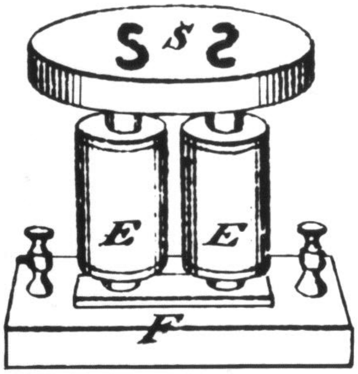

Fig. 1-5. Sketch of Page-effect receiver that would produce musical tones, from Gray's patent, applied for in 1875.

It is interesting at this point to notice how close these early instruments came to incorporating the successful characteristics of the future telephone. Reis's transmitter with its make-and-break contact was based on the wrong principle. However, if its contact was adjusted such as to always lightly touch the diaphragm, a variable resistance transmitter would be formed of the type that was later used widely (see Chapter 2). It is reported that a Reis telephone was once brought into court to demonstrate that it could not transmit speech, but that the diaphragm

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[7] Elisha Gray, "Improvement in Electric Telegraphs for Transmitting Musical Tones," Patent No. 166,095, dated July 27, 1875; application filed January 19, 1875.

became jammed against the electrode and the telephone actually worked (MacMeal 1934, 7). Reis's and Gray's receivers, based on the Page effect, were also using an ineffective principle. However, if a small gap was left between the electromagnet and the metal resonator on Gray's receiver, the result would be like the Bell-type instrument used in all subsequent telephone receivers. Gray, himself, made this step forward in his patent caveat the following year (see the following).

On New Year's Day 1875, a couple of weeks before filing the patent mentioned previously, Gray was experimenting with a multiple telegraph transmitter (Hounshell 1975, 148). When he altered the tension of the spring, he found that he "was able to initiate many different [voice] sounds involving the vowels only." Clearly, Gray believed that speech transmission could be accomplished by a single transmitter. However, no further work appears to have been done by Gray on either the transmitting or the receiving of spoken sounds prior to filing his patent caveat on February 14, 1876. With his strong ties to Western Union and his conviction that the harmonic telegraph was more important than the telephone, Gray concentrated his efforts on developing a receiver for the harmonic telegraph. In 1875, Gray filed numerous patent applications on his multiple-telegraph system.

Meanwhile, Bell's telegraph experiments continued, and his harmonic telegraph proved to be very similar to Gray's. In February 1875, Bell had a meeting with the renowned physics professor, Joseph Henry, who earlier had discovered magnetic induction (as Faraday had also done). Henry was then Secretary of the new Smithsonian Institution in Washington, where the meeting with Bell was held. Bell had been having trouble with his telegraph experiments, and he told Henry that he felt he didn't have the electrical knowledge necessary to overcome the difficulties. In a letter to his father, Bell says that Henry told him tersely, “Get it” (Bell 1875a, 7, 9). Later in the same letter, Bell says, “My visit to the Smithsonian Institute seems to me to be the brightest spot in my whole life.”

By the spring of 1875, Bell had arranged for experimental apparatus to be constructed at the Charles Williams electrical shop at 109 Court Street in Boston (Rhodes 1929, 20-25). There, he enlisted young Thomas Watson of the Williams shop to assist him. Although construction details differed from Gray's vibrating-reed transmitter, Fig. 1-4 above describes the operation of Bell's transmitters equally well. Bell's receivers, which unscrambled the multiple telegraphic signals, were similar to the transmitters except for electrical contacts, and the circuit of one of the receivers is shown schematically in Fig. 1-6.

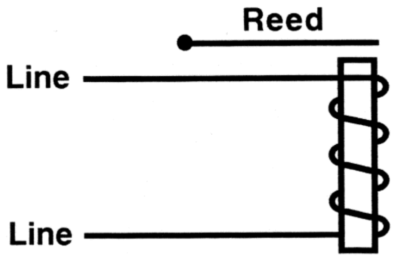

Fig. 1-6. Diagram of tuned vibrating-reed telegraph receiver used by Bell.

For Bell's experiments that spring, three transmitters with reeds tuned to different resonant frequencies were connected in parallel to a single line (2 wires). This line went between distant rooms above the Williams shop and was connected to three receivers, whose reeds were tuned respectively to match those of the transmitters. Although all three receivers were connected to the same line, a receiving reed would vibrate substantially only when the signal was generated by the transmitting reed of the same resonant frequency.

Because of his recent meeting at the Smithsonian with Professor Henry, it is certain that Bell understanding of magnetic induction was refreshed – after all, Henry had discovered it. With this understanding freshly in mind, Bell made an astute observation while working with Watson on the afternoon of June 2, 1875. Two of the telegraph instruments that Bell and Watson were testing are shown in Fig. 1-7, where lines have been added to show how these two instruments were connected through a battery. In the enlightening test, the screw on the electrical contact was too tight such that the contact was always closed and current flowed steadily through the circuit.

Watson later reported “that the steel reed I had snapped, magnetized by its long use in connection with magnets, was functioning as a magneto-electric generator and by its vibration had generated in its magnet an electric current that was moulded [sic] into undulations exactly analogous to the sound waves of the plucked reed” (Watson 1915, 1016). Watson goes on to say, “He [Bell] realized immediately that the apparatus that could generate, transmit and receive so efficiently one sound with its fundamental tone and with its overtones could undoubtedly be made to do the same for any sound, even speech itself. The gods had arrived ….”

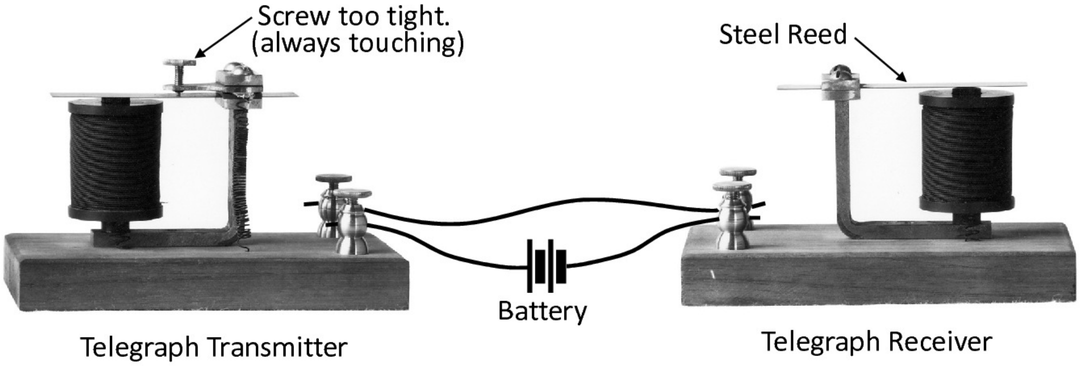

Fig. 1-7. Tuned telegraph transmitter (left) and receiver (right) designed by Bell and constructed by Watson in 1875. *Smithsonian Institution photo No. 17,204*.

Thus Bell had recognized Henry's magnetic-induction effect in this test with the too-tight screw. On the night of June 2, Bell wrote a brief letter to his sponsor, Gardner Hubbard, informing him that he made an accidental discovery that day of the very greatest importance (Bell 1875b). He further said that he succeeded "without any battery whatever!" That is, the battery was removed, but the wires were connected together so that the circuit was still complete. It is thus clear that Bell and Watson had gotten a similar result with and without the battery.

For Bell, the speaking telephone was born at that moment on June 2, 1875, but Gray also had a moment of inspiration on New Year's Day of the same year. However, at this point the race for development of the telephone was strongly affected by motivation. Gray, mainly concerned with telegraphy, was interested in the telephone merely as a curiosity. Bell, on the other hand, was an amateur in the field of telegraphy; however, he was a professional in the world of speech and was highly motivated to develop the speaking telephone. Before Bell and Watson parted that night in June, Bell gave Watson directions for making what they hoped would be their first speaking telephone.

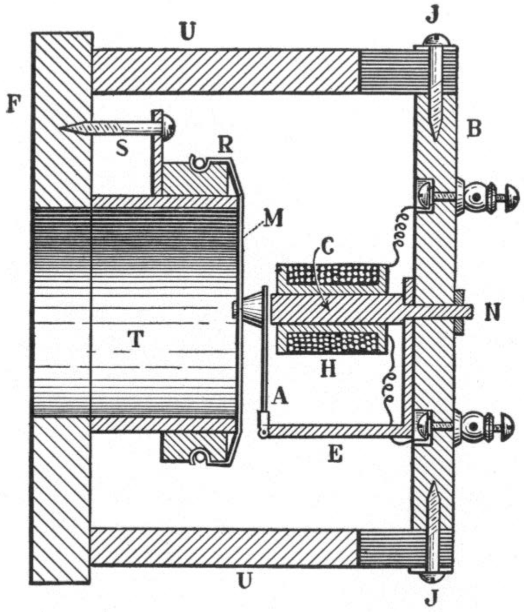

Fig. 1-8. Cross section of Gallows telephone designed by Bell and constructed by Watson in June 1875. *Drawing reproduced from Rhodes (1929) with permission of Ayer Co. Publishers*.

On the following day, June 3, 1875, Watson constructed in a single day what was to be called the gallows telephone because of its shape. Figure 1-8 is a drawing of this telephone. Electrically, the gallows telephone is quite similar to the harmonic telegraph receiver (Fig. 1-7); mechanically, its tuned reed had been replaced by a loosely hinged steel armature (A) that was attached to a parchment membrane (M) with a piece of cork.

By the evening of June 3, the new gallows telephone had been adjusted and was placed on Watson's work bench. It was connected by 200 feet of wire to one of the harmonic telegraph receivers in a room two stories up. In Watson's own words, "It was a meager result and a bitter disappointment" because they "had anticipated a much greater conversational fluency even in that first telephone" (Watson 1915, 1,017).

During the following months, Bell's work was divided between the telephone and the telegraph because his friends and financial backers were of the opinion that it was more practical to develop the multiple telegraph than to develop the telephone. Gray spent his time working on the multiple telegraph receiver (Hounshell 1975, 148). It is clear from subsequent events that Gray also had a telephone transmitter on his mind, but it was of a different sort than Bell's.

On February 14, 1876, Valentine's Day of the centennial year, an extraordinary coincidence occurred when Gray and Bell (or, more precisely, Bell's attorney) both filed papers on the invention of the telephone at the U.S. Patent Office in Washington. One thing is clear: neither Bell nor Gray had actually transmitted speech by telephone as of the time of the filings.

Gray's filing on that day was a caveat, rather than an actual patent application.[8] The caveat procedure, no longer used by the Patent Office, was intended to protect an idea while the inventor prepared an actual patent application. Gray's "talking telegraph" caveat described a transmitter in which a light metal rod that was connected to a diaphragm would be inserted into a liquid of high electrical resistance. Figure 1-9, from Gray's caveat, illustrates this principle. As the diaphragm (a) would vibrate, the distance between the end of the rod and the conductor (b) would vary and this would change the resistance of the circuit. The receiver in Gray's caveat was described briefly as including "an electro magnet of ordinary construction acting upon a diaphragm to which is attached a piece of soft iron." The description of Gray's receiver had thus changed significantly from his Page-effect device of the previous year to one that was similar to Bell's gallows telephone.

Bell's filing on that day was an application for a patent on an improvement in telegraphy.[9] After a discourse on the difference between pulsatory currents (intermittent direct currents) and undulatory currents (alternating currents), Bell described several methods of producing undulatory currents. He quite naturally described the inductive method used in his gallows telephone, and he included a descriptive diagram of that method. Bell's patent diagram is shown in Fig. 1-10. In that figure, the transmitter is on the left, the receiver is on the right, b and f are coils of the electromagnets, and E and g are ground connections to complete the circuit. A battery was used to produce a magnetic field in the coils because no permanent magnets were employed in this particular arrangement. Except for the acoustic cones, the transmitter and receiver were the same. Bell went on to briefly describe other methods of producing undulatory currents, including a liquid resistance transmitter similar to that described in Gray's caveat.

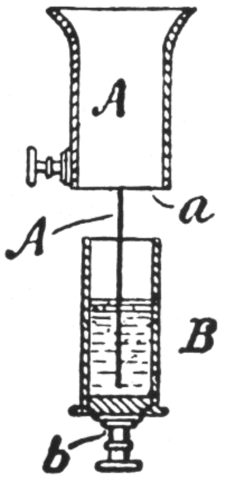

Fig. 1-9. Drawing of liquid transmitter from Gray's patent caveat, filed on February 14, 1876.

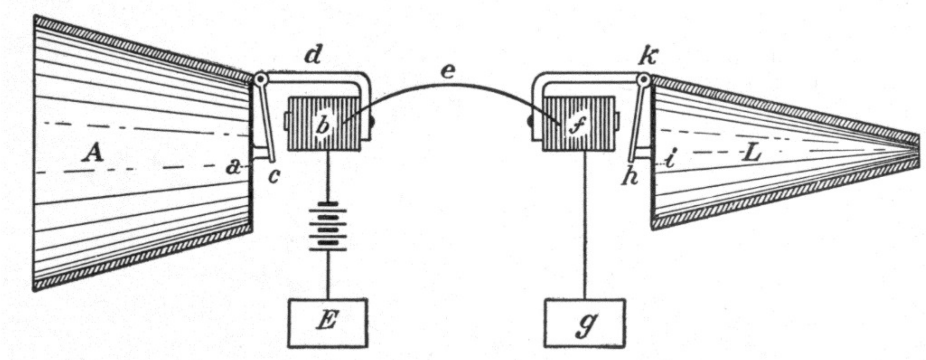

Fig. 1-10. Diagram of inductive transmitter (left) and receiver (right) from Bell's patent, applied for on February 14, 1876.

Clearly, Bell and Gray had broken the transmitter barrier inherent in the methods of Bourseul and Reis. Both Bell and Gray recognized that undulating or fluctuating currents, rather than on-off pulsating currents, were needed to reproduce amplitude and frequency -- loudness and tone -- and thus reproduce speech. And both described workable methods of producing such alternating currents. Bell and Gray further broke the receiver barrier inherent in the Page effect, describing an electromagnetic device of the type used today.

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[8] Elisha Gray, "Talking Telegraph," caveat filed with the U.S. Patent Office on February 14, 1876. Copies of caveats are not available from the Patent Office, but a copy of Gray's caveat can be found at the Smithsonian's National Museum of American History.

[9] Alexander Graham Bell, "Improvement in Telegraphy," Patent No. 174,465, dated March 7, 1876; application filed February 14, 1876.

Bell subsequently began a new series of telephone experiments on February 18, 1876 (Finn 1966, 5-8). He started with experiments on the induction principle, using a tuning fork near the electromagnet. Later, he replaced the electromagnet with a dish of water and made the tuning fork part of the electrical circuit. By March 9, this had evolved to an arrangement similar to Gray's liquid transmitter (shown schematically in Fig. 1-9). On March 10, using a device similar to this, the famous words were spoken: "Mr. Watson -- Come here -- I want to see you."[10]

Two facts stand out about this first telephone conversation. First, the well-known account refers to an event that took place almost two months after Bell's patent application had been submitted, and three days after the patent had actually been issued. Second, the transmitter used in this demonstration was not of the induction type used in almost all of Bell's earlier work and described in detail in his patent. Rather, it was a variable-resistance liquid transmitter. Bell's experiments with liquid transmitters represent only a brief interlude in his work; they were initiated on about March 8, just two days before the successful demonstration, and they apparently ended around April 18 (Finn 1966, 5, 12). By that time, Bell had resumed work on the electromagnetic induction transmitter.

During that same period, Gray put all of his effort into developing the multiple telegraph as he planned to exhibit that device at the Centennial Exhibition (Hounshell 1975, 155-158). Only after witnessing Bell's demonstrations with the telephone at the Exhibition did Gray attempt for the first time to build a liquid transmitter, as described in his patent caveat. Gray's attempts in July to operate this transmitter were not successful and he did not continue his experiments with the telephone.

Bell pursued the magnetic-induction design, with only this brief interlude to test a liquid resistance transmitter. He may have looked with disdain at the crude resistance transmitter, knowing that a much more sophisticated design would work and that it would work even without batteries. Bell returned to his work on the induction design and succeeded by that summer of 1876. He successfully demonstrated the induction transmitter at the Centennial Exhibition in Philadelphia in June, and went on to commercialize that development. By the spring of 1877, an improved induction telephone went into service, and the induction design was used exclusively in commercial service for five years before being displaced by the Blake resistance transmitter. These developments are discussed in the next chapter.

For a while there was little interest in the telephone, and Bell's backers offered to sell the patents to Western Union for $100,000 (Rhodes 1929, 50-51). They were turned down. In about a year, however, attitudes changed and there followed about 600 related law suits, the most important of which are summarized by Rhodes (1929, 52-75 and Appendix A). None of the legal challenges to the Bell patents was successful, and Bell's Patent No. 174,465 is thought to be the most valuable patent ever issued (Brooks 1975, 47).

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[10] Slightly different versions of Bell's statement have been reported by various authors: Brooks (1975, 49); Finn (1966, 8); Rhodes (1929, 28); and Watson (1915, 1,018). The above wording corresponds to Bell's handwritten notes for March 10, 1876 in Vol. I of his notebook, *Experiments made by A. Graham Bell.*

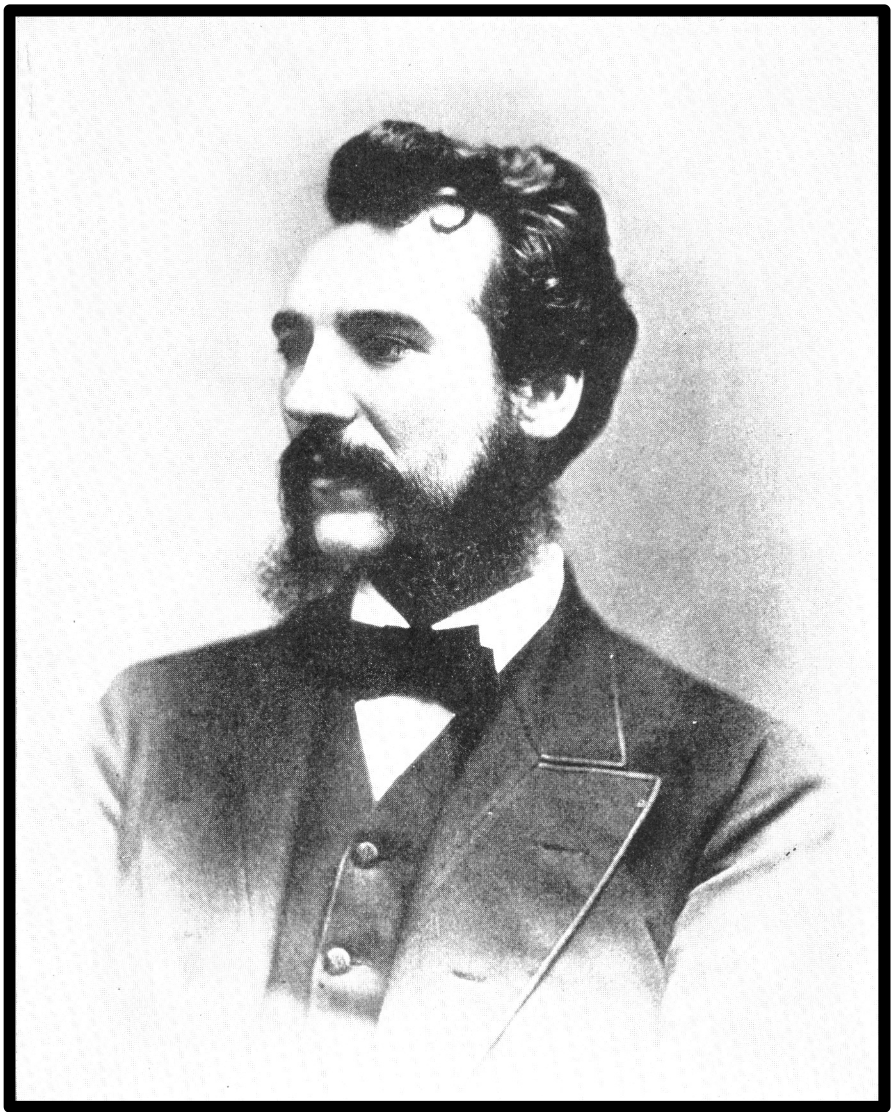

Fig. 1-11. Alexandar Graham Bell in 1876.
Reproduced from Rhodes (1929), Harper & Brothers Publisher.

Chapter 2
Transmitters

Within several years of Bell's sweeping patent of March, 1876, all the basic components of a modern telephone had been developed and the patents applied for. Although these early developments are recognized today as the major innovations in telephony, their patents were interpreted much more narrowly than was the Bell patent of 1876. Consequently, numerous patents were issued during this period, usually covering only specific details of an invention. These early developments and patents are described in order to understand the basic operating principles of the telephone's components and to see how these components evolved. Later developments are also covered, bringing the technical account up to the end of the era in 1984.

Bell’s Induction Transmitter

When Bell hastily built the Gallows telephone in June 1975 he clearly understood magnetic induction, but he might not have thought about the magnetic properties of the metals he was using (magnetic properties are summarized in the Appendix). The armature, which was connected to a diaphragm in the Gallows telephone, was hard steel. Watson later stated that the armature had been magnetized through usage, so it was probably very weakly magnetized (Watson 1915, 1016). More importantly, the magnetic domains could not realign easily in the hard steel armature. Thus with or without the battery current, sound waves from their voice were just vibrating (moving) a weak magnet in front of a coil of wire.

Had Bell used a soft iron armature and the battery, the battery current would have created a strong magnetic field that would have temporarily magnetized the armature – much more strongly than the weak permanent magnetism of his steel armature. With a more magnetized vibrating armature, the Gallows telephone would have worked better. In fact, Watson reported that in January 1915 Bell did speak to him clearly using “an exact duplicate of the first telephone made in 1875” (Watson 1915, 1021). But we don’t know anything about the magnetic properties of the armature used in that reproduction.

In the autumn of 1876, Bell realized this shortcoming, and he designed an improved telephone, which was used both as a transmitter and a receiver (see next chapter for receivers). This improved design is shown in his patent diagram of January 1877 (Fig. 2-1).[1] Here the diaphragm is a thin sheet of soft iron, the coil cores are soft iron, and the strong permanent magnet is made of hard steel plates. The permanent magnet temporarily magnetizes the coil cores, which in turn temporarily magnetize the diaphragm. With this arrangement the diaphragm is strongly magnetized, and when it vibrates it induces a significant current in the coil wires. By experimenting, Bell and Watson found that a permanent magnet worked better at providing a steady magnetic field than a battery current through the coils (Fagen 1975, 16; Rhodes 1929, 38).

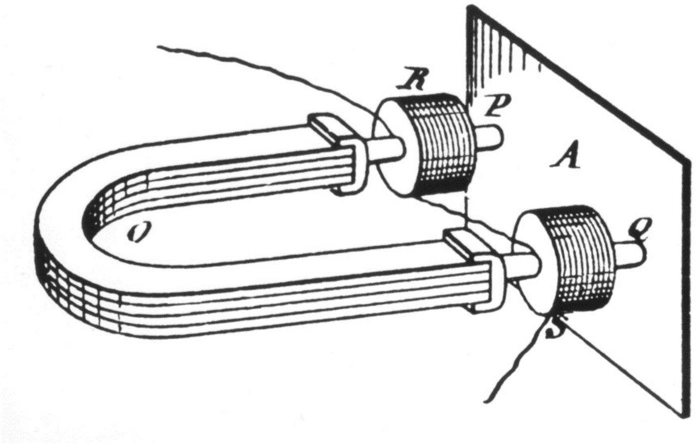

Fig. 2-1. Drawing of the improved permanent-magnet "telephone" from Bell's patent, applied for in 1877.

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[1] Alexander Graham Bell, "Improvement in Electric Telegraphy," Patent No. 186,787, dated January 30, 1877; application filed January 15, 1877.

Fig. 2-2. Hand telephone designed by Bell in 1877. *Smithsonian Institution photo No. 17204-H.*

The box telephone of 1877 (see Chapter 8 for early telephone sets) was built exactly on this principle, but it was awkward to use. During May, 1877, Bell began making his telephones in a more convenient cylindrical form with a large end to house the diaphragm (Rhodes 1929, 42-43; Fagen 1975, 20). One of these hand telephones was called a butter-stamp telephone because of its shape, but the hand telephone that was most commonly used is shown in Fig. 2-2. Because a horseshoe magnet was rather wide, Bell used a straight bar magnet in the hand telephones, placing a voice coil on only one end of the magnet near the diaphragm. The hand telephone was introduced on the Williams' Coffin wall phones in 1878. Bell's induction telephones remained in service for many years. However, induction transmitters were eventually displaced by resistance transmitters, which could generate larger electrical currents because of their battery.

Turnbull and Warnke's Sound-powered Transmitter

Although Bell's induction transmitter was eventually displaced in commercial telephones, Bell's concept was sound, and a very important variation of this design appeared later in military and industrial applications. This sound-powered transmitter was designed by Arthur Turnbull and Herbert Warnke in the 1930s and is still in use by the U.S. Navy. The transmitter is similar to Nathaniel Baldwin's magnetized-armature receiver that is described in Chapter 3. Turnbull and Warnke obtained a patent on their design in 1941.[2]

In this design, two bar magnets are used as can be seen in a partly disassembled view in Fig. 2-3. The magnets are made of an aluminum-nickel magnet alloy, which has better hard magnetic properties than regular high-carbon steel. The pole pieces and armature are made of a silicon steel, which has better soft magnetic properties than iron.

A central cross-section of the working parts in diagram form is in Fig. 2-4, as viewed from the side of Fig. 2-3 (but of course right-side up). A single coil is wrapped around a flattened tubular coil form with a hole shaped like a race track rather than a circle. The magnetically soft armature runs down the center of the coil. The armature is fixed on one end and attached with a long skinny bolt on the other end to a corrugated diaphragm.

In transmitter operation, the high-pressure part of a sound wave pushes the free end of the armature close to the South Pole of the lower pole-piece such that the armature becomes magnetized with its North Pole on this free end. Then during the low-pressure part of the sound wave, the armature is pulled up near the North Pole of the upper pole-piece such that the armature becomes magnetized with its South Pole on the free end. The changing magnetic field in the armature induces an electric current in the coil winding – magnetic induction – and the current carries the characteristics of the sound wave (frequency and amplitude).

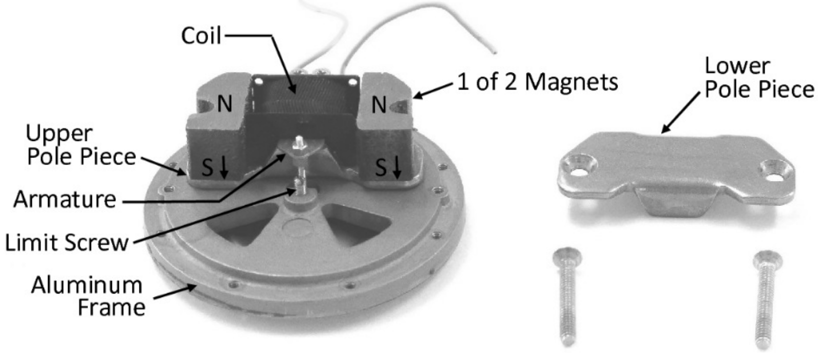

Fig. 2-3. Upside-down view of partly disassembled transmitter from a U.S. Navy H-203/U handset.

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[2] Arthur Turnbull, Jr., and Herbert R. Warnke, "Telephone Instrument," Patent No. 2,245,511, dated June 10, 1941; application filed December 4, 1937.

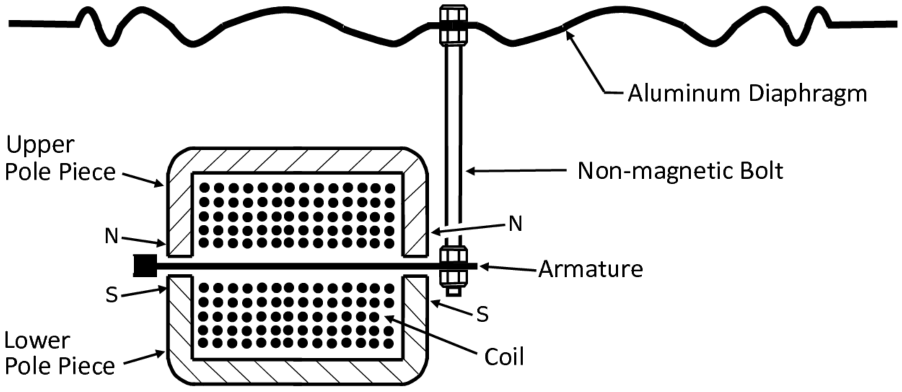

Fig. 2-4. Diagram of working parts in Turnbull's & Warnke's sound-powered Telephone design.

To enhance its sensitivity even more, the diaphragm has been intentionally corrugated to produce a broad resonant frequency range around 1200 cycles per second, right in the middle of the voice frequency range. Because the transmitter and receiver in the Navy's handset (Fig. 2-5) use the same element, their resonant frequencies match and amplify the vibrations. Early carbon transmitters and hand-held receivers (e.g., Western Electric's No. 323 transmitter and No. 144 receiver) took advantage of this amplification, although the resonance distorts sound fidelity.

Turnbull and Warnke's design is remarkably powerful. Dynalec advertises satisfactory performance of over 30 miles for the No. H-203/U handset, which it makes for the U.S. Navy (Dynalec 2011). Stromberg-Carlson and others manufactured this handset as well. Output of the transmitter in this handset was measured by the author in normal operation and compared with the output from a Western Electric F1 transmitter (discussed later in this chapter) in normally operating local-battery sets (3-volt batteries). The F1 transmitter produced an output voltage of roughly 4 times that of the H-203/U transmitter at about 1300 cycles per second for the same sound level. Thus the sound-powered transmitter output is only about 12 decibels below that of the F1 transmitter, although the F1 has a flatter frequency response.

Fig. 2-5. U.S. Navy sound-powered H-203/U handset made by Dynalec Corp.

Berliner's and Edison's Patent Claims

The breakthrough in resistance transmitters came soon, with the application of a well-known phenomenon: contact resistance between two conductors is sensitive to pressure. Contemporary electricians knew that a binding post that is screwed down loosely caused a high resistance in the line. Similarly, a telegraph key had to be pressed down firmly to actuate the sounder properly. Thus a resistance that could change with the pressure from sound waves would modify the current from a battery and the modified current would carry the characteristics of the sound wave. Emile Berliner, a dry-goods clerk living in Washington, D.C., was first to make a filing with the U.S. Patent Office on transmitters employing this principle.

Berliner filed a caveat with the Patent Office on April 14, 1877, and then on June 4 of that year he filed the corresponding patent application (Rhodes 1929, 77; Wile 1926, 88).[3] Figure 2-6 is a diagram from Berliner's patent.

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[3] The full text of Berliner's caveat is in Wile (1926, 309-313). Emile Berliner, "Combined Telegraph and Telephone," Patent No. 463,569, dated November 17, 1891; application filed June 4, 1877.

In this diagram, A is a metallic diaphragm to which one wire is connected, and C is the metal ball to which the other wire is connected. Vibrations of the diaphragm changed the pressure, and hence the electrical resistance, at the point of contact between the ball and the diaphragm.

The events that followed bear a striking resemblance to the Bell-Gray episode that began a year earlier. Like the concept of the telephone itself, the time had arrived for the idea of a pressure-sensitive resistance transmitter. Edison and others were working on this development, and the work of David Hughes in England is often cited in this regard.[4] Hughes demonstrated microphonic behavior of pencils of carbon in loose contact, and of simple nails laid upon one another.

On April 27, 1877, however, Thomas Edison filed a patent application that was similar to Berliner's caveat, and Berliner's and Edison's filings were declared in interference by the Patent Office.[5] This interference was not finally decided in favor of Berliner until 1886. Meanwhile, in 1880, Daniel Drawbaugh applied for a patent on a microphonic transmitter, and according to the rules of the Patent Office, no patent could be issued to any of the three until it was determined whether the Drawbaugh claim was valid or not. This was finally decided against Drawbaugh, as it was proved that the Edison carbon transmitter had been in public use for more than two years before Drawbaugh made his application for a patent, and his application was thrown out. A patent was then issued to Berliner on the broad principle of the microphone transmitter in November, 1891. In May of the following year, a patent was issued to Edison, so that both sides eventually got their patents -- more than fourteen years after the filing of the original applications.

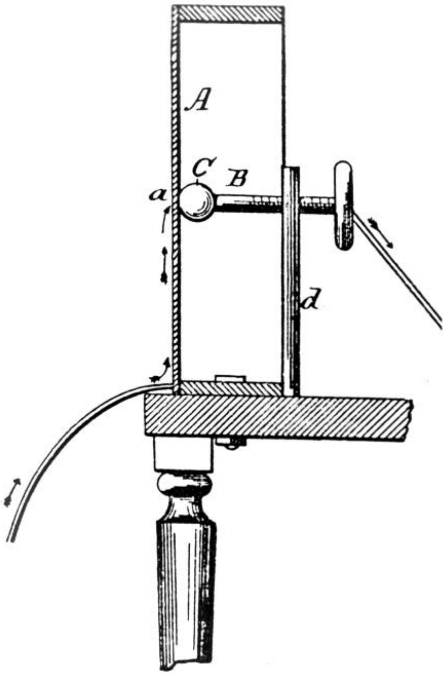

Fig. 2-6. Diagram of pressure-sensitive resistance transmitter from Berliner's patent, applied for in 1877.

Berliner's patent claim was broad:

> The method of producing in a circuit electrical undulations similar in form to sound waves by causing sound waves to vary the pressure between electrodes in constant contact, so as to strengthen and weaken the contact and thereby increase and diminish the resistance of the circuit.

Edison's patent claims were not so broad, as he had described contacts of "plumbago or similarly inferior conductor," or in other words, carbon. The breadth of Berliner's patent rights was thus of great interest, and on February 9, 1893, the U.S. Attorney General filed suit against Berliner and the American Bell Telephone Company, to whom Berliner had assigned the patent (Rhodes 1929, 82). After several trials and appeals, the matter was decided by the U.S. Supreme Court on May 10, 1897. Although decided in favor of Berliner, the courts restricted this patent to cover only a variable contact resistance transmitter having metallic electrodes. That was in sharp contrast to the broad scope given to the Bell patent.

Edison's patent describing carbon contacts was thus judged not to be in conflict with Berliner's patent covering metal contacts. Edison assigned his patent to Western Union, which eventually lost control of its telephone business to the Bell company. In the end, however, the Edison patent was annulled on a technicality because Edison's foreign patents for the same invention had expired.

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[4] Hughes's well known paper was published in a British journal, the Telegraph Journal and Electrical Review, on July 1, 1878. See Miller (1930, 51-53).

[5] Thomas A. Edison, "Speaking-Telegraph," Patent No. 474,230, dated May 3, 1892; application filed April 27, 1877. The description in the rest of this paragraph is taken directly from Webb (1902, 47-48), where the events are so concisely summarized.

Blake's Single-contact Transmitter

In 1878, Francis Blake of Weston, Massachusetts, took the Berliner-Edison ideas to an advanced stage of development and designed the most successful single-contact transmitter that was ever to appear. Blake used a block of carbon as one electrode and a bead of platinum as the other (as shown in Fig. 2-7).[6] In this diagram, H is the platinum electrode, which is held between the carbon electrode (I) and the diaphragm (C). The platinum electrode (H) is fastened to a light spring (G) that presses toward the carbon electrode (I). A heavy spring (K) presses both electrodes toward the diaphragm. Blake initially applied for a U.S. patent on January 3, 1879, and later subdivided that application into four separate patents.[7] These patents were eventually also assigned to the Bell company (Webb 1902, 36; Wile 1926, 128). In its commercial form, the Blake transmitter and its induction coil were mounted in a wooden box, as shown in Fig. 2-8. This transmitter was known to transmit the quality of the voice in a manner unexcelled by others, and it was used almost universally for local work in this country during the 1880s and into the 1890s. Having only one point of contact, however, the current capacity of the Blake transmitter was limited, and the carbon granule transmitters described in the next section eventually took over.

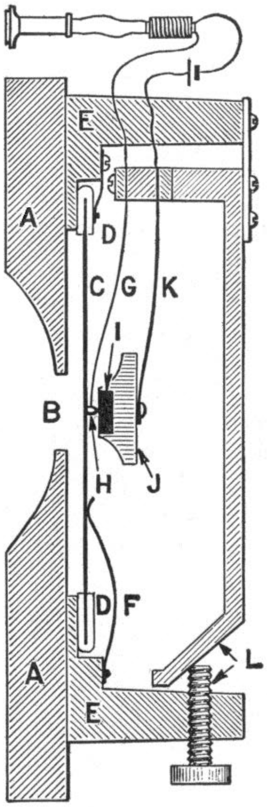

Fig. 2-7. Cross section of Blake's resistance transmitter of 1878. *Reproduced from Rhodes (1929) with permission of Ayer Co. Publishers.*

Fig. 2-8. Blake transmitter. *Courtesy of AT&T Archives.*

Hunning's Carbon Transmitter

Only one radical improvement remained to be made, and this was made a year later by Henry Hunnings. Hunnings, a clergyman in England, applied for a British patent on September 16, 1878, and subsequently applied for a U.S. patent on May 14, 1881 (Rhodes 1929, 79).[8] Hunnings's patent diagram is shown in Fig. 2-9. Hunnings used the metal diaphragm (A) as one electrode, using a parallel rigid metal plate (B) as the other electrode, filling the intervening space (C) with powdered carbon (engine coke). In this manner, instead of one point of pressure contact, many points of contact were established so that the transmitter current could be increased substantially.

The Hunnings carbon transmitter, sometimes called the Hunnings dust transmitter, had two practical problems. One was the tendency for the carbon particles to become packed together, and the other was its low electrical resistance. The packing problem was solved by Edison, who obtained a patent covering the use of granules of carbonized hard coal, which did not readily pack together.[9] Edison's patent drawing is shown in Fig. 2-10. In this

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[6] This drawing, from Rhodes (1929, 80), shows the workings of Blake's transmitter more clearly than the complicated drawings in Blake's patents. See also Miller (1903, 34); McMeen and Miller (1912, 52); and Miller (1933, 13).

[7] Francis Blake, "Speaking-Telephone," Patent Nos. 250,126, 250,127, 250,128, and 250,129, all dated November 29, 1881; applications for the first 3 were filed on September 15, 1881, while the latter was filed on October 31, 1881.

[8] Henry Hunnings, "Transmitter for Telephones," Patent No. 246,512, dated August 30, 1881; application filed May 14, 1881.

[9] Thomas A. Edison, "Telephone," Patent No. 406,567, dated July 9, 1889; application filed February 19, 1886.

figure, A is the diaphragm, B is the frame, D is a metal cup that holds the carbon granules (C), and F is an electrode attached to the diaphragm. The concept of a piston-like transmitter button is clearly present in this drawing.

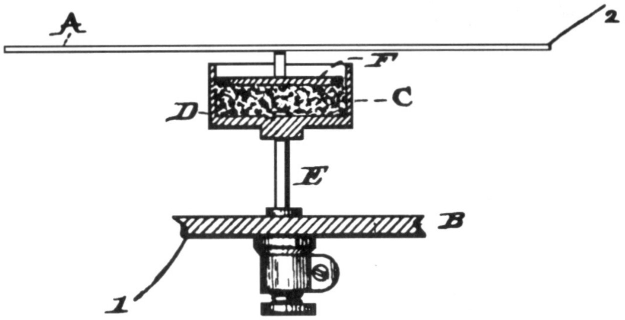

Fig. 2-10. Cross section of carbon-granule transmitter from Edison's patent, applied for in 1886.

The low resistance problem was solved by the use of an induction coil (see Chapter 4), Edison again playing a major role. During the latter part of the century, when the Blake transmitter was widely used for local service, the Bell company developed and used a Hunnings-type transmitter for long-distance service. This so-called long-distance transmitter, shown in Fig. 2-11, had a horizontal diaphragm and granules of carbonized hard coal.

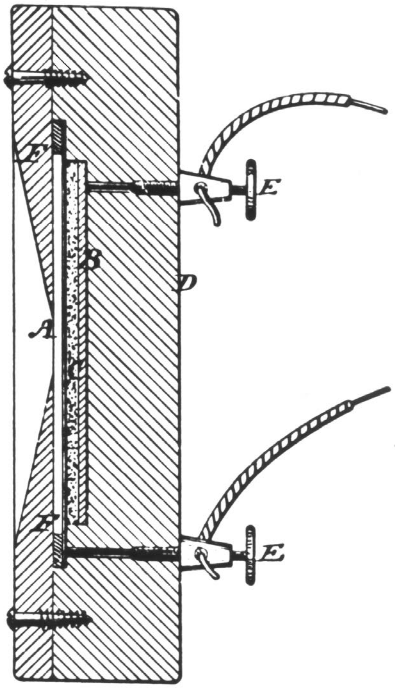

Fig. 2-9. Cross section of multiple-contact powdered-carbon transmitter from Hunning's patent, applied for in 1881.

White's Solid-back Transmitter

In 1890, Anthony White, a Bell engineer, developed the solid-back transmitter that was to be typical of transmitters used by all manufacturers well into the 1930s. The cross section of White's transmitter is shown in Fig. 2-12. The transmitter employed a small button consisting of a brass cup (W in the figure) partially filled with carbon granules of the Edison type and a piston-like plunger attached to the diaphragm. The front electrode (E) and the rear electrode (B) were made of carbon discs, the faces of which were highly polished. The walls of the brass cup (W) were lined with gummed paper to prevent short circuiting such that transmitter current flowed from one carbon electrode to the other. White applied for a patent on this transmitter on March 24, 1892.[10]

Fig. 2-11. Carbon-granule long-distance transmitter on a desk stand. *Courtesy of AT&T Archives.*

Subsequently, both the Blake transmitter and the long-distance transmitter were replaced by the solid-back transmitter. A number of versions of the solid-back transmitter were produced by Western Electric. Two such models that were widely used are the No. 229, introduced in 1895, and the No. 323, introduced in 1917 (Fagen/AT&T 1975, 83). The No. 229 and related types have a simple disk diaphragm that is attached to the button of carbon granules by a small threaded nut, as shown in Fig. 2-12 at p' and can be readily seen when the mouthpiece

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[10] Anthony C. White, "Telephone," Patent No. 485,311, dated November 1, 1892; application filed March 24, 1892.

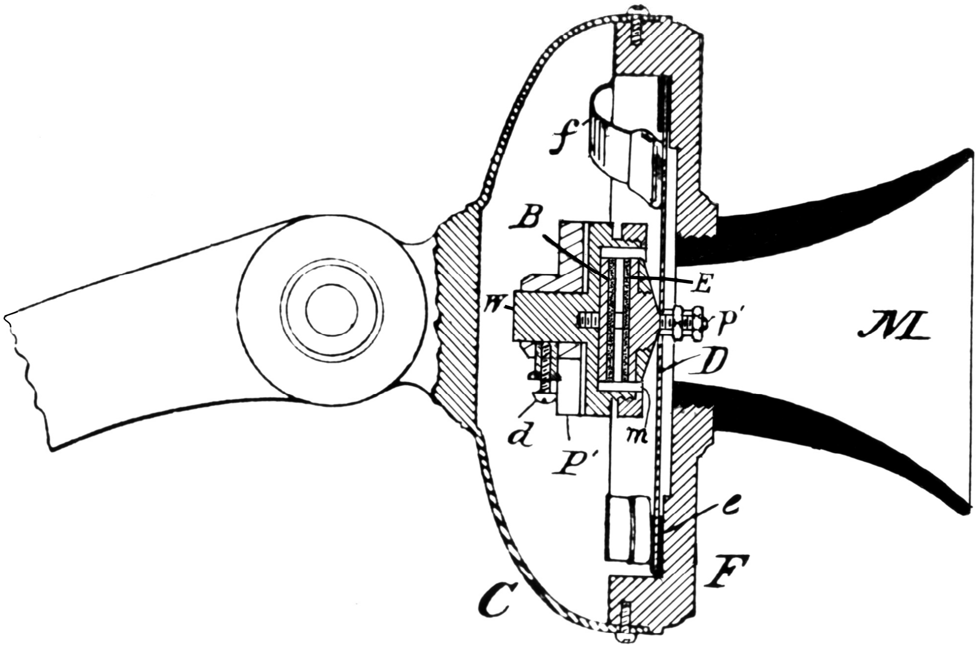

Fig. 2-12. Cross section of Solid-back carbon-granule transmitter from White's patent, applied for in 1892.

is removed. The periphery of the diaphragm is held against the faceplate (F) by two strong leaf springs (f). The diaphragm in the No. 323 (and similar 353 and 337) is held in place by a single spring. No screws or nuts can be seen when the mouthpiece is removed from these later transmitters, and no leaf springs are used on the periphery of the diaphragm.

Non-positional transmitters

All of the solid-back transmitter designs suffered short comings, the most serious of which were (a) position dependence, (b) carbon noise, and (c) frequency resonances. These problems were addressed in a major scientific effort at the Bell Laboratories, which was formally incorporated in 1925 – although it existed in reality from 1907 when the engineering departments of AT&T and Western Electric were centralized (Fagen/AT&T 1975, 144; Brooks 1975, 12). This scientific effort of the early 1920s followed shortly after the development of the vacuum tube amplifier, which made possible the quantitative measurement of transmitter responses like those presented near the end of this section (Colpitts 1937, 270). Between 1920 and 1925, the Bell System also began publishing several technical journals that record developments such as this.

The position-dependence problem can be visualized by referring to Fig. 2-13. In this normal upright position, the carbon chamber will have a gap at the top because of incomplete filling or settling of the granules over time. This is of little consequence in the upright position as shown, but if the transmitter were rotated

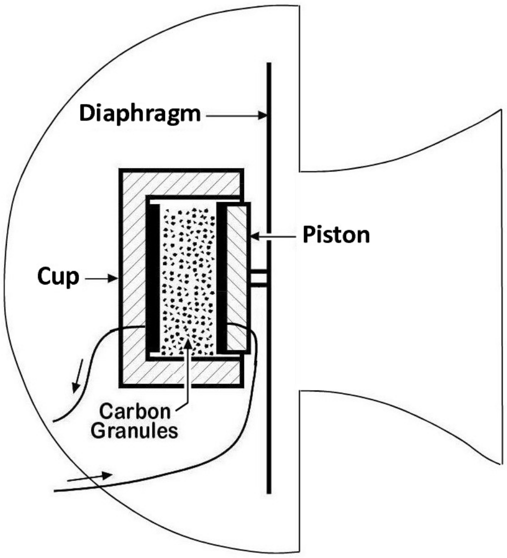

Fig. 2-13. Diagram of White’s solid-back transmitter showing the current path.

90 degrees to the right or left the gap would be either at the rear electrode or the front electrode. In either case, the conducting path would be open and the transmitter would not work at all. At intermediate angles, the performance would be degraded.

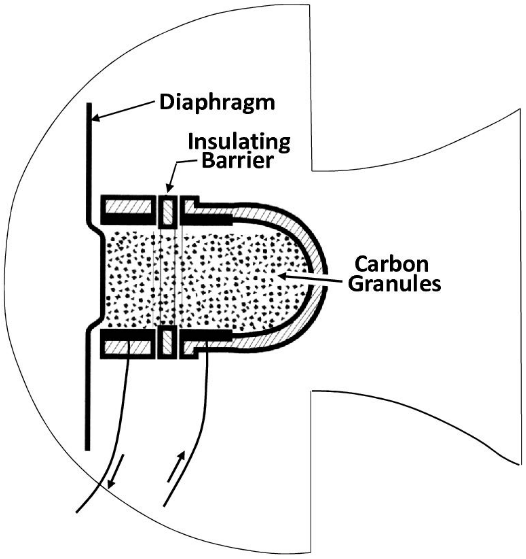

Fig. 2-14. Diagram of Western Electric's No. 395 barrier transmitter showing the current path.

These problems were partly solved with the barrier transmitter, which was patented by Charles Moore and assigned to Western Electric.[11] In the barrier design, cylindrical metal inserts in the carbon granule cup were used as electrodes, rather than using the flat front and rear faces. These cylindrical electrodes were separated by an insulating ceramic washer or barrier such that current flowed from one cylindrical electrode to the other, around the barrier. This construction reduced the effects of friction, which caused carbon noise, and made the transmitter relatively insensitive to position.

In constructing the Western Electric No. 395 barrier transmitter, some noticeable changes were made in Moore's design (Jones and Inglis 1932) as shown in Fig. 2-14. In this and the following three figures, the transmitter elements are shown within the outline of the graphical symbol for a transmitter. This depiction is for visual orientation, although these transmitters were usually mounted in handsets of different shapes. In the Western Electric transmitter, the electrode farthest from the diaphragm was made in a hemispherical shape that formed one end of the carbon chamber. Both electrodes were gold plated for good electrical contact. The diaphragm itself was placed in direct contact with the carbon granules, eliminating the need for a piston-like plunger, and a thin layer of phenol varnish was applied to the diaphragm to keep it electrically insulated from the carbon granules.

The No. 395 transmitter still had one major positional limitation, however. The transmitter would not work properly in the position where carbon granules fall away from the diaphragm. Because this would be a typical position of a handset in normal use, the transmitter element was turned around such that the diaphragm was behind the carbon chamber and the dead position was face down. This orientation produced the bullet-shaped structure in the mouthpiece of the early Western Electric E1 handset, which was introduced in 1927.

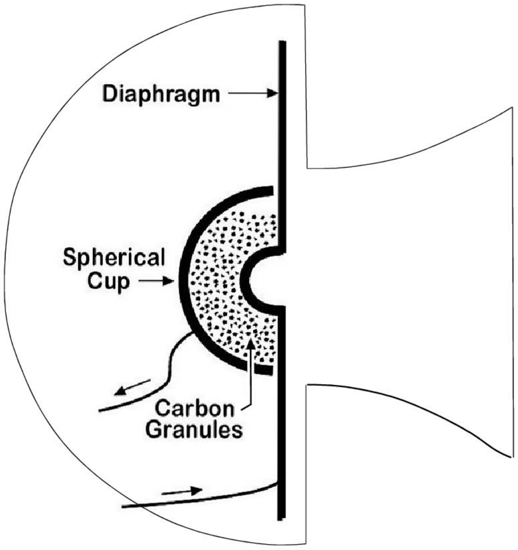

Fig. 2-15. Diagram of Eaton's non-positional transmitter showing the current path.

In one of the last great patents of the developing period, George Eaton described a truly non-positional transmitter that used hemispherical electrodes (see Fig. 2-15).[12] Eaton was Chief Engineer at Kellogg where this transmitter was developed during the period 1930-1933 (Eaton 1933, 14). The hemispherical shape of the electrodes eliminated any position in which a significant portion of either electrode would be

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[11] Charles R. Moore, "Telephone Transmitter," Patent No. 1,565,581, dated December 15, 1925; application filed October 3, 1921.

[12] George R. Eaton, "Microphone," Patent No. 2,014,427, dated September 17, 1935; application filed April 11, 1933.

uncovered even when the carbon chamber was not completely full. A hemispherical depression was pressed into the diaphragm to form one electrode, and the protrusion was gold plated for good electrical contact. The hemispherical cavity in the cup was also gold plated. This non-positional transmitter was installed as standard equipment in all Kellogg Masterphones starting in 1933.

Western Electric's No. 395 transmitter was not a big success and was soon replaced by the F1 transmitter that was similar to Eaton's design. For Western Electric, the F1 transmitter marked the return to a direct-action type in which one electrode moves with the diaphragm (Jones 1938, 338). Like Eaton's transmitter, the electrodes of this transmitter were nearly hemispherical in shape and the active surfaces of both electrodes were gold plated; the external exposed contacts were silver plated.[13] This transmitter was backfitted to the E1 handset in 1934.

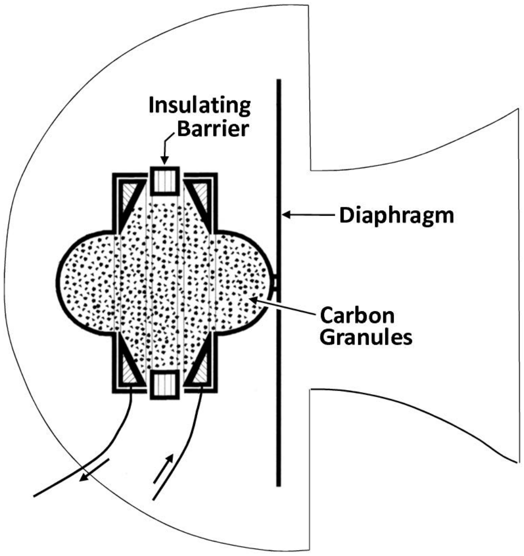

Fig. 2-16. Diagram of Automatic Electric's non-positional transmitter showing the current path.

Automatic Electric developed a non-positional transmitter that has several features of Western Electric's old barrier transmitter (Telephony 1935, 50). In the Automatic Electric transmitter, current flows between two annular electrodes that are separated by a paper bellows, which acts as a barrier, as seen in Fig. 2-16. These washer-shaped electrodes, with one countersunk face, have a triangular cross-section and are made of carbon. The front electrode is held by a thin Duralumin cup that is riveted to the diaphragm and moves with it. The inside surfaces of the front and rear parts of the transmitter cup are coated with an insulating enamel such that conduction is only between the carbon electrodes, around the barrier. The dome-shaped front and rear parts of the transmitter cup provide a large reservoir of carbon granules such that the electrodes are covered with carbon granules in all positions. This transmitter, known as Type 35A7, was introduced as a backfit in Monophone handsets in 1935, and with minor modifications was used in all later Automatic Electric telephones.

Stromberg Carlson made a non-positional transmitter that is interesting for its utter simplicity. This transmitter, shown schematically in Fig. 2-17, takes the original solid-back design and merely enlarges the cylindrical cup such that it has a much larger diameter than the piston-like electrodes. The cup, which is clearly visible on the rear of this No. P-24562 transmitter (and its variants), is made of bakelite and is therefore non-conducting. The rear carbon electrode is mounted on a brass disc. The front carbon electrode is held by a thin Duralumin cup (empty) that is riveted to the diaphragm and moves with it just as in the Automatic Electric transmitter. The two polished carbon

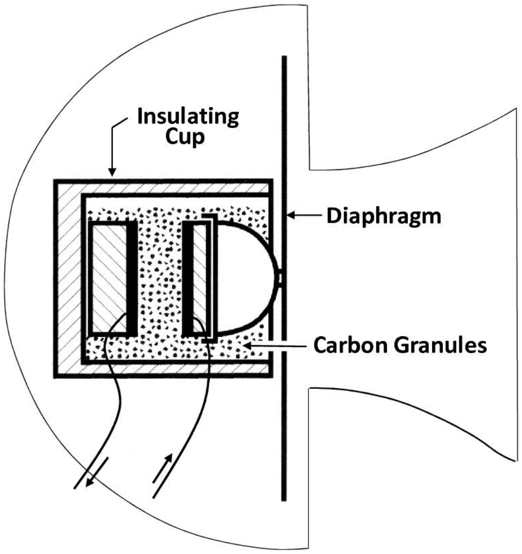

Fig. 2-17. Diagram of Stromberg-Carlson's non-positional transmitter showing the current path.

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[13] It is reported (Pleasance 1989, 125) that variations of Kellogg's non-positional transmitter were made under license by most other companies, and this seems likely. However, that author's reference for this statement is not correct and the present author has been unable to find any reference to license arrangements.

electrodes are thus immersed in a sea of carbon granules such that the electrodes are fully covered in all positions, even if the cup is not full. This transmitter was introduced in Stromberg Carlson's No. 1197 and 1198 handset desk stands (e.g., Stromberg-Carlson catalog "B" edition, B-12-12-42, 1942, p. 176).

After World War II, Western Electric developed a somewhat smaller T1 transmitter element that is similar to the F1 transmitter and was designed for the 500-type telephone (Cobb 1952). Additional improvements in design and economics were realized in several areas. Contours of the carbon chamber were further improved, as was the quality of the transmitter carbon. Eventually, this T1 transmitter design was adopted by Kellogg and Stromberg Carlson but not by Automatic Electric, who continued to use their own transmitter design.

Properties of Resistance Transmitters

The frequency response of carbon transmitters was improved over time. Because early transmitter diaphragms comprised vibrating membranes clamped to rigid rims, they had natural resonating frequencies like a drum head. The major resonance of Western Electric's No. 323 solid-back transmitter occurs just above 1,000 cycles per second, right in the middle of the voice frequency range, as can be seen in Fig. 2-18.[14] This figure shows the relative response (i.e., the voltage produced relative to some arbitrary reference voltage) to sound waves of different frequencies for several transmitters. The resonance, or pronounced sensitivity, near 1,000 cycles per second for the No. 323 transmitter can be seen to line up exactly with the major resonance of the companion No. 144 receiver (see Chapter 3). This alignment compounded the resonance effect, giving rise to the megaphone sound, which is objectionable by today's high-fidelity standards. However, the matching resonances of these early instruments provided a very high sensitivity, producing loud, piercing voice sounds that were understandable.[15]

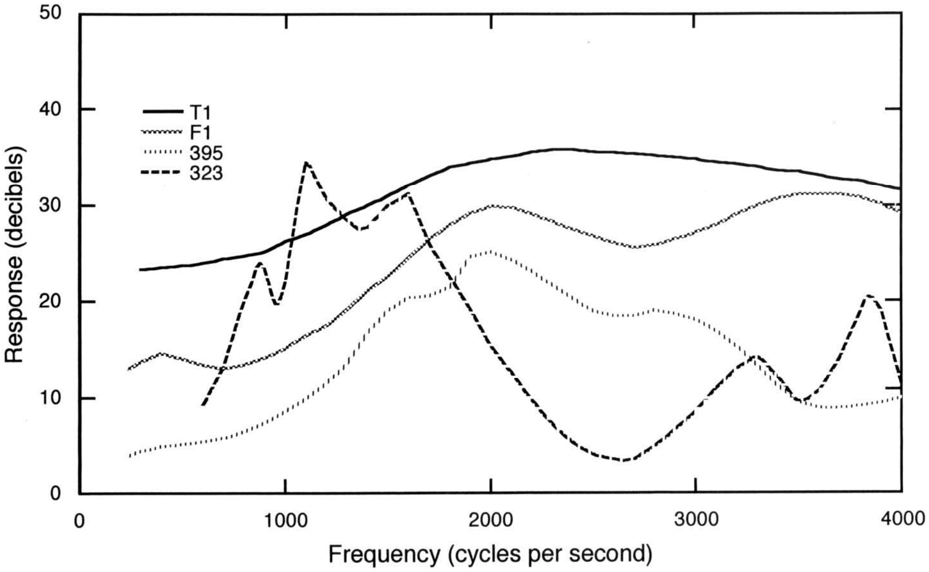

Figure 2-18. Frequency response of Western Electric carbon transmitters.

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[14] Figure 2-18 was derived from three consistent sources of Bell Laboratories information: Jones (1938, 348); Cobb (1952, 318); and Fagen/AT&T (1975, 149). For reference, a 20-decibel increase in response corresponds to a ten-fold increase in voltage.

[15] A curious feature of the earlier No. 229 solid-back transmitter is that one of its leaf springs is always positioned midway between the diaphragm's edge and its center. The asymmetric positioning of clamping springs is even shown in the patent drawing, Fig. 2-12. This transmitter has a still sharper resonance than the No. 323, with one clean narrow peak at 1,100 cycles per second (the fundamental frequency) and a second smaller peak at 2,200 cycles per second (the first harmonic). Measurements by the author do not show any significant difference in the fundamental or first harmonic with the spring in either position, so alignment with the receiver's resonance is unaffected. However, the damping effect of this oddly positioned spring should reduce higher frequency overtones, thus affecting the quality or timbre of the sound transmitted. One thing is certain: in 1892, no instruments existed to measure this type of performance, and results would have been judged subjectively.

Figure 2-18 shows that this sharp resonance at about 1,000 cycles per second has been eliminated in Western Electric's No. 395 barrier transmitter and replaced by a more gradual frequency response that peaks at 2,000 cycles per second. This was achieved in the No. 395 by using a thin Duralumin diaphragm, with an effective mass of only 1/10 that in the earlier transmitters, and by loosely fastening the periphery within a series of paper rings called books. The performance of the successful F1 transmitter can also be judged from Fig. 2-18, where it is seen to have an overall increase in sensitivity as well as a more uniform frequency response, with improvements especially in the high-frequency range. Still further acoustical design improvements in the T1 transmitter permitted a return to the simpler rigid clamping of the diaphragm without a performance penalty by utilizing back pressure from a plastic acoustic chamber behind the transmitter to suppress the frequency resonances. Success was achieved in eliminating unwanted resonances in the T1, as seen in Fig. 2-18, resulting in a transmitter of high sound fidelity, as well as good overall sensitivity.

The electrical property of a resistance transmitter that must be dealt with in circuit design is merely a resistance. Resistances of the important Western Electric transmitters, which are mentioned in later chapters, are given in Table 2-1. Transmitters made by other manufacturers have similar resistances. The values in Table 2-1 are taken from measurements on 18 transmitters distributed among the types shown. Each measurement was made with an appropriately applied operating voltage, and with the transmitter in its normal position. The resistance of a given transmitter will vary in the range shown during normal usage as the result of movement of the carbon granules, temperature, and other ambient conditions. Because of this large variability, a more precise tabulation of transmitter resistances is not possible. Resistances of earlier transmitters, including Hunnings and Blake types, have been reported by Finn (1966, 14).

Table 2-1. Resistance of various
Western Electric transmitters

Transmitter	Resistance Range ohms
229	25-75
323	"
395	75-275
F1	"
T1	"

A couple of interesting observations about resistances of the solid-back transmitters (e.g., Nos. 229 and 323) are worth mentioning. Blowing into these transmitters will cause their resistance to increase by as much as four times. Long periods of inactivity will also increase their resistance. These resistance increases are rather persistent, but a gentle tapping on the side of the transmitter will dislodge the carbon granules and return the resistance to its normal range.

Conversely, sucking on these early transmitters will cause their resistance to fall to as low as 5 ohms. In a 3-volt local-battery circuit, this would result in a direct current of about 500 milliamperes. This is substantially higher than maximum current capabilities, which lie in the range of 60 to 280 milliamperes, and would result in damage from overheating (Miller 1933, 22, 24).[16] Direct currents in the range of 25 to 30 milliamperes are adequate to produce robust signals with most transmitters.

* * *

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[16] Because of the disastrous effects of such abuse, which might occur from a child's playing with a telephone, early cone-shaped mouthpieces usually had 3 grooves or a small hole near their base to prevent a suction from being drawn on the diaphragm.

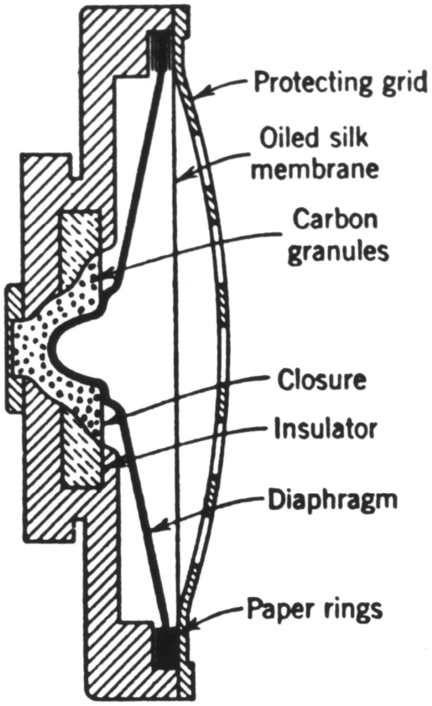

Fig. 2-19. Cross section of the Western Electric F1 transmitter.
Courtesy of AT&T Archives.

Chapter 3
Receivers

Development of the modern telephone receiver took place quite differently from development of the carbon transmitter. These resistance transmitters, as seen in the previous chapter, had a simple operating principle, a complicated evolution, and a construction that depended at first on art more than science. The receiver's operating principle, by contrast, is relatively sophisticated; however, its evolution was uncomplicated and its construction was "a very simple matter" (Miller 1903, 18).

In Europe during the late 1800s, a number of different shapes of magnets were used in attempts to improve the efficiency of the standard cylindrical receiver used in the U.S. These early receivers had names, such as the Phelps Crown receiver, the Goloubitzky telephone, the Gower receiver, and the Ader receiver. Because of the great sensitivity of the standard Bell-type instrument, "it must be confessed that but few of these instruments offer any considerable advantage over the standard receiver" (Webb 1902, 26).

Most commercial telephone receivers were thus based on the same principle as Bell’s box telephones and hand telephones that were described as transmitters in the previous chapter. As pointed out, Bell’s telephones also worked as receivers. Their operation as receivers is described more thoroughly in the following paragraphs. There was, however, a successful receiver that operated on a somewhat different principle that was designed by Nathaniel Baldwin. The Baldwin receiver will be discussed near the end of this chapter where its relevance will be mentioned.

Monopole Receivers

Figure 3-1 shows a monopole receiver that is similar to those shown in several figures in Chapter 8. In this view, with the cap removed, you can see a coil (an electromagnet) with a core that is sitting on the end of a bar magnet inside the handle. The thin soft iron diaphragm is also visible in this view. This is the same arrangement of parts as in Bell’s hand telephones that were discussed in Chapter 2.

Fig. 3-1. Typical monopole receiver with the cap removed.

The heart of a receiver is the electromagnet, which pulls on the diaphragm and causes it to vibrate and make the sound waves you hear in your ear. Figure 3-2 shows a diagram of the working parts of a monopole receiver. The permanent magnet temporarily magnetizes the iron core of the coil, now called a pole piece because it is attached to a pole of a permanent magnet. When no current is flowing, the magnetized pole piece pulls down on the iron diaphragm as indicated in the diagram. When the undulating electric current (the voice signal) is positive, the electromagnet will generate a magnetic field that is, say, north pole at the top. This adds to the strength of the magnetic field of the pole piece and pulls the diaphragm farther down. When the current is negative, the electromagnet will generate a magnetic field that is south pole at the top. This subtracts from the strength of the magnetic field of the pole piece allowing the diaphragm to relax and deform even less than with no current flowing. This action produces one cycle of deflection for each cycle of the electric current and produces larger deflections for larger currents. Thus the sound waves generated by the vibrating diaphragm have the frequency and amplitude of the voice signal (i.e., the loudness and pitch).

The core of the coil must have a relatively large steady background magnetic field or bias. Without this steady magnetic field, the core would pull on the diaphragm equally during each half cycle of the electric current thus generating sound waves with twice the frequency of the electric current and would not reproduce intelligible speech (Fagen/AT&T 1975, 86-87; Burden/AE 1948, 56-57. Further, the magnitude of the deflections of the diaphragm would be only about half that with the magnetic bias thus making the receiver less sensitive.

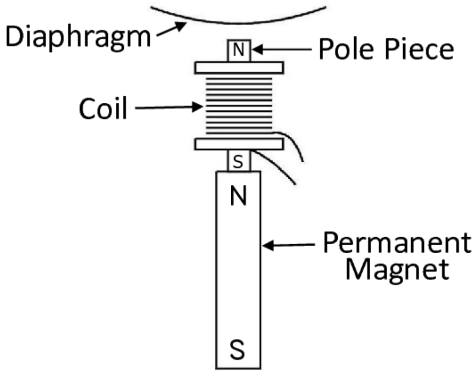

Fig. 3-2. Diagram of a monopole receiver.

Of course the magnetic bias could be provided by running a direct current through the coil in addition to the alternating current. Bell's battery powered experimental tests used such receivers (and transmitters). Direct-current receivers have been made, such as the Automatic Electric receiver mentioned later in the book. But dc receivers produce large objectionable clicks when switches are operated such that these receivers were never widely used.

Bipole Receivers

Figure 3-3 shows an Automatic Electric Type 23 receiver, which is similar to Western Electric's No. 144 receiver and typical of handheld receivers on candlestick phones and magneto wall phones of the early decades of the 20th Century.[1] In this figure you see a horseshoe permanent magnet with an electromagnet attached to both poles. The exact same principles work in the bipole (or bipolar) receiver as in the monopole receiver, although more attention has to be paid to details.

Fig. 3-3. Typical bipole receiver with the cap removed

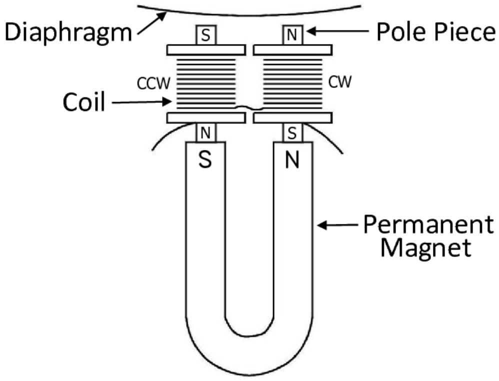

Fig. 3-4 Diagram of a bipole receiver.

Figure 3-4 shows a diagram of a typical bipole receiver. Look first at the coil (electromagnet) on the right, which is attached to the north pole of a horseshoe-shaped permanent magnet. This coil functions exactly the same as the coil in a monopole receiver – strengthening or weakening the magnetic field of the pole piece. The coil on the left is attached to the south pole of the permanent magnet, so the polarity of this coil's iron core is reversed compared with the core of the other coil. Because both the north pole and the

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[1] The No. 144 receiver, with its hard-rubber shell, was identical to the No. 143 receiver, except that the latter had a slightly less expensive composition shell. These receivers are usually referred to as the No. 144, regardless of which shell they have.

south pole of a magnet will attract iron, the cores of the two coils pull together on the iron diaphragm (thin curved line at the top of Fig. 1) even without any current in the coils.

Suppose that the coil on the right is wound in a clockwise direction (CW) and at some instant in time its electric current produces a magnetic field that is north at the top. This adds to the strength of the magnetism in the core of this coil and strengthens the pull on the diaphragm. If the coil on the left is wound in the counterclockwise direction (CCW), then this coil's magnetic field will be south at the top, strengthening its coil's magnetism at the instant in time when the other coil's field is north at the top.

In this manner, the two coils work in unison at all times, together increasing the pull on the diaphragm during one half cycle of the ac signal and together decreasing the pull on the diaphragm during the other half cycle. The bipole receiver with two coils is thus more powerful than a monopole receiver, but functions in the same way. It interesting that the bipole concept is identical in all details to Bell's improved telephone of 1877, including the opposite winding direction of the two coils (see Chapter 2).

Watchcase Receivers

Figure 3-5 shows a Western Electric No. 557 receiver element that was introduced in the E-type handset in 1927 (Jones and Ingles 1932). This receiver is typical of watchcase-style receivers that were used in early handsets and headphones by all manufacturers. In this view one can see the semi-circular permanent magnet, to which is bolted underneath the iron strips that form the pole pieces.

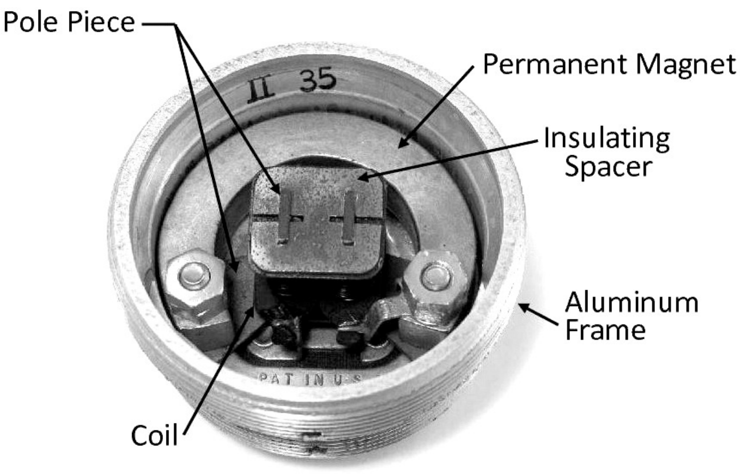

Fig. 3-5. Top view of a No. 557 receiver with the diaphragm removed.

Figure 3-6 shows a diagram of the working parts of the receiver as viewed from the bottom of Fig. 3-5 as if the aluminum frame were not present. The flat pole pieces are bolted (bolts not shown) to the ends of the permanent magnet and bent up at right angles to form the cores of the coils. The components in Fig. 3-6 can now be compared with the components in Fig. 3-4. You can see that the components are functionally the same. The horseshoe magnet has been replaced by a semicircular magnet, and the pole pieces are attached to the ends of this magnet – attached on the bottom sides rather than on the tips. Polarities and coil winding directions, CW and CCW, are the same in the 557 as in the earlier bipolar receiver. New alloys were being used that had improved magnetic properties, but the permanent magnet was still a hard steel alloy and the pole pieces and diaphragm were still soft alloys of iron.

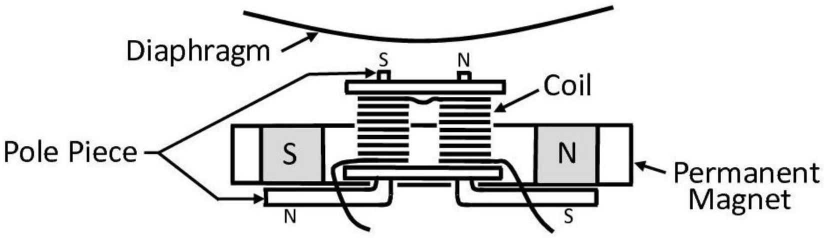

Fig. 3-6. Diagram of a No. 557 "watchcase" receiver.

Western Electric No. HA1 Receiver

When the Western Electric No. 302 telephone was introduced in 1937, its F1 handset contained a new HA1 receiver (Jones 1938). This receiver unit was also used in the No. 706 hand-held receiver on some candlesticks and wall phones of the late 1930s. Figure 3-7 shows a bottom view of this receiver element. In this receiver a pair of bar magnets is used instead of a single semicircular or horseshoe permanent magnet. One bar magnet can be seen in this view, and the other is hidden in the rear.

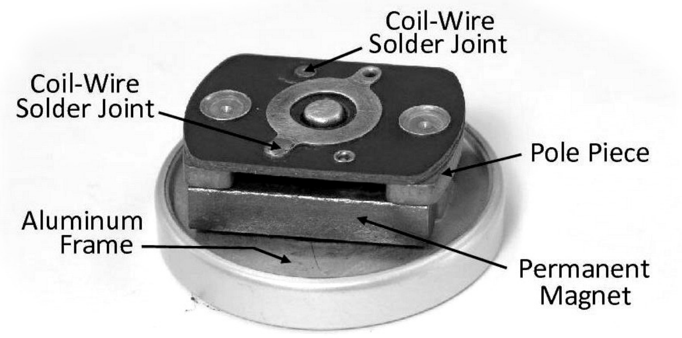

Fig. 3-7. Bottom view of an HA1 receiver.

A diagram of the working parts of the HA1 receiver is shown in Fig. 3-8. This view would be from the bottom of Fig. 3-7 if the receiver were turned right-side up. The wires connecting the two coils and exiting from the coils are obscured in this view by the permanent magnet. Polarities and coil winding directions are also the same in the HA1 as in the earlier bipolar receiver. The pole pieces in the HA1 are thicker than the strips used in the No. 557 receiver, but otherwise the two designs are quite similar. The HA1 is thus still a bipolar receiver.

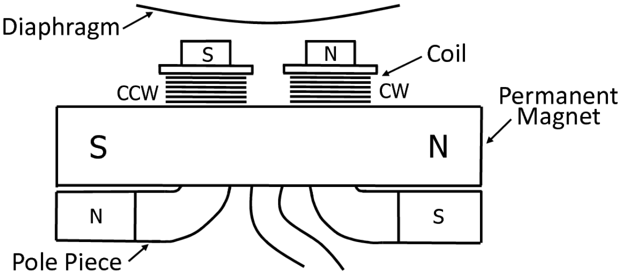

Fig. 3-8. Diagram of an HA1 receiver.

Western Electric No. U1 Receiver

A lot of technical advances were made during the WW-II war years, including development of a varistor (see the Appendix) that can short-circuit large voltage pulses around a receiver thus muting the loudest clicks from switch operation. Otherwise, the varistor plays no role in the operation of the receiver and will be omitted from most of what follows. The Western Electric No. U1 receiver, which was introduced in the G-type handset in 1949, is shown in Figs. 3-9 and 3-10 (Cobb 1952). The dark gray metal in Fig. 3-10 is a cap-shaped permanent magnet that is cast out of a hard steel alloy similar to that used in the bar magnets of the earlier HA1 receiver.

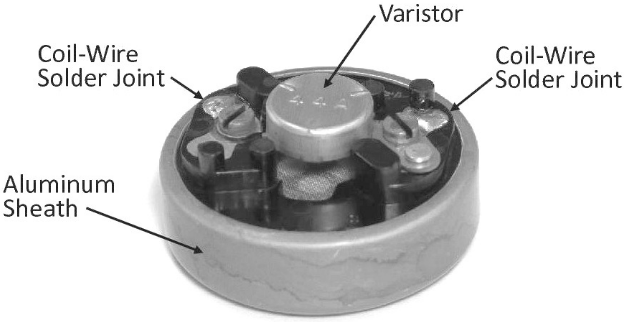

Fig. 3-9. Bottom view of a U1 receiver.

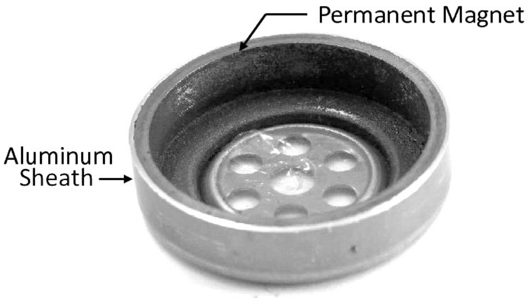

Fig. 3-10. Cutaway view of the top part of a U1 receiver.

The geometric arrangement of components in the U1 receiver is very unusual and a diagram of the working parts is shown in Fig. 3-11. This diagram shows the parts separated, but when assembled the north pole of the permanent magnet rests on the south pole of the pole piece. The U1 receiver can now be recognized as a monopole receiver with a large hollow core. The pole piece (north pole) pulls on the inner edge of the iron-alloy ring armature, bending it down because the outer edge rests on the non-magnetic rim (not shown in the diagram). The gap between the diaphragm and the pole piece is much smaller than the gap between the diaphragm and the permanent magnet, so the force on the diaphragm is dominated by the pole piece. When the coil is energized with an ac voice signal, the strength of the magnetism in the pole piece is first strengthened and then weakened thus causing the diaphragm to vibrate just as in a monopole receiver. The light-weight aluminum diaphragm in the U1 receiver is able to move faster than the earlier iron-alloy diaphragms, giving the U1 improved high-frequency response.

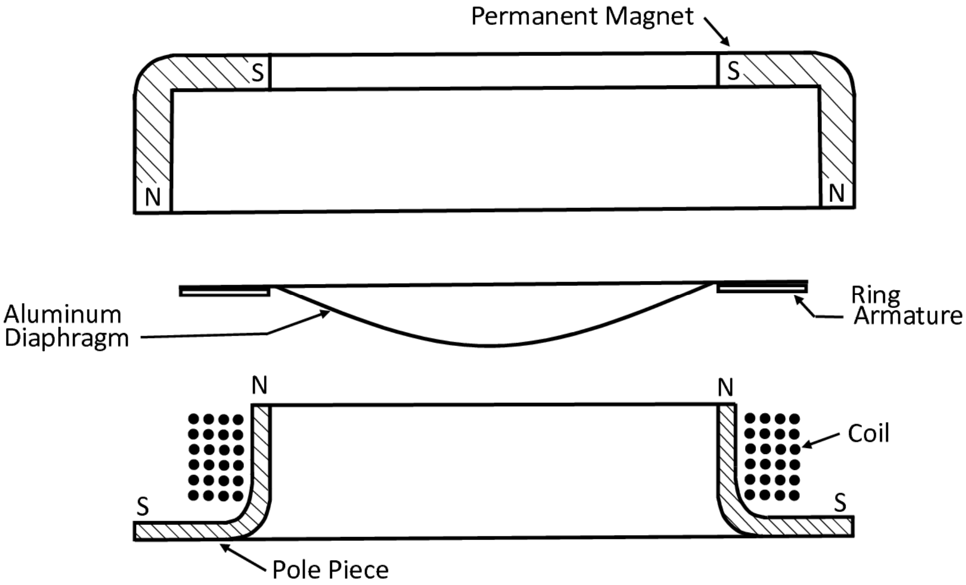

Fig. 3-11. Diagram with an exploded view of a U1 receiver.

Western Electric No. LA2 Receiver

If there is beauty in simplicity, then the LA2 receiver is simply beautiful. This light-weight receiver is ultra-simple and was developed for the Trimline handset that was introduced in 1965. The small LA2 design weighs only a third as much as the U1 receiver, is obviously cheaper to manufacture, and has performance characteristics that are similar to the U1 (Stevens 1966, 37; AT&T Bell Laboratories 1969, 220). Figure 3-12 shows the bottom of an LA2 receiver, although some of the parts are still obscured from view.

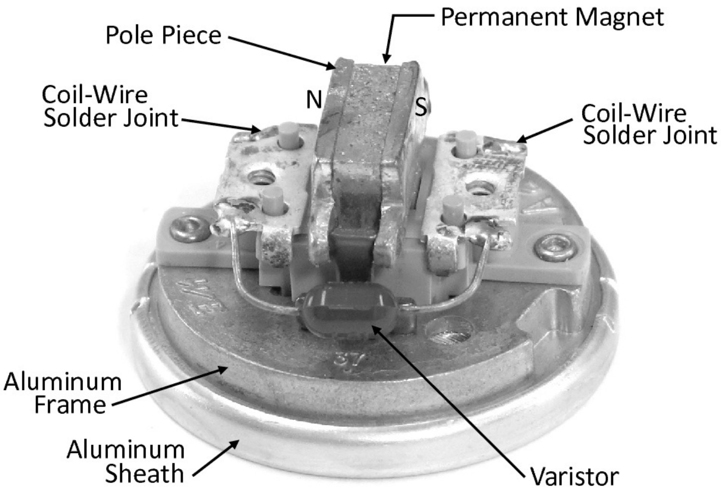

Fig. 3-12. Bottom view of an LA2 receiver.

Dissected views of this receiver are shown in Figs. 3-13 and 3-14 (right-side up). The first of these shows the coil assembly in place while the second figure shows the permanent magnet and pole pieces with the coil assembly removed.

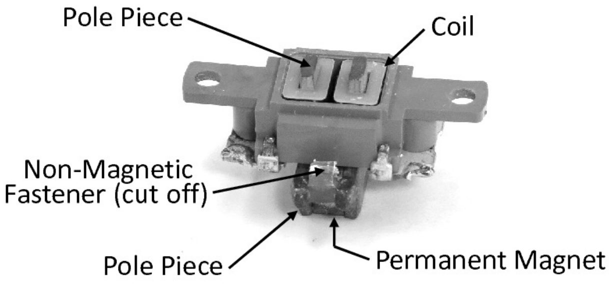

Fig. 3-13. LA2 magnet and coil assembly.

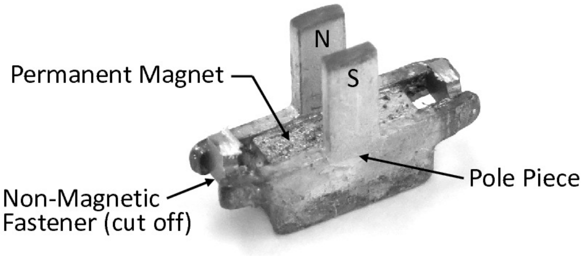

Fig. 3-14. LA2 magnet without coil assembly.

Like the U1 receiver, the LA2 uses a very light-weight aluminum diaphragm with a soft iron-alloy armature. Unlike the U1, however, the armature in the LA2 diaphragm is a small round button in the center rather than a ring around the periphery. Figure 3-15 shows a diagram of magnetic parts of an LA2 receiver, which can now be seen to be a rather standard bipolar receiver whose operation is described above. The LA2 and an almost identical LB1 were the last of the receivers designed by the Bell System and were intended to be used in all of their future telephones.

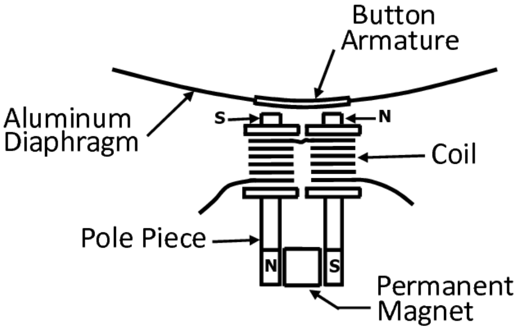

Fig. 3-15. Diagram of an LA2 receiver.

The Baldwin Receiver

Although Baldwin's design used the same underlying principle – that an electric current produces a magnetic field – his receivers were constructed quite differently from Bell's. Baldwin's design was patented in 1910, and a diagram displaying the important parts is shown in Fig. 3-16.[2] The coil is wound on a tube that has been flattened such that its hole is shaped like a racetrack rather than a circle. A strip of soft iron runs through this flattened tube to serve as the armature. Thus the electromagnet's coil has its main effect on the armature rather than on the pole piece of a permanent magnet as in all the other receivers.

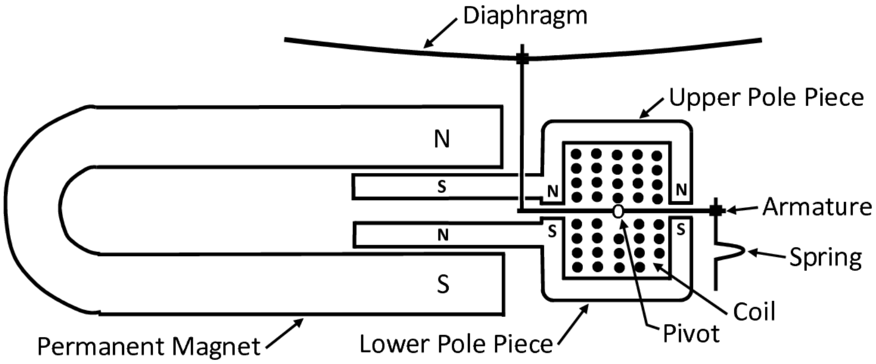

Fig. 3-16. Diagram of Baldwin's magnetized-armature receiver.

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[2] Nathaniel Baldwin, "Telephone Receiver," Patent No. 957,403, dated May 10, 1910; application filed July 1, 1909.

A more pictorial sketch of the coil region is shown in Fig. 3-17, which is from Baldwin's 1910 patent. Here, 18 is the coil, 19 and 20 are the pole pieces, 21 indicates extensions of the pole pieces which fasten to the permanent magnet, 23 is the flanged end of the coil form, 25 is the armature, and 25a is a spacer.

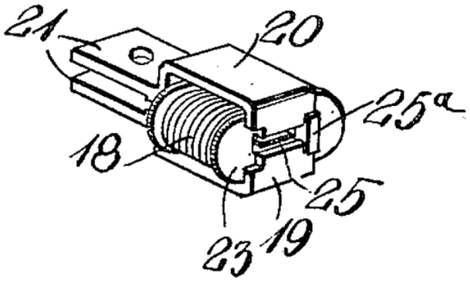

Fig. 3-17. Baldwin's patent drawing of the coil assembly in his receiver.

Referring again to Fig. 3-16, the armature in Baldwin's design is pivoted at its middle, with one end of the armature connected to the diaphragm and the other end connected to a spring. One end of the armature is pulled up under tension by the diaphragm while the other end of the armature is pushed up by compression of the spring. Adjusting nuts are provided on the connections such that the tension and compression forces are the same and the armature is balanced in its at-rest (no voice current) position as shown. In this manner, little or no mechanical force is required to rock the armature back and forth.

In a standard receiver the coils increase and decrease the magnetism of the pole pieces of the permanent magnet. In Baldwin's design, however, the coil magnetizes the iron armature while having little effect on the pole pieces, which are outside of the coil. Because the armature is made of magnetically soft iron, the magnetic field in the armature can change very easily in response to the external magnetic field of the coil. Thus during the positive half of an electric current cycle, one end of the armature will be a north pole and the other end will be a south pole, just like the polarity of the electromagnet's coil. Let's say that the north pole of the armature is on the right side in Fig. 3-16 where it connects to the spring. This end of the armature will be repelled by the upper pole piece and attracted by the lower pole piece. This push-pull action is reversed on the left end of the armature where the armature's south pole will be attracted to the upper pole piece and repelled by the lower pole piece. Thus the armature will rotate clockwise during this half of the electric current cycle, with little or no resistance due to the stiffness of the diaphragm. During the negative half of the current cycle, the polarity of the armature is reversed and the armature will rotate counterclockwise.

Baldwin received two later patents that were modifications of this scheme and employed a circular-shaped magnet instead of the long horseshoe magnet in his original design.[3,4] The later of these patents was for a watch-case-style "Type C" receiver, which was used as a headphone. Figure 3-18 is a bottom view of Baldwin's Type-C receiver element where you can see the wide circular magnet, the ends of which have been trimmed such that the north pole is attached to the upper pole piece and the south pole is attached to the lower pole piece. Although Baldwin's balanced-armature receiver was used primarily in radio headsets rather than telephones, it is described here because this design is a precursor to a sound-powered telephone that has been widely used in military and industrial applications.

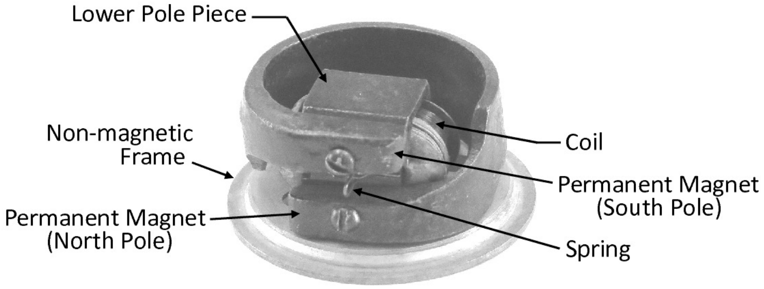

Fig. 3-18. Baldwin's Type-C receiver element.

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[3] Nathaniel Baldwin, "Telephone Receiver," Patent No. 1,153,593, dated Sept. 14, 1915; application filed March 27, 1913.

[4] Nathaniel Baldwin, "Sound-Producing Device of the Telephone-Receiver Type," Patent No. 1,581,155, dated April 20, 1926; application filed June 14, 1922.

Turnbull and Warnke's Sound-powered Receiver

Turnbull and Warnke's sound-powered telephone was described as a transmitter in Chapter 2, where it is shown in Figs. 2-3 and 2-4. The same transmitter element also works as the receiver in the sound-powered telephones. Its operation as a receiver can be described with reference to Fig. 2-4. During the positive half of an electric current cycle, one end of the armature will be a north pole and the other end will be a south pole. Let's say that the north pole of the armature is on the right side in Fig. 2-4. This end of the armature will be repelled by the upper pole piece and attracted by the lower pole piece. This push-pull action will rotate the armature clockwise. During the negative half of the current cycle, the polarity of the armature is reversed and the armature will rotate counterclockwise. This is essentially the same action as in Baldwin's receiver. The effectiveness of Turnbull and Warnke's sound-powered telephone was described in Chapter 2.

Properties of Receivers

The frequency responses of the Western Electric receivers are shown in Fig. 3-19.[5] This figure illustrates the relative response (i.e., the sound intensity produced relative to some arbitrary reference sound level) to a fixed ac voltage at different frequencies.

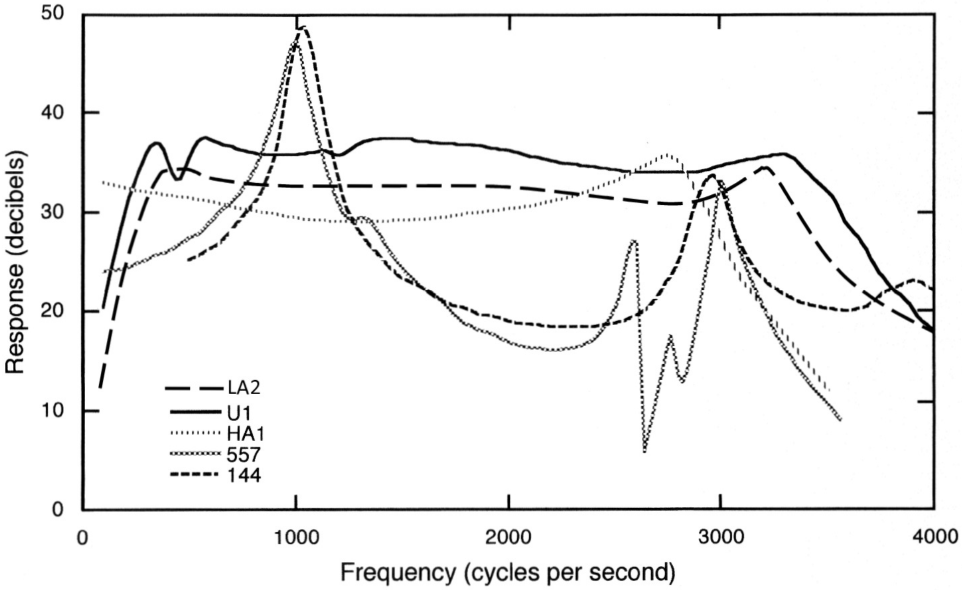

Fig. 3-19. Frequency response of Western Electric receivers.

It is somewhat surprising that a resonant receiver (the No. 557) was used in the E1 handset because the companion No. 395 transmitter was already of the non-resonant type. However, the poor response of the No. 395 transmitter at 1,000 cycles per second, when combined with the resonant response of the No. 557 receiver, produced a rather uniform overall response. Further, the electrical impedance of the voice coils was reduced to about half that of the earlier receivers. By lowering this impedance, the loss in the sidetone path and the transmitting efficiency were increased, resulting in a lower sidetone in the booster circuit then being widely used (see Chapter 16).

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[5] Figure 3-19 was derived from four consistent sources of Bell Laboratories information: Jones (1938, 348); Cobb (1952, 318); Fagen/AT&T (1975, 149), and Stevens (1966, 37). For reference, a 20-decibel increase in response corresponds to a ten-fold increase in voltage.

By 1937, when the next receiver type was introduced in the Western Electric F1 handset, research at the Bell Laboratories had advanced to a point where a good theoretical understanding of acoustics permitted a major practical advance (Jones 1938, 351; Colpitts 1937, 272). Prior to the introduction of this new HA1 receiver element, all receivers in the U.S. and abroad used simple resonant diaphragms. However, these resonances magnified annoying clicking noises from switch operation and condenser discharges, as well as contributing to unnatural voice sounds.

By using a somewhat smaller-diameter diaphragm with different clamping and mechanical properties, the prominent resonances were eliminated from the voice frequency range in the HA1 receiver, as can be seen in Fig. 3-19. This change significantly improved sound fidelity and reduced the loudness of the clicks produced by electrical disturbances. The HA1 receiver element was self-contained with no removable parts, but it was still rather heavy and expensive to produce.

Additional improvements in receiver performance were made with the U1 receiver element that was introduced in the G1 handset of the Western Electric 500-type telephones (Cobb 1952), although these performance improvements were modest as can be seen in Fig. 3-19. Efficiency was increased, and high-frequency response was extended from about 3,000 cycles per second in the HA1 to about 3,500 cycles per second in the U1. Low-frequency response of the U1 below 500 cycles per second is not as good as the HA1. However, the loss of low frequency sensitivity was intentional, to eliminate power-frequency hum (60 cycles per second and several harmonics). This was accomplished by piercing the diaphragm. But the U1 receiver was still heavy and expensive to produce. Finally, the cost and weight were reduced sharply with the LA2 receiver, with very little loss in overall performance as can be seen in Fig. 3-19.

The electrical properties of a receiver are a little complicated. Because a receiver has a coil, it has an inductive impedance. Because it is a real coil (non-ideal) made of fine wire, the coil also has a dc resistance. The receiver also functions a little like a transformer because the alternating magnetic field of the voice coils induces eddy currents in the solid pole pieces of the magnet.[6] Thus, there is an additional resistance that shows up at operating frequencies that is not apparent in a dc measurement. It is not necessary to describe these properties in detail, but it is useful to indicate the dc resistance and the total ac impedance of a receiver under operating conditions (i.e., undamped, with the diaphragm moving freely).

Table 3-1 lists measured values for a number of popular receivers produced by several manufacturers, and the instruments in which these receivers are used will be identified in Part Two. Table 3-1 also lists the phase angle, which is a measure of the proportions of inductive and resistive impedance in the total. Values in Table 3-1 were measured on two or more receivers of each type, and with a couple of exceptions variations among each type were less than ± 10 percent. Miller gives receiver properties for two of these receivers, and those values are in excellent agreement with the corresponding values in Table 3-1 (Miller 1933, 35, 38).[7]

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[6] The use of thin iron plates or small wires, rather than solid pieces, in the cores of induction coils, retardation coils, and transformers reduces eddy-current losses in those components.

[7] Stromberg-Carlson No. 27A: 80 ohms dc, 258 ohms at 1,000 cycles per second, 51-degree phase angle. Western Electric No. 144: 84 ohms dc, 215 ohms at 800 cycles per second, 50-degree phase angle.

Table 3-1. Electrical properties of various receivers.

Receiver	Resistance ohms (dc)	Impedance[a] ohms (ac)	Phase Angle deg
		Western Electric	
122	75	260	40
144	85	240	50
557	30	130	60
HA1	25	120	55
U1	35	145	45
LA2	35	145	45
		Automatic Electric	
23 (polarized)	80	230	55
23 (dc)[b]	50	530	60
38	45	230	75
41	25	120	70
		Kellogg	
41A	65	350	60
89-A	40	250	70
		Stromberg-Carlson	
27A	80	230	52
34230	30	120	65

[a] Total undamped impedance at 1,000 cycles per second.

[b] Measured with dc flowing.

* * *

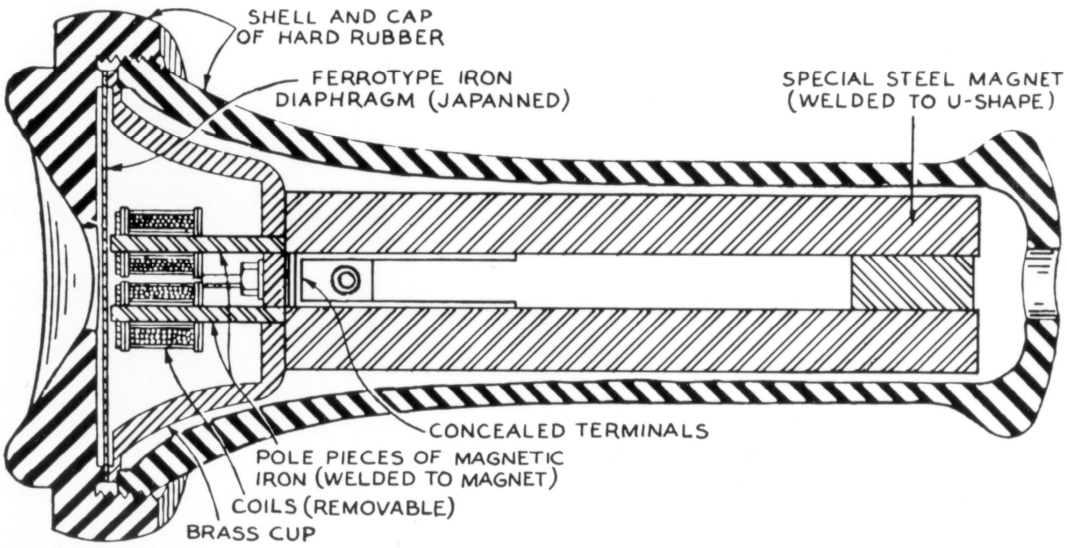

Fig. 3-20. Cross section of Western Electric No. 144 bipolar receiver. Courtesy of AT&T Archives.

Chapter 4
Induction Coils

Induction coils with two windings were being made experimentally within a few years of the discovery of magnetic induction in 1831. Nicholas Callan, a priest turned physics teacher in Ireland, and Charles Page, a physician from Massachusetts later known for his discovery of magnetostriction (the Page effect), are credited with the earliest work with induction coils (Armagnat 1908, 7-10; Shiers 1971). By 1838, Page had constructed a coil that was in most respects a prototype of later coils; it consisted of primary and secondary windings of insulated copper wire on a hollow wooden bobbin containing a core of soft iron wires. By the mid-1870s, the induction coil was being used for scientific studies, medical treatments of dubious value, and theatrical purposes (producing gigantic sparks). Its use in a telephone circuit as a transformer was probably the first legitimate commercial application of the induction coil.

Although induction coils were not used in standard telegraphy, coils were used by Gray and Bell in their harmonic telegraph work. Induction coils were also used in early telephone improvements patented by Berliner and Edison. Because these coils were used for different purposes, when and why the coil was introduced into standard telephone circuits is somewhat obscure. In attempting to understand this, it will be helpful to first identify the principles and functions of an induction coil in a telephone.

Principles of an Induction Coil

Induction coils are transformers, so what is said here about induction coils applies equally to transformers. Consider two coils of insulated wire wrapped around an iron core as shown in Fig. 4-1. Suppose an alternating current (ac) generator is connected to Coil No. 1. The generator could be a telephone transmitter, a magneto, or any source of ac voltage. During the positive half of an ac cycle, the current will go clockwise around the circuit containing the generator. This current will create a magnetic field in the core that causes its internal atomic magnets to line up such that the core has its north pole at the top (see the Appendix for an additional discussion of magnetism).

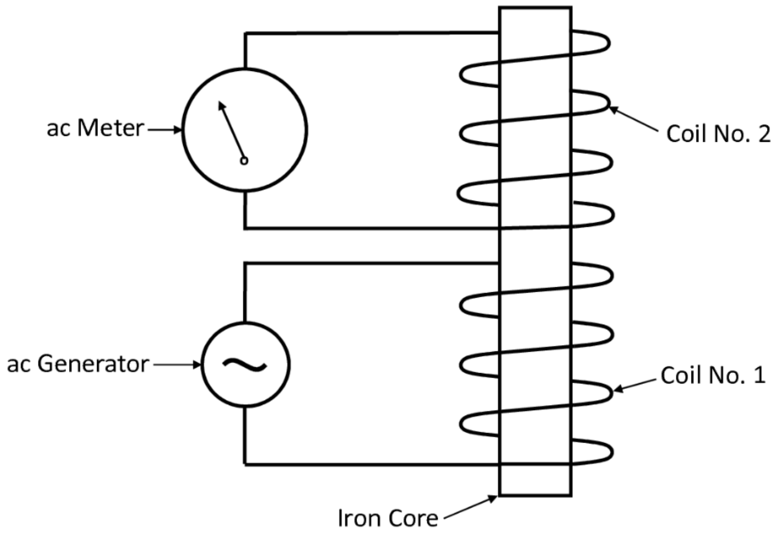

Fig. 4-1. Two coils wrapped around the same iron core.

An instant later, during the negative half of the ac cycle, the current will go the other way and the top of the iron core will become a south pole. Thus during each cycle of ac current, the magnetic field in the iron core changes back and forth between north pole and south pole at the top. In other words, the ac generator has created a magnetic field that is changing with time in the iron core – an ac electromagnet.

Now consider Coil No. 2, which is wire wrapped around a magnetic field that is changing with time. This is precisely the condition that will induce an electric current in the coil's wire. If an ac meter is connected to Coil No. 2, it will register a current or voltage, whichever meter is used.

Suppose there are 500 turns of wire in Coil No. 1, 500 turns in Coil No. 2, and 1 volt of ac put out by the generator. Because there is a lot of symmetry in physics, it is not too surprising that the alternating magnetic field that is created by Coil No. 1 is exactly the right size to produce 1 volt of ac that the meter would see across Coil No. 2. Now suppose the number of turns in Coil No. 2 is doubled to 1000 without making any other changes. The same alternating magnetic field would be created in Coil No. 1, but Coil No. 2 is like two 500-turn coils together, each of which picking up 1 volt. Thus the meter across Coil No. 2 will read 2 volts. It is generally true that the voltage across coil No. 2 will be the turns-ratio (2 in this case) multiplied by the voltage across Coil No. 1. Thus the turns-ratio of a coil is an important parameter. Other parameters of a transformer related to the turns-ratio are discussed in the Appendix.

It is possible to have more than two coils of wire in an induction coil or transformer, and each of the additional coils would pick up a voltage from the varying magnetic field produced by Coil No. 1. If Coil No. 1 is the coil to which a voltage source is attached, it is called the primary winding. Coil No. 2 would be the secondary winding, and Coil No. 3 (if there were one) would be the tertiary winding. In practice, the secondary and tertiary windings are usually wound on top of the primary winding rather than at different axial locations along the iron core as shown in Fig. 4-1.

In early cylindrical telephone induction coils, the iron core was made of a bundle of small iron wires rather than a solid iron rod. These wires have been partially pushed out so they can be seen in Fig. 4-2. This arrangement reduces small circular currents (eddy currents) that are induced in the iron itself, thus reducing losses. In later transformer-style induction coils (e.g., in a Western Electric 302), the core of the coil is formed from thin laminated layers of iron or magnetically soft iron alloys for the same reason.

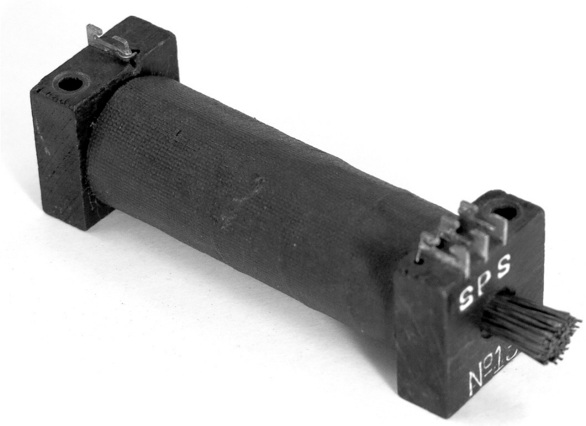

Fig. 4-2. Western Electric No. 13 induction coil with iron wires for its core.

Functions of a Telephone Coil

In its simplest form, the emerging telephone circuit consisted of a resistance transmitter, an electromagnetic receiver, and a battery in series, as shown in Fig. 4-3. In this arrangement, a high-voltage, multi-cell battery was required to produce an adequate transmitter current through the combined resistances of the transmitters (about 50 ohms each), the receivers (about 80 ohms each), and the line (say 200 ohm). For these combined resistances, a 12-volt battery would have been required to produce a satisfactory direct current of about 25 milliamperes. Furthermore, the ac voice signal reaching the receivers was relatively weak, and an increase in signal strength was desired.

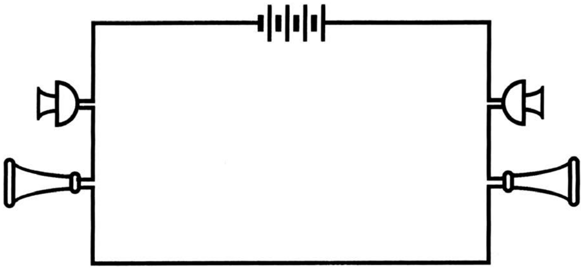

Fig. 4-3. Simplest series circuit for telephones with resistive transmitters and electromagnetic receivers.

An induction coil (i.e., a transformer) as connected in Fig. 4-4 improved both situations. First, by placing the battery in a part of the circuit with a low-resistance winding of the coil (about 1 ohm), a large transmitter current could be obtained with a small battery. For example, a 3-volt battery will produce a 59-milliampere current through a 50-ohm transmitter and a 1-ohm coil (51 ohms total). Second, by choosing the turns ratio correctly for the coil windings (about 4 to 1), the impedances of the transmitter and its load could be matched so that the power delivered to the line would be maximized.[1] Matching impedances in this manner results in about a 3-fold increase in the power delivered to the line.

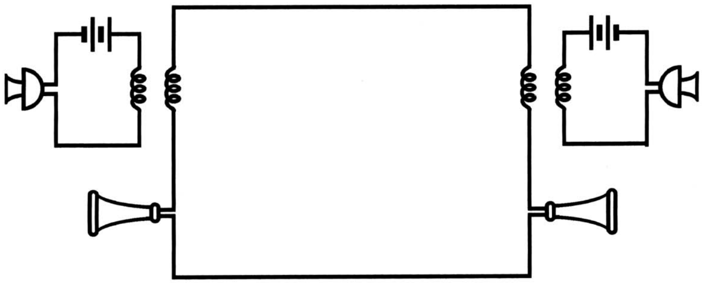

Fig. 4-4. Telephone circuit using induction coils (transformers) to induce transmitter voltages in the receiver circuit.

An additional benefit of using a coil in this manner is that no direct current would be present in the receiver to alter the magnetic field of the permanent magnet. It would still be correct to think of Fig. 4-4 as a series circuit with the coil simply considered to be a part of the transmitter (i.e., transmitter element, battery, and coil). This so-called local-battery circuit (shown in Fig. 4-4) was used universally in magneto telephones for more than 50 years.

In summary, the induction coil performs two main functions: (1) it isolates dc parts of a circuit, and (2) it matches impedances. In later common-battery circuit applications, the isolation function is more important than the impedance-matching function and coils will be seen having turns ratios of nearly 1-to-1. Induction coils with more than two windings will also be seen in those circuits. Because induction coils are designed for the purpose at hand, coil specifications are described in later chapters in the context of their circuit applications.

Early Applications of a Telephone Coil

Returning to the emergence of the induction coil in telephone applications, each inventor's use of a coil can now be examined in comparison with the coil's main functions. Gray, in his telegraph work, used induction coils to convert interrupted low voltages into high-voltage (or high-tension) pulses. Induction coils are used in this manner today in automobile ignition systems. In his patent of July 1875, on an electric telegraph for transmitting musical tones, Gray put the batteries and vibrating interrupter in the primary circuit of the coil and put the electromagnetic receiver in the secondary circuit. The resulting large-voltage pulses were used to drive the high-resistance electromagnetic receiver. It is noteworthy that Gray used this coil in a matter-of-fact manner and made no mention of the induction coil in his summary claims statement.

Bell also used an induction coil in his early telegraph work. About December 1873, it is reported that Bell thought of improving the operation of his harmonic telegraph by having the vibrating transmitter make and break the primary circuit of an induction coil and by putting the secondary circuit on the main line (Rhodes 1929, 6). This was just as Gray would describe in his July 1875, patent. Bell eventually did away with the induction coil, however, and concentrated on his development of the induction telephone. In Bell's use of this instrument as both a transmitter and a receiver, his components, being exactly the same, had perfectly matched impedances and would not have benefitted from an induction coil.

In his patent of January 1878, Berliner describes the use of two induction coils in a circuit using a transmitter and receiver of similar construction (and hence of similar impedance), as shown in Fig. 4-5.[2] The coils in this arrangement seem to be of dubious value. They do isolate the battery circuits into local-battery circuits, as Berliner called them. This has some advantage in conserving battery power if the line

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[1] See the Appendix for a discussion of transformers and matching impedances. An example directly related to the discussion above is worked out there.

[2] Emile Berliner, "Improvement in Telephones," Patent No. 199,141, dated January 15, 1878; application filed October 16, 1877. The graphical symbol used in Fig. 4-3 for both the transmitter and the receiver is based on Berliner's earlier drawing shown in Fig. 2-1 of Chapter 2. This symbol is used in some references as the standard graphical symbol for a transmitter. It is used here because the transmitter and receiver in Berliner's circuit were not the usual types.

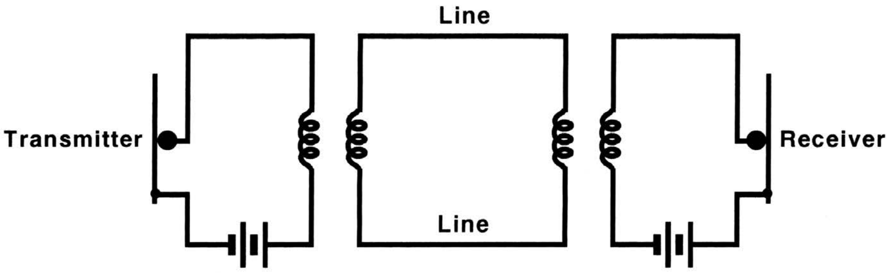

Fig. 4-5. Circuit of Berliner's telephone that is based on his patent, applied for in 1877.

had a high resistance, but his receiver required a battery, too, so no battery power would have been wasted there. The voltage step-up for line transmission would also have had some advantage in transmission efficiency. Because line losses go as the square of the current, it is better to have a high voltage and low current than a low voltage and high current of equal power capacity. But the two coils were identical and the voltage was stepped back down at the receiving end; no impedance matching was provided or was apparently needed since the transmitter and receiver were similar. These two advantages are minor and do not appear germane to the importance of the induction coil in telephone design at this stage of development.

Edison filed a patent application a few months after Berliner's filing, and in Edison's patent he also used an induction coil.[3] The main thrust of Edison's patent was the description of a new transmitter using sequentially activated contacts and a rheostat. In his circuit (as shown in Fig. 4-6), Edison did, incidentally, use an induction coil, and he did include the use of this coil in his patent claim. Overall, Edison's patent specification appears to cover two relevant functions of the coil, namely, (1) isolation of the transmitter in a local circuit, and (2) step-up of the signal voltage. However, Edison did not achieve a true local-battery circuit because he curiously left the battery in a location that would allow battery current in the line circuit as well as in the local circuit. Furthermore, Edison did not accurately describe the step-up function as seen from a statement near the end of his patent specification: "... thus obtaining a powerful current on the line from a weak local current." This statement is simply not correct as the signal power in the primary and secondary circuits are the same (energy is conserved), and the current is actually stepped down by the coil that Edison used (it was the voltage that was stepped up). In a patent filed just a few months later in 1878, Edison used a coil in a more conventional way; that is, in the manner shown in Fig. 4-4.[4] The main purpose of this later patent was to cover the use of lampblack as an electrode in the transmitter, and only passing mention was made of the coil.

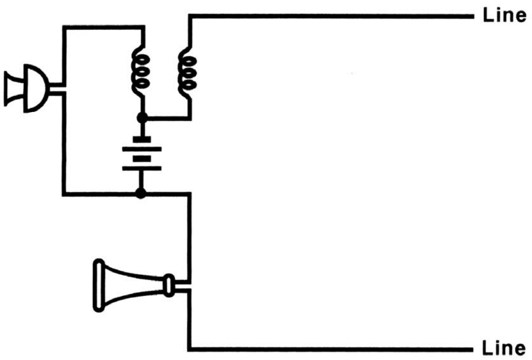

Fig. 4-6. Circuit of Edison's telephone that is based on his patent, applied for in 1877.

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[3] Thomas A. Edison, "Improvement in Speaking-Telephones," Patent No. 203,013, dated April 30, 1878; application filed December 13, 1877.

[4] Thomas A. Edison, "Improvement in Speaking-Telephones," Patent No. 203,016, dated April 30, 1878; application filed March 7, 1878.

Looking back, it appears that none of the early users of induction coils in telephone circuits had a clear understanding of the true functions of the coils, although Edison almost did. The isolation function of the coil was probably recognized by all because of the similarity to telegraph circuits where isolation of local-battery circuits was accomplished with relays. The concept of matching impedances, however, does not appear in any of these early patents. Nor does this concept appear in turn-of-the-century texts on telephony, where the coil is still described as a step-up transformer to provide higher line voltages (Webb 1902, 17; Homans 1904, 33, 101; Miller 1903, 17; Abbott 1904, 224-227; McMeen and Miller 1912, 158). Later texts, of course, describe the impedance-matching function (Albert 1943, 42; Fagen/AT&T 1975, 105). Because some step-up is required to match the low-impedance transmitter to the higher impedance line, the early step-up coils led to improvements in transmitted power, but some stepped up the voltage too much, resulting in power delivery that was less than optimum.

Commercial Induction Coils

The Bell organization probably came to a full understanding of impedance matching earlier than the others -- as was evidenced by their very successful No. 13 coil, developed in 1893 (Fagen/AT&T 1975, 109). This Western Electric coil has an effective turns ratio of only about 4, which matches impedances well for a typical line. American Electric, Kellogg, Stromberg-Carlson, and other coils of the same vintage invariably have higher turns ratios, suggesting that they were still being produced according to the faulty belief that more was better. Figure 4-7 shows the Western Electric No. 13 coil, which exhibits the traditional cylindrical shape of all early telephone coils. Figure 4-8 shows the later Western Electric No. 101A coil, which has three windings and resembles a modern doorbell transformer. Electrical properties of these and other coils are given in Part Three, where the various coil windings are identified in circuit diagrams.

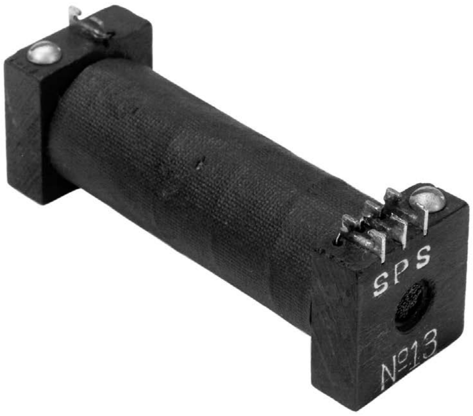

Fig. 4-7. Western Electric No. 13 induction coil used in the standard local-battery circuit from 1893 to the late 1930s.

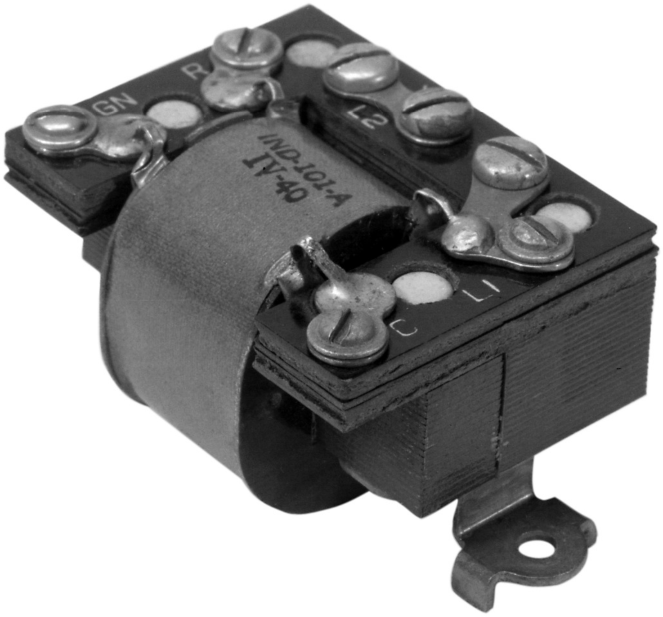

Fig. 4-8. Western Electric No. 101A induction coil used in the common-battery, anti-sidetone circuit of the 1930s and 1940s

Chapter 5
Magnetos

The signaling and switching components described in the next chapters have little or no effect on the talking circuit itself. And, in contrast to much of the work described in earlier chapters, these developments were largely adaptations of existing technology, rather than new inventions intrinsic to the telephone.

Watson's Magneto of 1878

Early methods of signaling included the use of telegraph sounders, vibrating bells, buzzers, and Watson's "thumper" (Rhodes 1929, 176-177). Each method suffered some shortcoming that made it unacceptable. All required multi-cell, high-voltage batteries to overcome line resistance, and this was a major disadvantage. Within two years, however, Watson patented developments that would lead to standardized methods of signaling with magnetos and ringers.

By late 1977, Thomas Watson was fully aware of the principles of electromagnets and magnetic induction, and he filed a patent application for a call-signal apparatus.[1] One of his patent drawings is shown in Fig. 5-1. This drawing shows a telephone like the box telephone, which was not new in the patent, but the drawing also shows a magneto and a ringer (see next chapter for ringers). A magneto like this went into production in the Williams Coffin telephones (see Chapter 8).

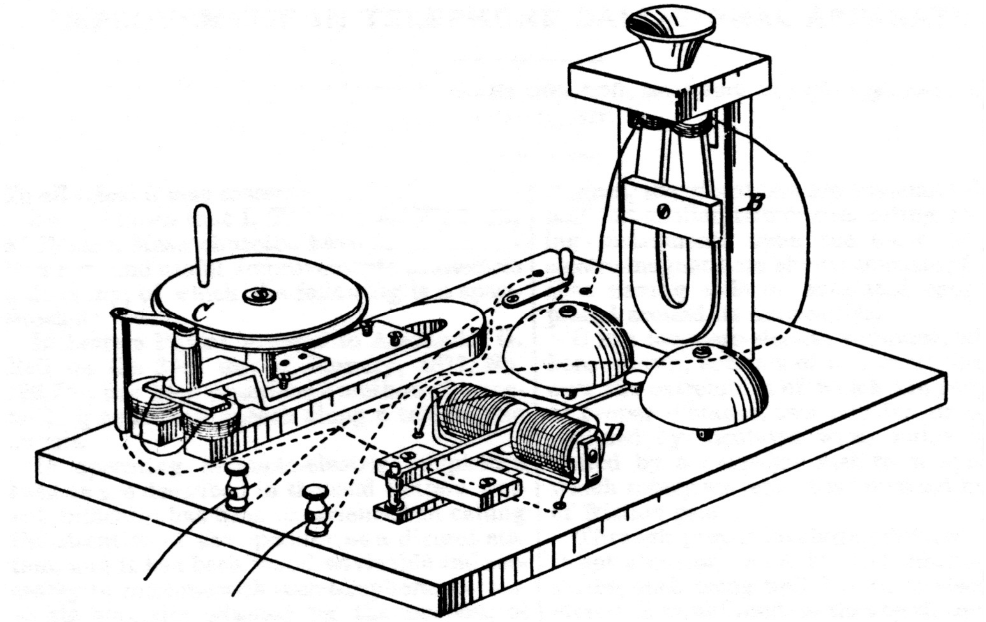

Fig. 5-1. Sketch showing magneto and ringer in a telephone circuit
from Watson's patent, applied for in 1877.

In this figure, focus attention on the magneto on the left side of the drawing. Here two coils of wire would be spun around near the poles of a horseshoe permanent magnet, so an electric current would be generated by the induction principle. The details of this process are better understood from Fig. 5-2, which shows only the rotating part of this magneto. The two coils are wrapped around soft-iron cores, with the windings in opposite directions (one clockwise, CW, and the other counterclockwise, CCW) and connected

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[1] Thomas A. Watson, "Improvement in Telephone Call-Signal Apparatus," Patent No. 202,495, dated April 16, 1878; application filed October 11, 1877.

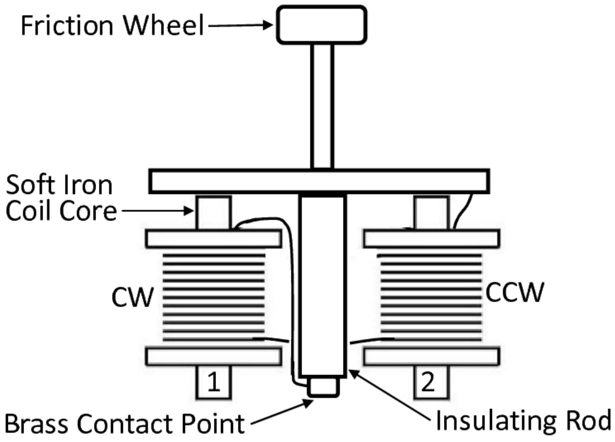

Fig. 5-2. Coil detail for Watson's patent diagram.

together at the bottom. One of the other end wires is connected to the steel bar that holds the coil cores, and this bar makes contact to the stationary parts of the magneto through the bearing surfaces. The remaining end wire is connected to a contact point on an insulating-rod extension of the rotating shaft. This contact point rubs on a leaf spring, which is mounted on the base. In Fig. 1, the leaf spring and contact point are on the top of the rotating shaft, but Fig. 2 has been drawn more like the Williams Coffin phones where the contact is on the bottom of the shaft.

During rotation, when the point labeled 1 is directly over the north pole of the permanent magnet, the internal atomic magnets line up such that this coil's core becomes magnetized with its north pole at the top. At that instant the point labeled 2 is directly over the south pole of the permanent magnet such that the core of its coil is magnetized with its south pole at the top. By the time the point labeled 1 moves over the south pole of the permanent magnet and the point labeled 2 is over the north pole, the atomic magnets have been rearranged to reverse the polarity. As rotation continues, this back-and-forth changing of the polarity constitutes a changing magnetic field that is felt by the coil windings; an alternating current is thus produced. By winding the coils in opposite directions, they work together to produce this current.

Watson's magneto is interesting because it demonstrates so vividly the principle of magnetic induction, but it was not the first magneto generator. Watson was forthright about this. In his patent he stated: "I do not claim ringing a bell by the use of a magneto-electric current, as that has been done before...." Crude versions of a magneto generator were constructed as early as 1832 (Karrass 1909, 105). Like the one shown in Fig. 5-1, the early magnetos consisted of horseshoe magnets with several bobbin-like coils that were rotated on a shaft in the vicinity of the magnetic poles. Horseshoe magnets of the time were made of relatively thin stock (1/16th to 1/8th inch thick) in contrast to the heavy bar stock used later. Consequently, a number of magnets would be piled up to produce a stronger field, and this laminated construction is shown clearly in Bell's patent drawing for his induction telephone (Fig. 2-1). Although this detail is not shown in Fig. 5-1, photographs of early magnetos constructed by Watson show this lamination (Fagen/AT&T 1975, 119).

Siemens' Magneto of 1856

Watson was apparently not well informed about the work of others. In 1856, more than 20 years before Watson's work on signaling, Werner Siemens in Germany developed a sophisticated form of the magneto that is recognized as the prototype for the commercial telephone generators yet to come (Karrass 1909, 106-107). In Siemens' magneto, the magnets were fastened together with spacers in between them in the form of the familiar tunnel-shaped array, and a cylindrical armature was placed in the tunnel between the poles. Siemens' magneto-induction machine with this "Zylinder-Induktor" is shown in Fig. 5-3.

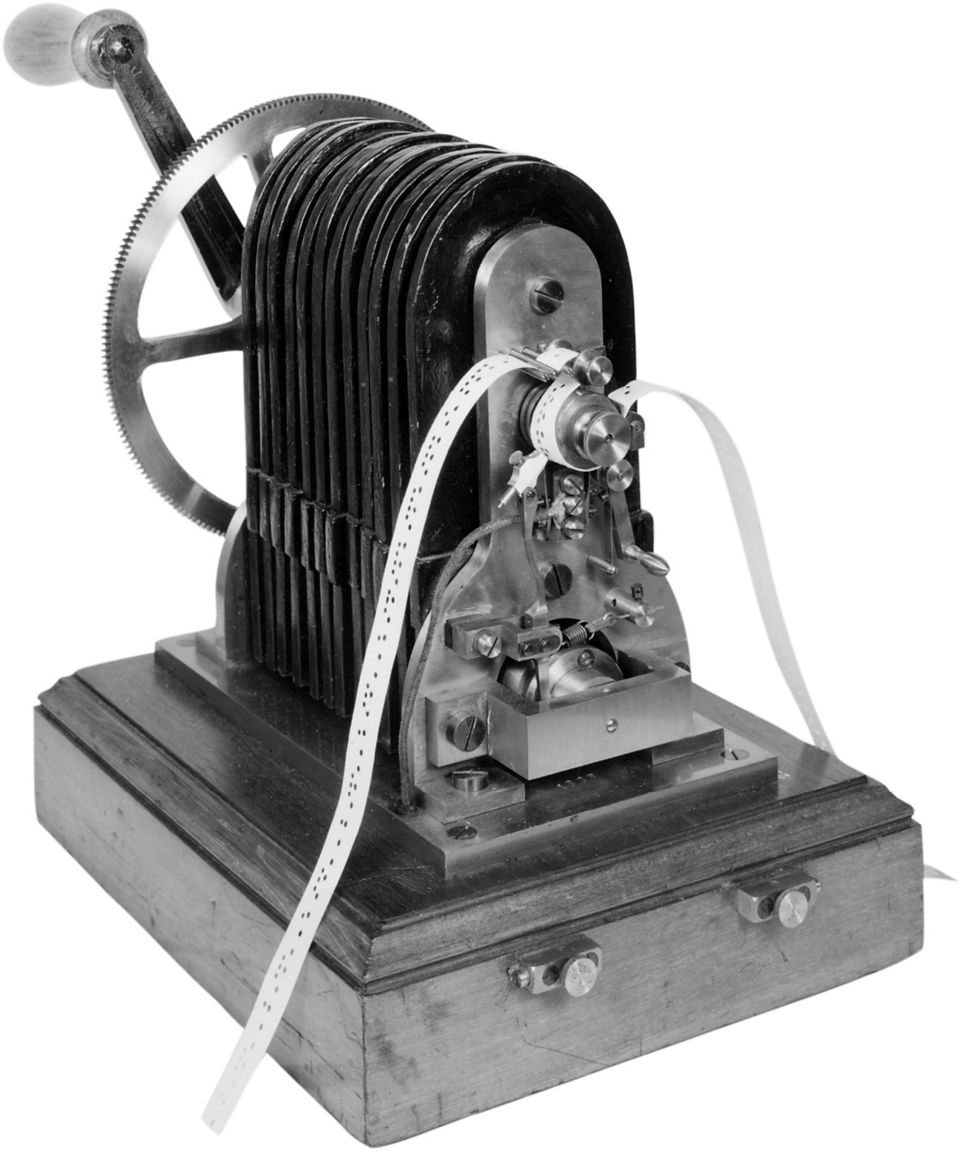

Fig. 5-3. Siemens' 1856 magneto with the cylindrical armature, shown here fitted with an automatic telegraph sender. ***Courtesy of Siemens Museum, Munich.***

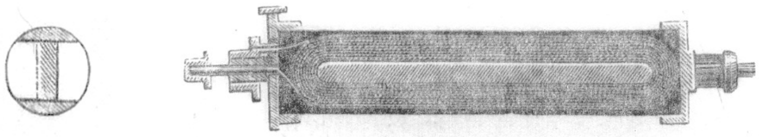

Fig. 5-4. Sections of the cylindrical armature of Siemens' magneto. ***Drawings reproduced from Karrass (1909)***.

Figure 5-4 shows a cross section and a longitudinal section of the cylindrical armature of the Siemens' magneto. Better diagrams are shown below for the similar Western Electric magnetos.

Western Electric's Magnetos

The Siemens-type magneto, apparently overlooked by Bell and Watson, was not adopted by the Bell System until 1881, and then it was used for more than 50 years.[2] Figure 5-5 shows the popular Western Electric No. 48A 5-bar magneto that bears a clear resemblance to the Siemens magneto shown in Fig. 5-3. This magneto was used in Western Electric equipment from 1911 through the 1940s.

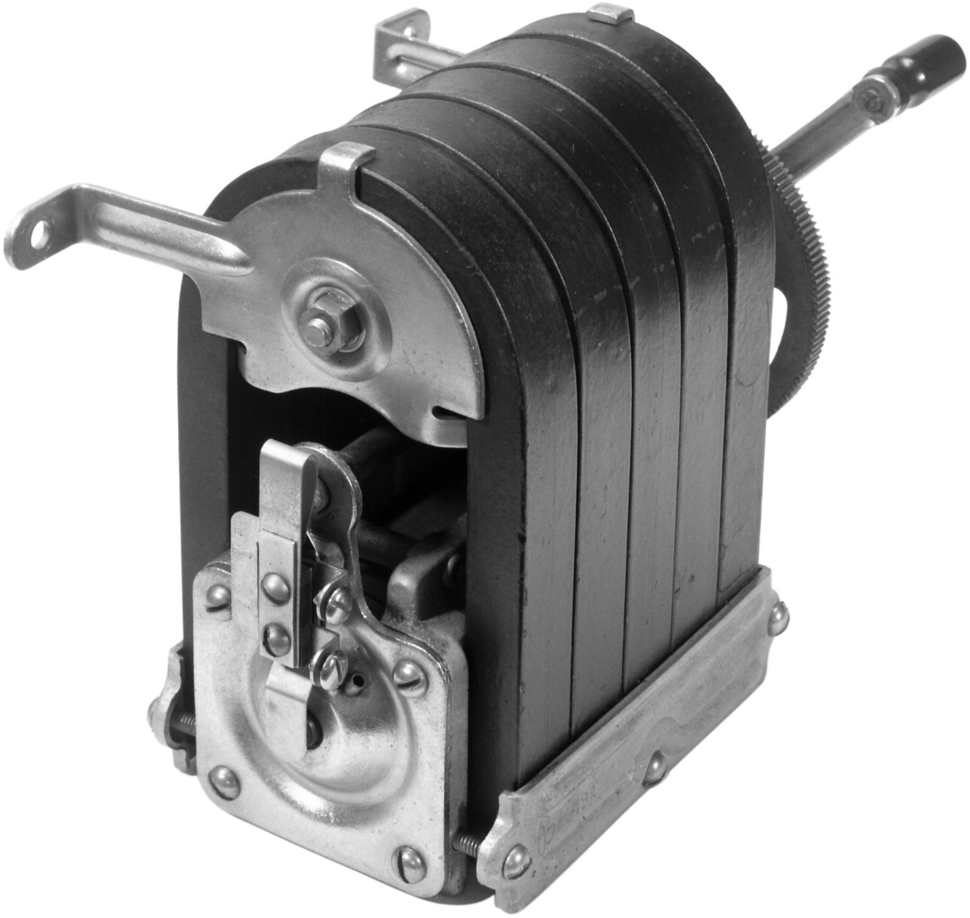

Fig. 5-5. Western Electric No. 48A magneto used from 1911 through the 1940s.

Figure 5-6 shows a diagram of a Western Electric cylindrical armature of the Siemens-type, including a cross-sectional view. Because of the shape of its cross section, this armature is referred to as an H-shaped armature in American texts, although in German texts it is called I-shaped or the double-T armature. In Fig. 5-6, the shape of the cylindrical armature can be seen along with the single coil winding on the center web of the armature. One end of the coil wire is connected to the armature's soft-iron frame, and electric conduction is through the shaft (2) to the bearing, which is not shown in this figure. The other end of the

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[2] In Fagen/AT&T (1975, 119), it is said that "it was about this time [1881] that Siemens developed the so-called `H-shaped' armature." As seen above, that development was actually made in 1856.

coil wire is connected to a contact point that runs through the insulated center of the other shaft (3). This contact point rubs on a leaf spring on a switch that can be seen in Fig. 5-8 below.

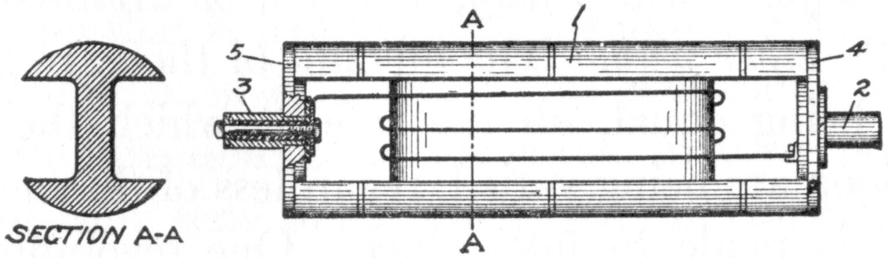

Fig. 5-6. Diagram of Siemens-type cylindrical armature for a magneto. ***Drawing reproduced from McMeen & Miller (1912).***

Figure 5-7 shows a section through the middle of the magneto, with the coil wires omitted for clarity. When the point labeled 1 is by the north pole of the permanent magnet's pole piece, the point labeled 2 is by the permanent magnet's south pole. Thus the armature has been magnetized with its south pole at 1 and its north pole at 2. When the armature rotates half way around such that point 2 is by the north-pole piece and point 1 is by the south pole-piece, the internal atomic magnets have rearranged and point 1 is now the armature's north pole. Thus the changing magnetic field in the armature induces an alternating current in the wire wrapped around it. There is a bonus with this cylindrical armature because the winding wires themselves come so close to the pole pieces of the permanent magnet that they also see this magnetic field changing as they pass by.

By using many turns of wire tightly wound on the H-shaped armature, and by utilizing shaped pole pieces to enhance the magnetic field, large voltages could be produced. Voltages generated by typical telephone magnetos are around 75 volts ac, and these hand-cranked generators produce an average frequency of about 17 cycles per second in normal usage.

Figure 5-8 shows a more complete layout of the magneto's moving parts without the permanent magnets and their pole pieces.

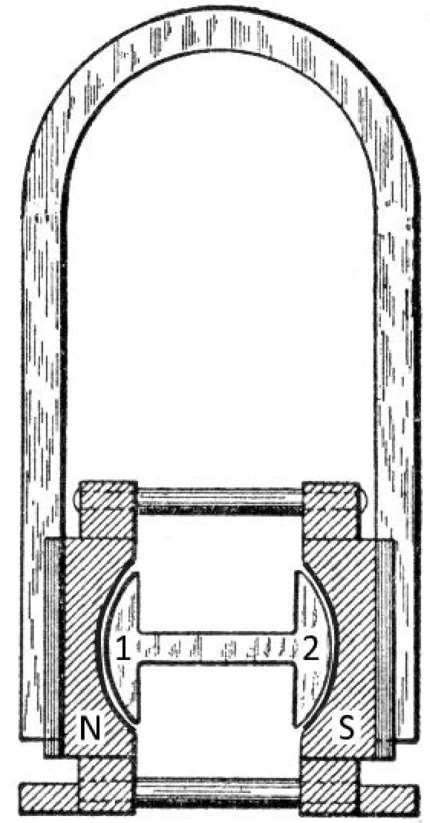

Fig. 5-7. Cross section of a magneto with the cylindrical armature. ***Drawing reproduced from McMeen & Miller (1912) and modified***.

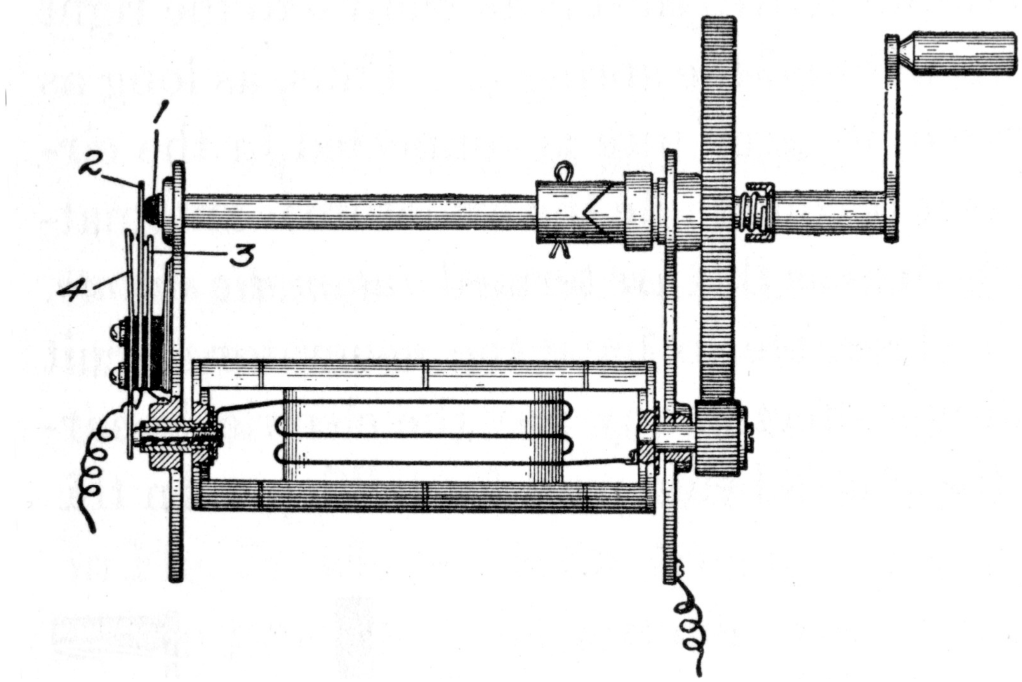

Fig. 5-8. Diagram of a shunt switch and its activation mechanism, shown with the cylindrical armature and its gearing. ***Drawing reproduced from McMeen & Miller (1912)***.

Electrical Properties and the Shunt

The armature winding of a telephone magneto has a fairly high ac impedance at voice frequencies. For example, the Western Electric No. 48A magneto shown in Fig. 5-5, which has a dc resistance of only about 100 ohms, has an impedance of 5,000 ohms at 1,000 cycles per second. This is ten times larger than the impedance of the telephone itself and would almost completely block the voice signal. Thus in early series circuits (see next section on ringers), a shunt switch was built into the magneto to bypass the magneto armature winding for talking. In later bridging circuits, that switch is used to open the armature circuit, effectively removing the magneto from the line.

This final detail of the telephone magneto is illustrated in Fig. 5-8. An automatic switch mounted on the end of the magneto is activated by the crank. When the crank is turned, a V-shaped notch in the driving collar causes the shaft to move outward so that the tip of the shaft (1) pushes on a switch contact. In this diagram, typical of a Kellogg magneto, the tip of the shaft is insulated and the switch, which has three terminals (2, 3, and 4), is of the single-pole-double-throw type. Western Electric magnetos generally used a 2-terminal switch, and the uninsulated shaft was one of the electrical contacts.

When central-office ringing machines came into use, they were matched to ringers already in service and thus designed to produce a sub-cycle frequency of 16⅛ cycles per second (a sixtieth of 1,000 rpm from the generators being used at that time), essentially the same frequency of a hand-cranked magneto. In 1917, the Bell company converted to direct-drive generators of 60 cycles per second and changed the standard ring frequency to 20 cycles per second, a third of 60 (Fagen/AT&T 1975, 120-121).

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Chapter 6
Ringers

Watson's Polarized Ringer

Less than 10 months after applying for a patent on the crude device shown in Fig. 5-1 of the previous chapter, Watson applied for a patent on an improved ringer that bears a striking resemblance to ringers that were still being manufactured 60 years later.[1] Figure 6-1 is a drawing from Watson's patent for this ringer. The only significant change that was made to Watson's design as ringers went into commercial operation was that the pivoting armature was moved from the top of the coils to the bottom to save space, as shown in Fig. 6-2.

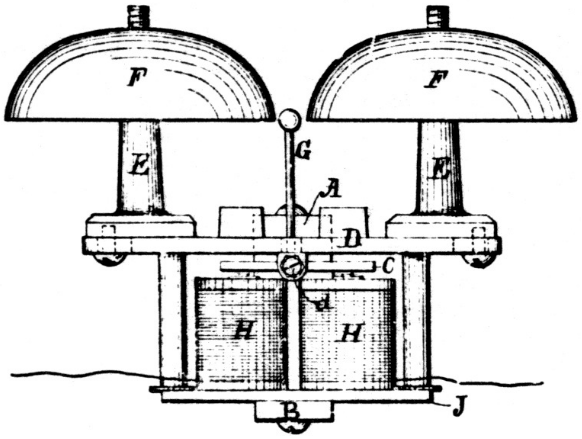

Fig. 6-1. Drawing of magnetically polarized ringer from Watson's patent, applied for in 1878.

In Fig. 6-2, a C-shaped permanent magnet (seen here head-on looking into the mouth of the C) forms the frame on which the rest of the ringer is assembled. A soft-iron bar is bolted underneath the top arm of the permanent magnet (north pole in the drawing), and cylindrical soft-iron coil cores are suspended from the bar. Thus the iron bar and the coil cores are magnetized (polarized), and the coil cores both have their north poles close to the ends of the armature, which is pivoted at its center. Mechanical details of the pivot have been omitted from the drawing for simplicity.

So far described, the polarized ringer's construction is symmetric and the magnetic forces on each end of the armature are equal when no ring current is present. However, the coils of the electromagnets are wound in opposite directions so that during any half-cycle of alternating current flow, one coil strengthens the field of its magnetic core while the other weakens the magnetic field of its core. The strengthened field pulls harder on its nearby end of the armature while the weakened field relaxes the pull on its nearby end. During the next half-cycle, the situation reverses such that the armature rocks back and forth, ringing the bells with the 16-to-20 cycle-per-second frequency of the ring signal. The permanent magnet in the polarized ringer thus performs the same function as the permanent magnet in a receiver, magnetizing the cores of the coils. However, in a bipolar receiver, the coils are wound such that the electromagnets operate in unison on the diaphragm whereas in the ringer the electromagnets operate in opposition to each other on the ends of the armature.

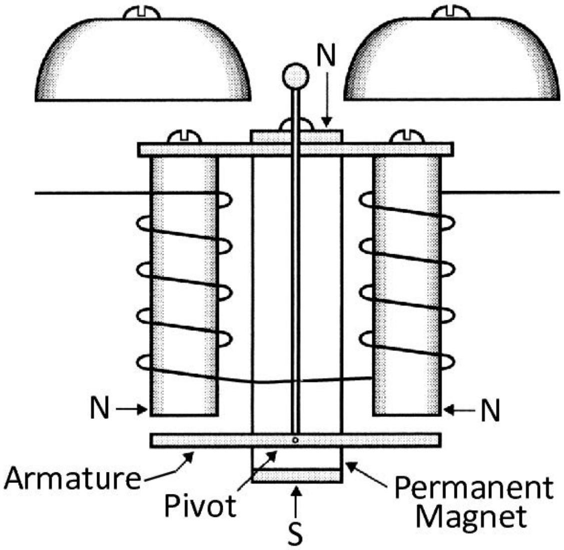

Fig. 6-2. Diagram of Watson-type polarized ringer used commercially until the mid-1930s.

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[1] Thomas A. Watson, "Improvement in Polarized Armatures for Electric Bells," Patent No. 210,886, dated December 17, 1878; application filed August 1, 1878.

Carty's Bridging Ringers

For about 15 years, ringers and magnetos were connected in series, as described in Watson's patent of April 1878 and shown in Fig. 6-3. Automatic switches (shunts) were used to short out or bypass the magnetos that were not being cranked, and low-resistance ringers (75 to 100 ohms) were utilized in those series circuits. At voice frequencies, however, the ringer coil impedance was rather high and transmission losses were undesirable.

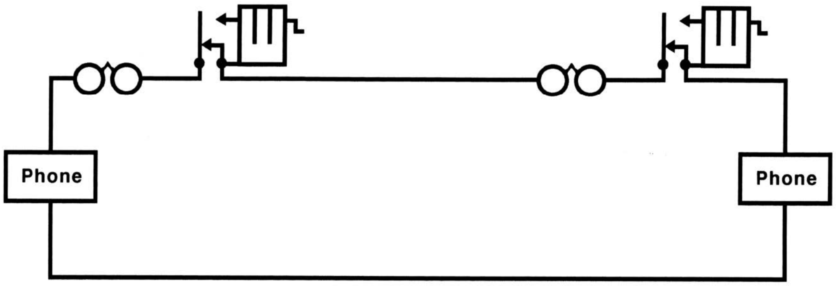

Fig. 6-3. Early series connection of low-resistance ringers.

John Carty, of the Metropolitan Telephone and Telegraph Co. of New York, developed a high-impedance ringer (1,000 ohms dc) that could be connected directly across the line in a bridging manner.[2] This arrangement is shown in Fig. 6-4. The impedance of these ringers was so high at voice frequencies that very little current was shunted through them to cause transmission losses (these impedances will be discussed below). In this arrangement, the automatic switch in the magneto was arranged to cut out (rather than short out) the magneto when it was not being cranked. In the bridging arrangement, therefore, no significant voice signal was lost as the result of either the magneto or the ringer.

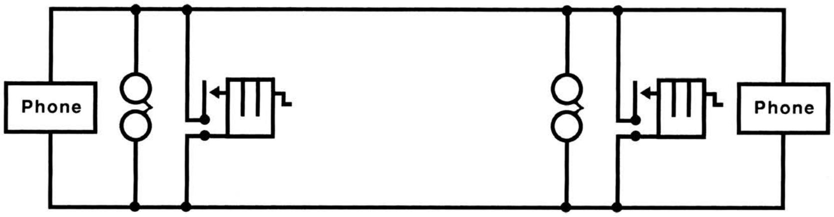

Fig. 6-4. Parallel or bridging connection of high-resistance ringers developed by Carty in 1890.

Frequency Ringers

With the growing number of telephones in service, there was a need for selective ringing on party lines. Of the many selective ringers developed – 161 patents according to one account (Fagen/AT&T 1975, 121) – only two were widely used: frequency ringers and biased ringers. Frequency ringers were used more often by the independent companies than by the Bell System, and these ringers had armatures that were mechanically tuned to resonate at specific frequencies. This was accomplished by using clapper cylinders of different weights instead of small balls and by suspending the armature on a piece of spring steel (a reed spring) rather than on pivots. For reference, Fig. 6-5 shows a standard pivoting armature of a non-resonant ringer.

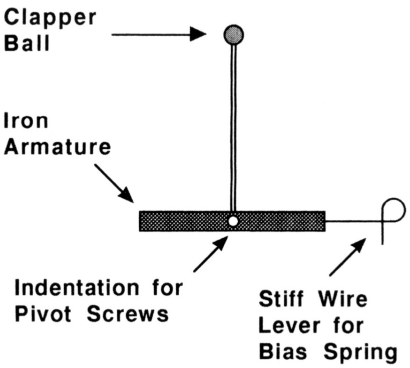

Fig. 6-5. Pivoting armature and clapper of an un-tuned ringer.

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[2] John J. Carty, "Telephone Circuit and Apparatus," Patent No. 449,106, dated March 31, 1891; application filed August 16, 1890. Carty later became the first chairman of the board of the Bell Telephone Laboratories (Brooks 1975, 168).

Figure 6-6 shows four different tuned armatures for harmonic ringers; that is, armatures that are tuned to resonate at multiples of some fundamental frequency, 16⅔ in this case. The reed springs are clamped (clamping arrangement not shown) to the lower part of the frame of the ringers to hold the armatures and clappers in place. Reed springs of different thicknesses were used in combination with different clapper weights to achieve the desired resonant frequencies. A condenser is always required in series with a ringer for common-battery service, and condensers of different sizes (ranging typically from about 1 microfarad for the lowest ringer frequency to 0.1 microfarad for the highest ringer frequency) were also used in frequency ringers to reduce the tendency for false ringing (see circuits in Chapter 16).

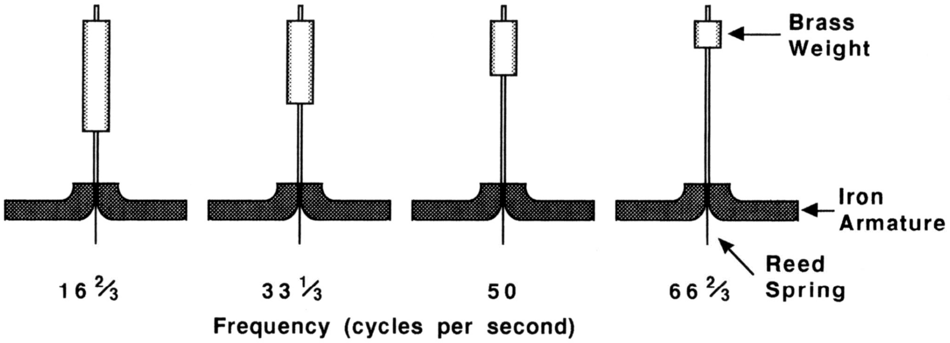

Fig. 6-6. Spring-mounted armatures and clappers for four mechanically tuned harmonic ringers.

An advantage of the harmonic ringer scheme was that more selective arrangements were possible than with biased ringers (next section). Although usual frequencies for harmonic ringers were 16⅔, 33⅓, 50, and 66⅔ cycles per second, 25 cycles per second was added at a later time and other frequency groups were also used. One other frequency group, which was referred to by Kellogg as decimonic, used frequencies that were multiples of 10 (20, 30, 40, and 60) cycles per second, with 50 cycles per second added later. Yet another frequency group was referred to as synchromonic and used frequencies that were multiples of 6 (30, 42, 54, and 66) cycles per second, although an out-of-sequence frequency of 16 cycles per second was added later.[3] An additional advantage of the synchromonic group was that no two frequencies were multiples of each other, and this further reduced the tendency for cross ringing compared with the other harmonic frequency groups. The principle of the harmonic ringer is, of course, the very same as that used by Gray and Bell in their harmonic telegraph instruments. All of the ringers were bridged across the line, but only one would respond when a ring signal of its particular frequency came down the line. Although four different harmonic frequencies were customarily used, eight-party selective ringing could be achieved by connecting four different ringers between each side of the line and ground and applying the ring signal between one line or the other and ground. With the later addition of the fifth frequency in these frequency groups, ten-party selective ringing could be achieved.

Biased Ringers

Biased ringers for party lines on common-battery service have their armature held against one pole piece by a small spring. Figure 6-7 shows the spring arrangement for early Watson-type ringers. For B-type and C-type ringers, a long stiff spring wire is used instead of a coiled spring. For selective ringing, the armature was held firmly against one pole piece, and voltages (hence currents) of only one sign (either positive or negative) were used for the ring signal. The signal for biased ringing was usually an alternating

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[3] Notice that the multipliers for the original synchromonic frequencies were 5, 7, 9, and 11. To build on this sequence, the logical choice for the additional frequency would seem to be 3 times 6, or 18 cycles per second. However, 54 cycles per second, which is already one of the synchromonic frequencies, is the second harmonic of 18 cycles per second (3 x 18 = 54) and this could lead to cross ringing. The choice of 16 cycles per second preserved the property that no two frequencies were multiples of each other.

current superimposed on either a positive or negative direct current, and this undulating current increased and decreased, but was always in one direction (Stacy 1936).

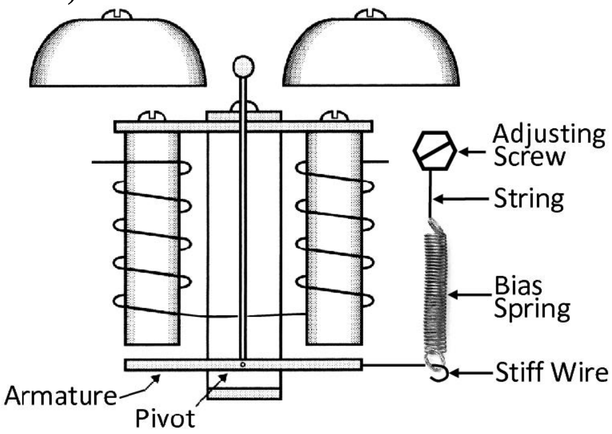

Fig. 6-7. Mechanical arrangement of bias spring on Watson-type ringer.

If the direction of the current was such as to try to pull the armature toward the pole piece on which it was already resting, the armature could not move. An undulating current in the other direction, however, would pull the armature away from its rest position, and the spring would pull it back during the low-current part of the cycle thus ringing the gongs. Biased ringers would therefore respond differently to currents in different directions. By simply switching the leads of a ringer, it could respond to either positive currents or negative currents.

There was a practical problem, however, with biased ringers in common-battery sets, where the ringer would normally be connected to the line via a condenser. For the armature in a ringer to be pulled in only one direction, current must flow through the ringer in only one direction. But a condenser, by its nature, cannot let current flow in only one direction. Consequently, a ringer in series with a condenser would always see an alternating current, whether the ring signal was ac or an undulating current.

For early four-party selective ringing, mechanical relays were used to connect the ringers directly to the ring signal as shown in Fig. 6-8. The condensers in series with the ac relays would preclude dc leakage paths when ringing was not taking place. When ringing was started, a high-voltage battery (e.g., a string of dry cells) was connected in series with an ac ring generator across the line to generate the undulating current. Suppose, for example, that the battery was connected such that the tip side of the line in Fig. 6-8 was positive and the ring side of the line was grounded. All four ac relays would operate and connect their respective ringers to ground. The two ringers connected to the ring side of the line (#1 and #3) would not respond because both sides of these ringer would then be connected to ground and no current would flow. The ringers connected to the tip side of the line (#2 and #4) would both respond, but only the one with the positive bias (#4) would ring the gongs for the reason described above.

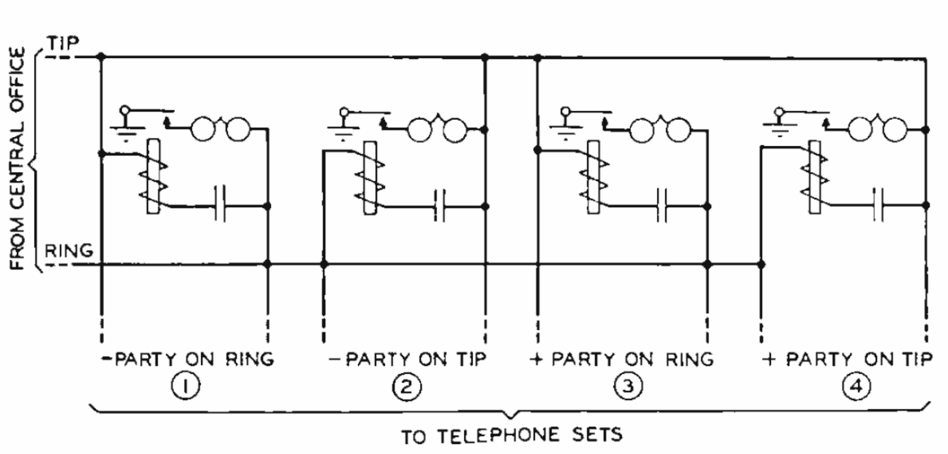

Fig. 6-8. Connections for four-party selective ringing using biased ringers and relays.
Drawing reproduced from Stacy (1936).

Around the time the Western Electric 302 was introduced, Bell Labs developed a neon-filled vacuum tube that was used instead of a mechanical relay (Ingram 1936). Four-party selective ringing using these gas-filled tubes was arranged as in Fig. 6-9. Like a high-voltage relay, no current flows through the tube until the control-gap voltage reaches about 70 volts, at which time the gas ionizes and becomes conducting (similar to a neon light). Unlike a mechanical relay, however, conduction through the main gap of the vacuum tube can only go in one direction because of the way the tube is constructed. Thus, current only flows through one of the four gas tubes (two are grounded) and its ringer responds as desired. Notice that no condensers are needed when using gas-filled tubes, and tubes reduce the ring current required from the central office compared with mechanical relays.

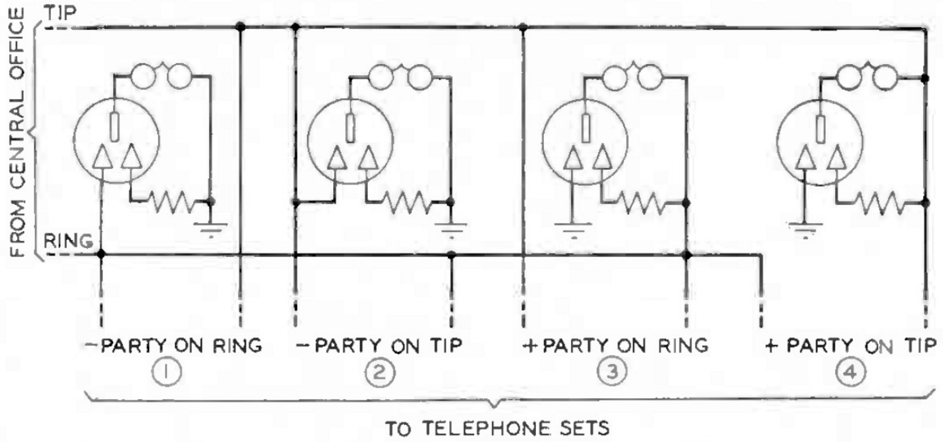

Fig. 6-9. Connections for four-party selective ringing using neon-filled tubes.
Drawing reproduced from Stacy (1936).

Variations in Electro-Mechanical Design

Until 1937, ringers were of the original Watson design, with only minor mechanical variations. Such ringers were made in both biased and frequency types, and they were used for local-battery and common-battery applications. With the introduction of the No. 302 combined telephones in 1937, a more compact B-type ringer was produced by Western Electric (Wiebusch 1942). A diagram of this ringer is shown in Fig. 6-10.

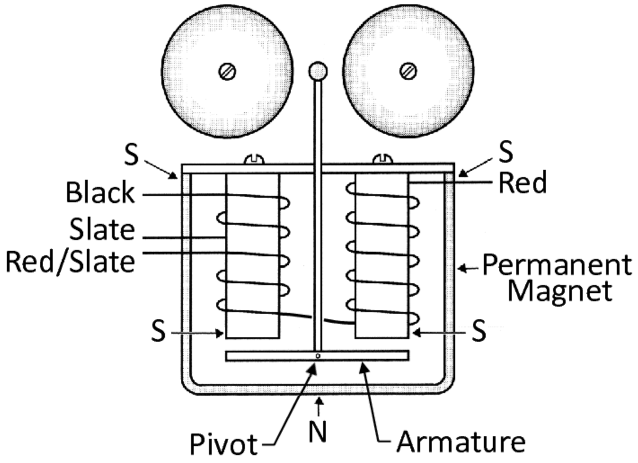

Fig. 6-10. Western Electric B-type ringer, introduced in 1937 in the 300-type telephones.

The operating principle of the B-type ringer is essentially the same as the earlier Watson-type ringers. In the B-type ringer, a U-shaped permanent magnet of chrome steel provides the polarizing magnetic field. Unlike a common horseshoe magnet or the C-shaped magnet in the earlier ringers, this U-shaped magnet does not have north and south poles at the tips of the U. Rather, both tips are south poles, and the north pole is at the bottom of the U, as labeled in Fig. 6-10. A soft-iron-alloy heelpiece is welded to the tips of the U, and soft-iron-alloy pole pieces, on which the coils are wound, are suspended from the heelpiece. Thus the heelpiece and the pole pieces are magnetized (polarized), and the pole pieces both have their south poles close to the armature, which is pivoted at its center. When there is no ring current, both magnetized pole pieces exert the same pull on the ends of the armature and no movement occurs. During one half-cycle of a ring current, the magnetic field in one pole piece is strengthened while the field in the other is weakened because the coils are wound in opposite directions. The strengthened field pulls harder on its nearby end of the armature while the weakened field relaxes the pull on its nearby end. During the next half-cycle, the situation reverses such that the armature rocks back and forth as the current alternates. Biasing of the B-type ringer is accomplished with a long thin spring wire (not shown).

Figure 6-10 shows a split winding in the left-hand coil with an extra pair of leads (four in all). This figure thus describes the B2A ringer used for caller identification for two-party message-rate service. The more common B1A ringer does not have a split winding; therefore, it has only two leads, but it is otherwise identical. Coil windings for the B2A ringer are shown here because they are the precursor of the split winding found on most later C-type ringers. Using a variety of different hookup schemes (involving these two unequal coil sections, the condenser, the tip and ring sides of the line, and ground), several different dc circuits can be established without altering the ac ringing circuit. These different dc circuits permit the central office to identify, for billing purposes, which party on a party line was placing a call. Thus, a party-line ringer would not only ring selectively on incoming calls, but it could also identify the calling party on outgoing toll calls.

In 1949, when the 500-type telephones were introduced, Western Electric produced the C-type ringer (Bredehoft 1951). The C-type ringer is quite different in appearance from the B-type and earlier ringers and is shown in Fig. 6-11. A single coil with a split winding is wound around a soft-iron-alloy core of square cross section, and this iron-alloy core is fastened with screws to a complex-shaped pole piece that looks something like the upper case letter G. This pole piece is stamped out of soft-iron alloy, of about ⅛-inch thickness, and is bent in several directions to achieve its complex shape. The north pole of a short, very strong, cylindrical permanent magnet rests against one surface of the pole piece, which takes on polarity south (not marked in the figure). Thus the extremities of the pole piece are both north poles as indicated. A soft-iron-alloy armature carrying the bell clapper is held by a thin reed spring near the south pole of the permanent magnet.

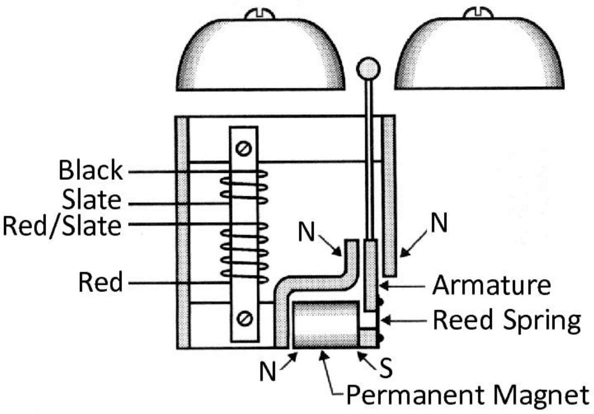

Fig. 6-11. Western Electric C-type ringer, introduced in 1949 in the 500-type telephones.

Although quite different in appearance, the C-type ringer functions in a manner similar to the B-type ringer shown in Fig. 6-10. When no ring current is flowing, both north poles of the pole piece exert the same pull on the armature. During one half-cycle of a ring current, when the top of the coil in Fig. 6-11 has polarity north, the magnetic field of the right-hand end of the pole piece is strengthened. During the next half-cycle, the magnetic field of that right-hand end of the pole piece is weakened. The magnetic field at the left-hand end of the pole piece is unchanged by the coil, so the armature is pulled back and forth between these ends of the pole piece. Biasing of a C-type ringer is accomplished with a long thin spring wire (not shown) similar to that in a B-type ringer. C-type frequency ringers were made by simply using stiffer reed springs and by attaching weights to the bell clapper.

The split winding of the C-type ringer serves the same purpose as that of the B2A ringer. This split winding arrangement was adopted as the standard arrangement, whether it was needed for caller identification or not, and two-lead C-type ringers were seldom used. Instead, the Slate and Red/Slate leads were connected together for private-line use. Several different hookups of B-type and C-type ringers are described in Chapters 17 and 19. Later ringers, such as the E-type, M-type, and P-type ringers, were developed for special applications (Spencer and McGee 1965). They had different sizes and shapes, but all incorporated a motor of a style similar to the C-type ringer shown in Fig. 6-11.

Electrical Properties of Ringers

Electrically, both ringers and receivers are electromagnets with similar types of properties. Thus ringers have a dc resistance, an inductive impedance, and another frequency-dependent impedance due to induced eddy currents. Ringers, however, are designed to operate at lower frequencies (around 20 cycles per second), so they have larger coils with higher resistances and impedances.

Table 6-1 lists the important resistances and impedances of several Western Electric ringers that span the range of typical values. Three to fifteen ringers of each type were measured to obtain these values, and estimated uncertainties are less than ±5 percent for dc resistances and around ±20 percent for ac impedances. Inductive impedances have been given at 20 cycles per second, rather than the related phase angles, because the inductive impedances are used in the following discussion.[4] The ringer impedances and phase angles at a voice frequency (1,000 cycles per second) have also been included because ringers are usually left in the voice circuit, making these properties important.

Table 6-1. Electrical properties of various Western Electric ringers.

Ringer	**Resistance ohms (dc)**	**Inductive impedance ohms (20 cps)**	**Total impedance ohms (20 cps)**	**Total impedance ohms (1,000 cps)**	**Phase angle deg (1,000 cps)**
38A	1,000	3,900	4,750	22,500	52
8A	1,400	4,700	5,300	30,000	52
78A	1,500	4,750	5,350	30,000	52
53B	2,500	11,000	12,500	55,000	52
B-type[a]	4,500	12,500	13,500	150,000	55
		(3,500 ohms dc red to red/slate leads) (1,000 ohms dc slate to black leads)			
C-type	3,650	16,000	16,500	225,000	65
		(2,650 ohms dc red to red/slate leads) (1,000 ohms dc slate to black leads)			

[a] Values in parentheses apply to the B2A ringer, which has split windings. Other values apply to both B1A and B2A ringers.

The Western Electric No. 38A ringer has a dc resistance of 1,000 ohms (500 ohms each coil) like Carty's original bridging ringer and is typically found in older local-battery magneto sets. This ringer is often connected directly to the line, without using any condenser. The No. 53B ringer is also used in magneto sets and has the highest resistance found in ringers in these sets. The No. 8A and 78A ringers are quite similar, but they are used in common-battery subsets, where they are connected in series with a 1-microfarad condenser.

The combined properties of a condenser in series with a ringer, like the No. 8A, are quite interesting. At a ring frequency of 20 cycles per second, an ideal 1-microfarad condenser has an impedance of 7,960 ohms.[5] The impedance of a condenser is always exactly out of phase with an inductive impedance (4,700 ohms for the No. 8A ringer), so these two impedance components actually subtract from each other making a substantial reduction in the overall impedance of the combined condenser-ringer circuit. Although these are the largest components of impedance in the combined circuit, there are also a dc resistance, a frequency-dependent resistance, and phase angles that affect the way all these components combine together. Thus,

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[4] $Z_{\text{Inductive}} = Z_{\text{Total}} \sin \theta$, where $Z_{\text{Inductive}}$ is the inductive impedance, Z_{Total} is the total impedance, θ is the phase angle, and $\sin \theta$ is the trigonometric sine function.

[5] See the Appendix for this value and discussions of the impedances of condensers, coils, and resistors and of the unusual way these impedances add together.

the overall impedance cannot be deduced easily from the individual values given above, but the result is about 4,300 ohms, compared with 5,300 ohms without the condenser for this ringer. The combined properties of a ringer and its associated condenser can be characterized by a ringer equivalence number (REN), which is discussed further in Chapter 22, where examples are given. A typical ringer with its condenser consumes a little less than 1 watt, when operated at 75 volts and 20 cycles per second, and an early ringer without a condenser consumes about the same amount.

The B-type ringer, which is also used in common-battery circuits, has a much higher inductive impedance (12,500 ohms) than the earlier No. 8A ringer. This high impedance was deliberate and quite cleaver because it permitted the B-type ringer to be used with a smaller 0.5-microfarad condenser (bulky condensers were a mechanical design problem in the early years). At 20 cycles per second, this condenser has an impedance of 15,920 ohms, twice that of a 1-microfarad condenser. These large impedance components of comparable size again subtract, giving a substantially reduced overall impedance of the combined condenser-ringer circuit. In this case, the overall impedance is about 9,000 ohms, compared with 13,500 ohms without the condenser. This reduced value is not too different from the overall impedance of the No. 8A ringer with its larger condenser, another result that was deliberate, because newer equipment was designed to be compatible with the older equipment it replaced. The C-type ringer was also designed with a high-impedance coil so it could be used with the smaller 0.5-microfarad condenser.

It was mentioned earlier that high-resistance ringers are used in a bridging manner (i.e., connected across the line). Their total impedance at 1,000 cycles per second, given in Table 6-1, shows why these ringers can be left across the line without affecting the performance of the talking circuit. At voice frequencies, the impedances of the other components (see Table 2-1 and Table 3-1) are just a few hundred ohms. Those transmitter and receiver impedances are so small compared with the ringer impedances (22,500 ohms and up) that the ringers behave as open circuits (no significant current) and can usually be ignored when considering the voice circuit. Notice that an ideal 1-microfarad condenser at 1,000 cycles per second has an impedance of only 159 ohms (see Appendix), which will not significantly reduce the ringer circuit impedance as the condenser did at 20 cycles per second.

Finally, it has been pointed out that the B-type No. B2A ringer and most C-type ringers have split coil windings. The dc resistances of these coil sections are shown in parentheses in Table 6-1. The B-type No. B1A, more commonly found in the Western Electric 300-type sets, has overall properties that are identical to those of the B2A ringer; the coil windings on the B1A ringer simply have not been cut and the extra leads have been omitted.

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Fig. 6-12. Western Electric No. 8A biased ringer.

Chapter 7
Switches and Dials

Hook Switch

Even the simplest electrical component in a telephone was patented early and its inventor remembered by historians (e.g., Rhodes 1929, 178). Hilborne Roosevelt, a pipe organ builder in New York and one of the founders of the first telephone company in that city, applied for a patent on a telephone switch in 1877.[1] One of his patent drawings is shown in Fig. 7-1, where the spring-switch (S) makes contact with a pin (P) to complete the receiver circuit when the receiver is lifted up. In another drawing in Roosevelt's patent, a pin (A) was included in a circuit such that the switch functioned as a single-pole, double-throw switch.

In later designs, a hook was used to hold the receiver, instead of a string as in Roosevelt's patent; hence, the switch is referred to as a hook switch or a switch hook. Although the mechanical design of many hook switches is very clever, their electrical operation is rather obvious. Many different arrangements of electrical contacts are used in commercial telephone hook switches, and descriptive symbols are used in diagrams in this book to identify their function.

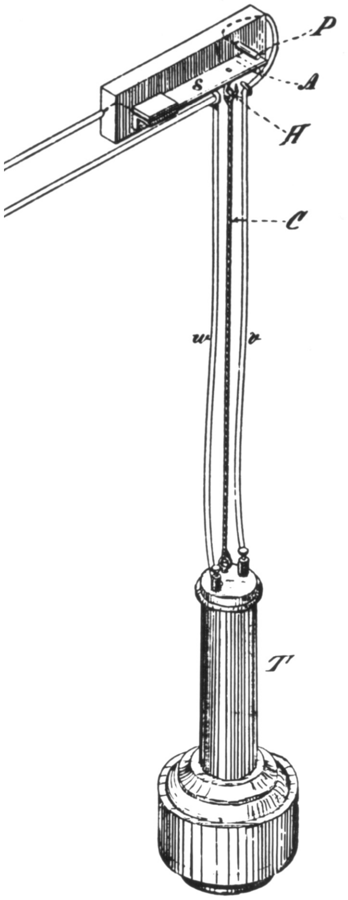

Fig. 7-1. Drawing of switch for telephone from Roosevelt's patent, applied for in 1877.

Automatic Switching (Dialing)

The telephone dial comprises only a small part of a system of automatic switching, and most of the switching equipment is at the central office or exchange. Although central-office switching is generally outside the scope of this book, a brief discussion is presented here to reveal the concepts of the early methods so that the function of a rotary dial in a telephone set can be understood.

Surprisingly early and surprisingly complete, the patent of Connolly, Connolly, and McTighe was issued in 1879 and contained most of the concepts of later commercial dial systems.[2] The heart of this system, and the later Strowger system that was so successful, was the mechanical ratchet and pawl (or dog). Just as each swing of a clock pendulum advances the escape wheel by one tooth, each stroke of a relay advances the ratchet wheel in the switch by one tooth with clockwork precision. Figure 7-2, reproduced from the patent, shows how this works. A pointer (E^2) attached to the ratchet wheel (E^1) moves to a different contact location (corresponding to each tooth in the ratchet wheel) according to the number of current pulses passing through the relay.

To provide the current pulses, a rotary dial instrument was used in the subscriber's telephone and, in the patent specification, this dial was said to "be of the kind usually employed as transmitters or senders in the ordinary dial-system of electro-telegraphy." As the dial was rotated, each tooth of the dial touched a spring or finger making and breaking electrical contact. This dial was connected in series in the main line from the central office, and it interrupted the direct current in that line.

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[1] Hilborne L. Roosevelt, "Improvement in Telephone-Switches," Patent No. 215,837, dated May 27, 1879; application filed October 3, 1877.

[2] M. Daniel Connolly, Thomas A. Connolly, and Thomas J. McTighe, "Improvement in Automatic Telephone-Exchanges," Patent No. 222,458, dated December 9, 1879; application filed September 10, 1879.

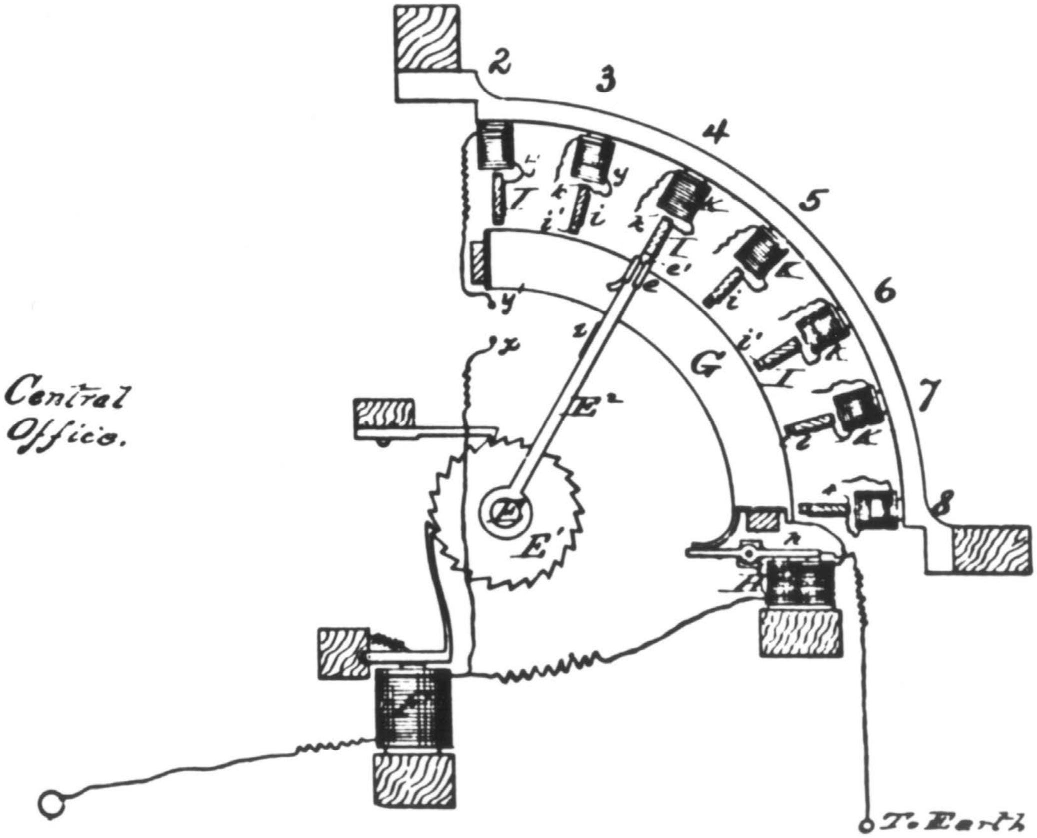

Fig. 7-2. Diagram of ratchet-and-pawl automatic exchange switch from patent of Connolly, Connolly, and McTighe, applied for in 1879.

Although the device described by Connolly, Connolly, and McTighe was perhaps ahead of its time and was not commercialized, it used (a) a ratchet-and-pawl mechanism to advance switch contacts at the central office, (b) a rotating dial in the subscriber's telephone set to produce the desired number of current pulses by making and breaking the circuit, and (c) the main telephone line, over which voice would be communicated, to transmit the dial current pulses. These are the principal elements of the later commercial dial systems.

Ten years later, Almon Strowger filed his now-famous patent for an automatic telephone exchange.[3] Two things are noteworthy about Strowger's design. First, it used a straight ratchet-and-pawl assembly to lift the switch contact to one of 10 levels; then it used a round ratchet-and-pawl assembly (as in the previous patent) to rotate the switch contact to one of 10 positions. By using this combination of linear and circular motions, 100 switch combinations could be contained in a single switching unit.

The second noteworthy thing about Strowger's design was that it was a commercial success. A Strowger system, referred to as the step-by-step system, was placed in commercial operation in LaPorte, Indiana, in 1893 and automatic switching has been in existence ever since. Strowger's company expanded, and in 1901 became the Automatic Electric Company (Pleasance 1989, 145; McCarthy 1990, 35).

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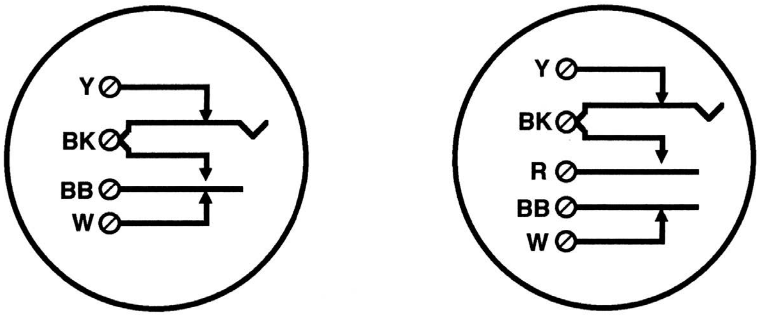
[3] Almon B. Strowger, "Automatic Telephone-Exchange," Patent No. 447,918, dated March 10, 1891; application filed March 12, 1889.

Rotary Telephone Dials

A rotary dial in a telephone set is, therefore, merely a normally closed switch that, during dial rotation, breaks contact a number of times corresponding to the telephone number selected. Actually, most dials, in addition to this so-called impulse switch, have several other switches that are used to (a) bypass the transmitter (thus lowering the resistance of the circuit for switching) and (b) remove the receiver from the circuit to eliminate audible dial noise.

Figure 7-3 shows electrical diagrams for the early Western Electric telephone dials. The contacts of the various switches are shown in the positions that they assume when the dial is not in use. The impulse switch in the Western Electric dials is connected to terminals Y and BK. The shunt switches in the earliest dials, used in candlestick desk stands, are arranged as a single-pole, double-throw (SPDT) switch, whereas the shunt switches in dials designed later for handset telephones are completely isolated from each other (as shown).[4] This change was required to accommodate the wiring in a handset (see Chapter 16). Shunt switches hold their alternate contact positions throughout the time of dial rotation and return to the positions shown when dial rotation ceases.



Candlestick Dial
(No. 2A)

Handset Dials
(Nos. 2H, 4H, 5H, and 6)

Fig. 7-3. Impulse switch (top) and shunt switches in early Western Electric dials.

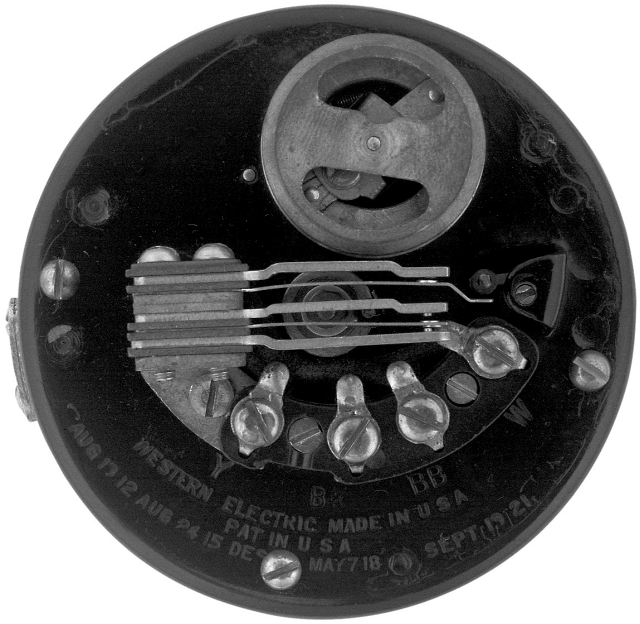


Fig. 7-4. Western Electric No. 2A dial showing switch sections (center) and speed governor (top).

Figure 7-4 is a photograph of the back of a Western Electric No. 2A dial and it shows the switch sections clearly. One other important feature (the round protrusion) that is seen is the governor. The governor controls the speed of the rotating parts so that the dial pulses are about 1/10th of a second apart. With such rapid pulses, a slow-acting relay at the central office remains closed while a fast-acting relay advances the switch. During the longer time period that it takes to begin dialing another digit (about 1 second), the slow-acting relay opens -- thus distinguishing between sets of dial pulses (Albert 1943, 195-196; Smith and Campbell 1921, 55-56).

Figure 7-5 shows the circuit diagram for Automatic Electric dials (open construction, no terminal markings), an early Kellogg dial (open construction, no terminal markings), and a similar Stromberg-Carlson dial (switch sections completely enclosed in a clear plastic dust cover). The electrical circuits of these three dials are the

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[4] These switch sections will be referred to as “shunt” switches although they are often used to open a circuit rather than to shunt current around a circuit.

same. Dials made by Automatic Electric Co. were often used on Kellogg and Stromberg-Carlson telephones in the 1920s and 1930s.

Figure 7-6 shows the circuit of the No. 7 dial used in 500-type telephones (all manufacturers) and the No. 8 dial used in the Princess-type telephones. These dials are both mechanically and electrically simpler than the earlier dials, and have no shunt switch for the transmitter. The circuit for the No. 10 dial (not shown) was used in the Trimline-type telephones and has only an impulse switch -- no shunt switches at all. That dial has only two connections and thus has no marked terminals or color-coded wires.

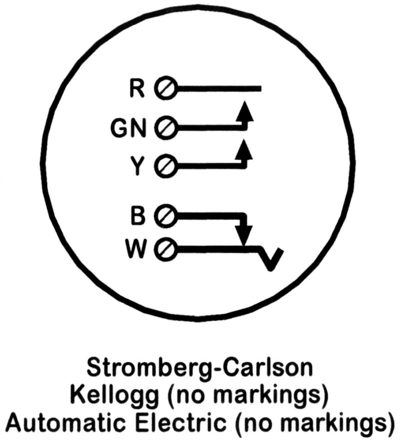

Fig. 7-5. Impulse switch (bottom) and shunt switches in Automatic Electric, Kellogg, and Stromberg-Carlson dials.

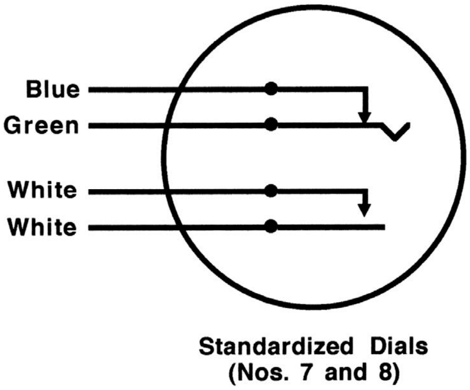

Fig. 7-6. Impulse switch (top) and shunt switch in 500-type (all manufacturers) and Princess-type telephones.

Touchtone Dialing

Modern dialing systems use electronic tone generators in telephone sets, rather than impulse switches, and transistorized circuits are used to generate the dialing tones. It is noteworthy that the transistor itself was invented at the Bell Laboratories and that John Bardeen, William Shockley, and Walter Brattain, were awarded the Nobel Prize for this accomplishment (AT&T Bell Laboratories 1956b).[5]

Touchtone dialing was introduced in 1963, after two years of market trials (Hiatt 1963). Two clear advantages were offered by this method of dialing. First, tone dialing is much faster than rotary dialing. Second, so-called end-to-end signaling is possible. That is, the tone frequencies can be used after a connection has been made to transmit information (e.g., checking a bank balance or selecting among several recordings). Further, it is easier electronically to handle ac signals within the voice frequency range than to process dc pulses, which produce radio-frequency interference, as with the rotary dial.

Because it was desired to use frequencies within the voice frequency range, a scheme had to be developed that would avoid false signaling ("talk-off") because of music, speech, or noise in the transmitter (Schenker 1960). In this scheme, eight tone frequencies were used, two at a time, in various combinations -- and was thus called dual-tone, multi-frequency (DTMF) dialing. When arranged in a four-by-four matrix (4 columns and 4 rows), these eight frequencies can be seen to produce 16 unique frequency pairs. Generally, only 12 of these frequency pairs are used in a standard touchtone dial (Fig. 7-7). Chapter 19 shows that the circuitry (except switches) is present to produce all 16 combinations. All 16 of the frequency pairs were used by the U.S. military in an automatic voice network called AUTOVON.

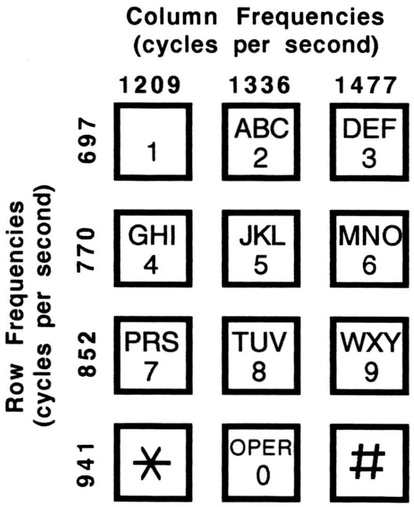

Fig. 7-7. Tone frequencies for dual-tone, multi-frequency (DTMF) dialing.

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[5] It was later claimed that Shockley did not actively participate in the transistor's development (Kessler 1997).

To facilitate signal processing, these frequencies were divided into two groups as shown in Table 7-1. Several considerations went into the selection of these frequencies. First, the frequencies needed to be within the range of about 700 to 1,700 cycles per second to avoid excessive distortion during transmission. Second, separation of frequencies had to be large enough to accommodate variations in telephone tone generators (± 1.5 percent), central-office detection equipment (± 0.5 percent), and carrier shift on toll lines (± 10 cycles per second) for a total of 4 percent plus 20 cycles per second (e.g., 60 cycles per second separation at 1,000 cycles per second). Third, the frequencies in Group A should not be a multiple of lower frequencies in the voice frequency range that have harmonics (higher multiples) matching a frequency in Group B (note that adjacent frequencies are in the unusual ratio of 21-to-19). Fourth, the selected frequencies were to avoid frequencies then under consideration for a tone ringer. All of these considerations were satisfied by the specific set of frequencies chosen.

Table 7-1. Touchtone dial frequencies

Group A cps (Rows)	Group B cps (Columns)
697	1,094[a]
770	1,209
852	1,336
941	1,477

[a] This frequency was later replaced by 1633 cps.

A major characteristic of the electronic limiters and filters used in detection of these tones is of interest. This characteristic is the ability to reject a tone in Group A if there are other tones of comparable amplitude present in Group A (likewise for frequencies in Group B). This prevents music, speech, and noise from being incorrectly identified if they should accidently contain a correct pair of frequencies. To keep the tone pairs clean, thus enhancing correct identification, touchtone dials are arranged to disable the transmitter during dialing. To further enhance the signal-to-noise ratio, tone signals are produced with larger amplitudes than average speech levels. Tone generators in touchtone telephones are covered in detail in Chapter 19.

Fig. 7-8. Western Electric No. 2AA dial.

Part Two
Design

Chapter 8
Early Commercial Telephones

During the first 25 years of commercial telephone service, rapid changes occurred in the size, shape, and performance of the telephones as early technical developments were introduced. After that, however, designs stabilized and advances occurred in stages. Thus, the everyday telephones of the 20th century fall into functional groups or generations that have similar performance and appearance features. Those functional groups or generations of instruments are examined in some detail in later chapters after briefly summarizing the telephones of the first 25 years.

Box Telephone of 1877

The first telephone placed in commercial service was based on Bell's patent design of January 1877. A simple box covered this telephone, which was used as both a transmitter and receiver. The only significant difference between this so-called box telephone and the patent drawing was that the diaphragm was round, rather than square. The box telephone of 1877 is shown in Fig. 8-1, and its simple electrical circuit is shown in Fig. 8-2. In Fig. 8-2, the graphic symbol for a receiver is labeled "telephone" to indicate that this instrument was used as both the transmitter and receiver.

Fig. 8-1. Box telephone of 1877 incorporating Bell's improved induction telephone for talking and listening. ***Courtesy of AT&T Archives***.

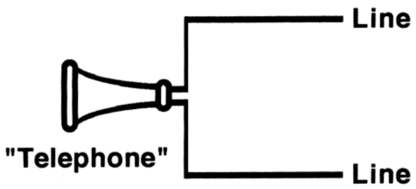

Fig. 8-2. Circuit diagram for the box telephone of 1877.

In application, two or more of these box telephones were simply connected in series on a line with a ground return; no batteries were required. The first line constructed for regular telephone use was installed in April 1877, between Charles Williams's electrical shop and his home about 3 miles away (Bruce 1973, 228; Fagen/AT&T 1975, 18-20; Rhodes 1929, 147-148). However, the first rented installations were made the following month. Thus, commercial telephone service began in May of 1877 with the box telephone designed by Bell. No signaling device was included in these earliest installations. In June of that year, however, Watson devised a “thumper” that would strike the diaphragm of the box phone and produce a tapping sound at the receiving telephone (Fagen/AT&T 1975, 114-116; Rhodes 1929, 176). Other devices similar to a battery-operated doorbell were tried for signaling, but they were not practical either -- especially on long lines with their higher resistance.

Fig. 8-3. Williams' coffin telephone of 1878 with Bell's hand telephones and Watson's ringer. ***Courtesy of AT&T Archives.***

Williams' Coffin Telephone

The next telephone with significant improvements was also of the induction type and was similarly produced by the Charles Williams shop. This phone, nicknamed the Williams' coffin telephone for the shape and construction of its cabinet, was introduced in 1878 and is shown in Fig. 8-3 (Fagen/AT&T 1975, 128; Rhodes 1929, 178). For convenience, two of Bell's hand telephones were often used, one for speaking and one for listening. Watson's magneto and ringer were included in this telephone, giving it the first practical means of signaling.

In Fig. 8-3, the magneto crank can be seen on the front of the cabinet, just below the bells. Below this crank is a switch to connect the phone for either signaling or talking. Roosevelt's hook switch had just been designed, but it was not yet incorporated in this telephone, although it appeared on later coffin telephones.

The two metal plates above the ringer are the saw-tooth electrodes of a lightning arrester. Telephone lines were usually overhead wires, just like telegraph lines. They provided a relatively good conducting path to ground for lightning, not unlike a lightning rod. Lightning arresters were adapted from telegraphy and provided a bypass around the telephone to shunt current from a lightning strike directly to ground. The Bell company eventually adopted the practice of mounting a protection device (fuse, heat coil, and lightning arrester) at a separate location near the point where the line entered a residence. Thus, lightning arresters are generally not found on later Western Electric telephones, although they are found on several other phones, as will be seen in the next chapter.

The simple series circuit for the Williams' coffin telephone is shown in Fig. 8-4. It is the same as that used in Watson's patent of April 16, 1878, as can be seen from the patent drawing in Chapter 5 (Fig. 5-1). The electrodes of the lightning arrester (merely connected across the line, one side of which was grounded in those early applications) have been omitted from Fig. 8-4 because they play no role in either signaling or talking. Also, it should be noted that the magneto is of the primitive type used by Watson -- not the Siemens type -- and has no shunt switches.

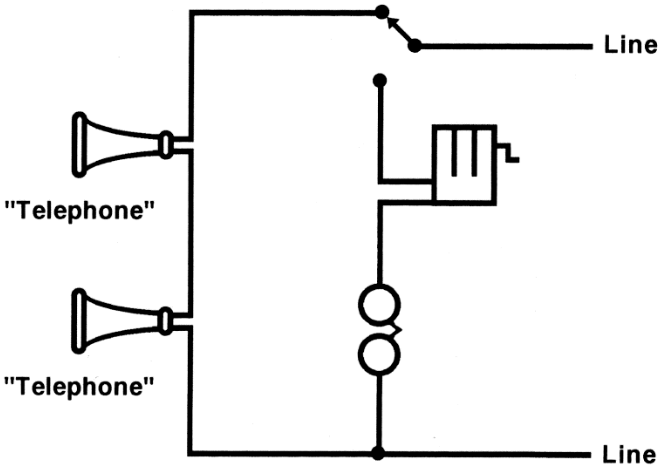

Fig. 8-4. Circuit diagram for the Williams' coffin telephone.

When switched from its signaling mode to its talking mode (as shown), this circuit is seen to be a simple series circuit, such as Fig. 8-2, except for having more telephones in series. Although it provided a big improvement in convenience to have a separate instrument for speaking and talking, the signal generated by the speaking instrument was now dissipated in three "telephones," rather than in one, reducing the signal strength in the distant listening instrument by two thirds. Thus the phone was sometimes used with just one "telephone."

Incidentally, both "telephones" were connected externally to the Williams' coffin phone (Fig. 8-3) so they could be (and later were) replaced by other instruments, such as the Blake transmitter with its coil and associated batteries.

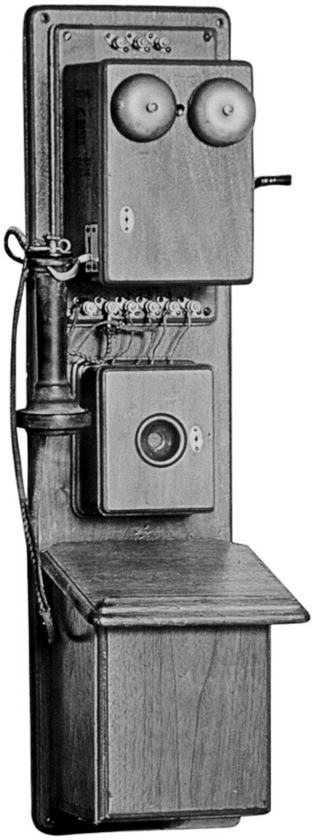

Fig. 8-5. Western Electric 3-box telephone of 1882 with Blake transmitter and Siemens-type magneto. ***Courtesy of AT&T Archives.***

3-Box and 2-Box Wall Phones

Though several other models were produced using Bell's hand telephones, the departure from sound-powered induction telephones was made with the 3-box wall phone of 1882 shown in Fig. 8-5. By that time, both Bell and Watson had left the company – Bell (in 1880) to pursue other creative activities, such as improving the phonograph, and Watson (in 1881) to start a new career as a shipbuilder (Bruce 1973, 281-282; Watson 1940, 3). With Bell and Watson gone, manufacturing shifted away from the Williams electrical shop, and the 3-box phone in Fig. 8-5 was the first to be manufactured by Western Electric, the new manufacturing arm of the Bell System (Fagen/AT&T 1975, 129).

The 3-box phone contained a number of advances, the most important of which was the Blake transmitter with its induction coil and local-battery circuit. Introduction of the Blake resistance-type transmitter, which produced a much larger voltage, spelled the end of Bell's induction "telephone" as a transmitter. This phone also had improved signaling and switching, with a magneto having the Siemens-type armature, an improved Watson ringer, and a Roosevelt-type hook switch. Batteries, of course, were needed for the resistance-type transmitter, and batteries for the 3-box phone were located in the rather large lower box.

Batteries of the time were wet cells consisting of two electrodes and a liquid electrolyte contained in a jar. The most common telephone battery was the Fuller cell, which had one zinc electrode, one carbon electrode, and a chromic acid solution for the electrolyte. The Fuller cell produced about 2 volts, and three such batteries (6 volts) were typically used.[1]

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[1] A lengthy discussion of early telephone batteries is given in Abbott (1904, 294-331).

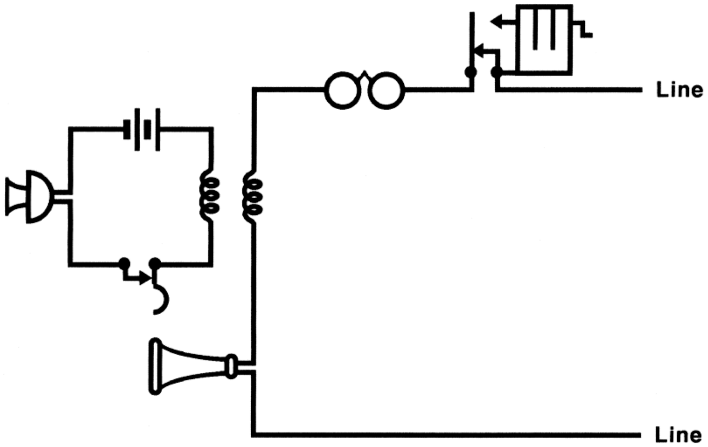

Fig. 8-6. Circuit diagram for the Western Electric 3-box telephone.

The basic circuit of the 3-box telephone is shown in Fig. 8-6. Disregarding for a moment the magneto and ringer (because they provide a relatively low-impedance pathway), this talking circuit has some important similarities to Fig. 8-4. That is, a separate speaking instrument and a separate listening instrument are placed in series on the line. In this case, the speaking instrument consists of a resistance transmitter, its batteries, and an impedance-matching coil, all of which can be thought of as a single unit. Direct current (dc) was introduced for the first time, but it was confined to the transmitter, the batteries, and the coil's primary winding (the so-called local-battery circuit).

Manual switching from a signaling mode to a talking mode was not required with this circuit, nor with any future circuit because the signaling devices were left in the circuit. The magneto has a shunt switch to short out the armature when not being cranked (as shown), thus eliminating its impedance when talking or when receiving a call signal. Watson's new ringer was used in series, thus adding some unwanted impedance, but the ringer's coil resistance was low. The simple hook switch in the local-battery part of the circuit (shown in the off-hook talking position) would disconnect the battery when the phone was not in use in order to save battery power.

Other variations of the 3-box phone were subsequently made. In 1886, the Hunnings-type transmitter with Edison's improved carbon granules -- called the long distance transmitter because of its still larger voltage output -- was mounted on a long arm and substituted for the Blake transmitter to form a 2-box version of the 1882 telephone. For a few years, this 2-box telephone was used for long-distance service, while the 3-box telephone (with the Blake transmitter) remained in local service.

When White's solid-back transmitter came out in the early 1890s, a 2-box model with that transmitter was introduced as a replacement for both the earlier 3-box and 2-box wall telephones. This 2-box phone is shown in Fig. 8-7. Carty's bridging ringer was also introduced at that time, as was the No. 13 induction coil (1893) (Fagen/AT&T 1975, 109). Thus, the 2-box telephone of the 1890s attained the local-battery circuit configuration that would be the standard for many years to come (see Chapter 15 for a full description of this circuit).

Fig. 8-7. Western Electric No. 21 2-box telephone with solid-back transmitter and monopole receiver. ***Richard Mountjoy: One Hundred Years of Bell Telephones.***

Desk Stands

Desk stands holding a transmitter, receiver, and hook switch became popular during the 1890s. These stands were used in combination with a wall-mounted box that held the rest of the telephone's components (ringer, coil, etc.), which would determine the telephone's circuit type (see Chapters 12, 15, and 16). Reflecting the mood of the 1890s, the desk stands had a variety of stylish shapes not unlike today's brass desk lamps. Some were rather bulbous and were referred to as pot-belly desk stands. Others were more sedate, like the Western Electric No. 10 tapered-shaft or oil-can desk stand shown in Fig. 8-8 with a solid-back transmitter and a monopole receiver. All of these desk stands were made of nickel-plated brass, incorporating many heavy machine turnings. These nickel-plated desk stands were the precursors of the simpler candlestick desk stands described in Chapter 10.

Compact Wall Phones

Top boxes of the 2-box and 3-box wall phones evolved into compact wall phones by 1895, and the first such phone of the common-battery type was the Western Electric model No. 68. Common-battery systems provided energy from the central office for talking and signaling, so batteries and magnetos were not needed in the subscriber's telephone. The No. 68 wall phone, which has a bridging ringer, was furnished without a transmitter or coil and could be outfitted several ways. A No. 225 transmitter could be flush-mounted in the door; a No. 229 transmitter with a tilting lug could be mounted on the door; or a separate long-arm transmitter like the No. 250 could be mounted on an additional large backboard beneath the No. 68's box. The coil inside the box would be a No. 18 (1894) or similar No. 20 (1897) coil (Fagen/AT&T 1975, 109). Figure 8-9 shows this phone fitted with a No. 229 transmitter with the tilting lug, a No. 122 bipole receiver, and a No. 20 coil inside to form the recently developed booster circuit, which is described in detail in Chapter 16. The large rolled foil-and-paper condenser (see Fig. 22-1) required by this circuit occupies the entire framed-in space behind the backboard of the No. 68's box. The two lower right-hand terminal locations, to which an external transmitter would be connected, are covered with blanks in the set shown in the figure.

Fig. 8-8. Western Electric No. 10 tapered-shaft oil can desk stand with a solid-back transmitter and monopole receiver.

Fig. 8-9. Western Electric No. 68 compact wall phone with a No. 229 solid-back transmitter and a No. 122 bipole receiver.

Fiddleback Wall Phones

Shortly after the compact No. 68 went into service, a short-lived style often referred to as a fiddleback wall phone was introduced. This early common-battery phone, the Western Electric model No. 85, is shown in Fig. 8-10. The transmitter on this phone is the No. 250 long-arm transmitter mentioned above and the receiver is a monopole receiver. The small boxed-in space beneath the writing shelf houses a hook switch, a bridging ringer, the large condenser, and a coil. The circuit for this telephone is also the booster circuit. Several variations of this common-battery telephone were subsequently manufactured by Western Electric. Western Electric also made several local-battery fiddleback wall phones. The local-battery fiddlebacks had an enlarged lower box to accommodate a magneto and batteries.

Several other telephone cabinet styles appeared in the 1890s, but the styles were short lived and those phones did not introduce new technical advances; they used the solid-back transmitter and other electrical features of the latest 2-box wall phone. One prominent style was an upright model, about six feet tall, which had the proportions of a grandfather clock. Another was similar to an old ink-well-type school desk and is often referred to as a vanity. Those decorative telephone cabinets were manufactured during a brief period, succumbing to the smaller, more practical models that appeared just after the turn of the century.[2]

Fig. 8-10. Western Electric No. 85 fiddleback wall telephone with a No. 250 solid-back transmitter and a monopole receiver.

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[2] A beautifully illustrated description of many of these early phones can be found in Mountjoy, 1995.

Chapter 9
Single-Box Magneto Wall Phones

By the turn of the century, technical developments were on a plateau. The difficult teething period of the transmitter was over, and the successful solid-back design had been in service for about a decade with little change. Common-battery systems were being installed, but local-battery telephones were still prominent. For these phones, the advent of the dry battery had been very important.

With the goal of universal service in sight, telephone designs became simple and utilitarian. For local-battery service, the single-box, wall-mounted arrangement containing all components – including 6-inch-tall dry-cell batteries such as in Fig. 9-1 – emerged as the style that would persist for more than 50 years. With their rugged oak and cast iron construction, and their self-contained power sources for both talking and signaling, these local-battery telephones had an independent quality that was characteristic of the rural areas they served.[1] With few exceptions, the electrical circuit of these phones was a standard local-battery circuit described in detail in Chapter 15. Only one of the Western Electric magneto wall phones (the No. 417) had a different circuit – an anti-sidetone circuit that is described in Chapter 18.[2]

Fig. 9-1. Typical dry cell telephone batteries (reproductions made by Dennis Hallworth, North Port, FL.)

Also by the turn of the century, the 17-year period of the original Bell patent had expired (in 1893) and competitors were on the scene legitimately. There were, by then, about 85 of these independent telephone manufacturing companies, including the Stromberg-Carlson Telephone Manufacturing Co., the Kellogg Switchboard & Supply Co., and just a year later the Automatic Electric Company (Pleasance 1989, 47, 111, 116, 124, 145, 201). In the sections that follow, a number of telephones are described in detail. In this and later chapters, attention will be focused first on Western Electric telephones because, as the exclusive phones of the Bell System, they were by far the most prevalent. However, Stromberg-Carlson (founded in 1894, merged with General Dynamics in 1955, and bought by Comdial in 1982),[3] Kellogg (founded in 1897, then sold to ITT in 1952), and Automatic Electric (founded in 1901 as an outgrowth of the Strowger company, then merged to become part of GTE in 1959) were major suppliers for the independent operating companies during the entire historical period. Therefore, Stromberg-Carlson, Kellogg, and Automatic Electric telephones are also described for a more comprehensive review that illustrates similarities across the industry.

All of the telephones described in this and later chapters have been examined and placed in operation by the author so that their electrical properties could be measured and understood. In Chapters 15-19, the electrical circuits of these phones are described in a way that will reveal their operating principles, and complete circuit diagrams are presented for most of the telephones shown.

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[1] Although most of these later wooden telephones were made of oak, some continued to be made of black walnut, as were many of the earlier sets.

[2] Anti-sidetone circuits produce low sound levels in the receiver for sounds that originate in the transmitter of its own telephone. See Chapter 17 for a discussion of the benefits of an anti-sidetone circuit.

[3] www.comdial.com/AboutUs/about_us.asp, 11/4/2002

Western Electric Magneto Wall Phones

Fig. 9-2. Western Electric No. 317 wall phone of 1907 with nickel-plated hardware and exposed terminals on the receiver and on the cathedral top.

In 1907, Western Electric introduced the ubiquitous No. 317 local-battery magneto wall phone, and this model remained in production for 30 years.[4] Although the model number remained unchanged for so many years, there were in fact many design changes in the No. 317 during this period. Figure 9-2 shows the earliest version of this model, which had an arched top on the backboard to accommodate external line terminals; this No. 317 also had a decorative groove in the door around the transmitter base. These distinctive features are referred to as a cathedral top and a picture-frame front, and they are typical of features of local-battery wall phones made by other manufacturers as well during the first decade of the 20th century.

This phone used the No. 122 receiver with external terminals, also called a pony receiver, a No. 229 solid-back transmitter, and an early No. 13 coil without soldering terminals (just 4 emerging wires). The ringer in this set, like all similar Western Electric ringers to follow, had an adjustable bell spacing to control loudness; the adjustment was accomplished with a pivoting bracket on the ringer frame.

Although the circuit in this early phone was exactly the same as in later versions, construction details still show the primitive character of a young industry. Bare solid wire was used for most of the wiring, and in many places the wood of the box provided the only insulation. Wires were recessed into very narrow saw-cut grooves in the rear of the backboard, and small diameter holes provided entry into the box from these grooves. Within the box, loose cloth sleeves of insulation were slipped over short spans of exposed wiring. These stiff wires were soldered directly to the four door hinges to provide the electrical connection to the transmitter and ringer, which were mounted on the door. Wires in the transmitter arm and in the receiver cord were flexible, but they were made with tinsel, rather than stranded copper wire that would be manufactured later.

Around 1909, major construction modifications were made to the No. 317 as the method of wiring was changed to utilize cloth insulated wiring throughout – still of the solid, single-conductor type, however. Grooves were no longer used in the rear of the backboard, and all the wiring was kept within the cabinet. External terminals were removed from the backboard, thus eliminating the need for the cathedral top. This version, shown in Fig. 9-3, has a plain top and a picture-frame front. External receiver terminals were also removed from the receiver (No. 144 on the phone pictured), in a slow trend toward elimination of all exposed electrical contacts (the transmitter cup and face plate were still part of the electrical circuit,

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[4] Western Electric wall phones and desk stands were given type numbers or model numbers (such as 317 or 20-B), and those numbers were stamped into the wood or metal parts of the sets. In the catalogs, however, 1,000 was added to these numbers when referring to a complete set with transmitter, receiver, and cords. Thus, the telephone shown in Fig. 9-1 is listed in Western Electric catalogs as a No. 1317; and a No. 20-B desk stand (next chapter) with transmitter, receiver, and cords is listed as a No. 1020-B.

however).[5] Overall cabinet dimensions were the same, except for the absence of the protruding cathedral top. Door hinges were moved from the right to the left to avoid the door's running into the magneto crank (an early design error), but the four hinges were still used as electrical connections.

A third version of the No. 317 is shown in Fig. 9-4 and appeared in Western Electric's 1911 catalog. Aside from minor dimensional changes, the only change in external appearance of this version was the elimination of the picture-frame groove on the door, giving this cabinet a plain top and a plain front. Inside, the wiring was changed again, this time using insulated stranded wire in certain locations because this wire was more flexible than the solid wire used earlier. The flexibility allowed this wiring to go directly to the transmitter and ringer on the door without requiring the soldering of any wires to the hinges, now only three in number.

The final variation of the No. 317 was introduced in 1916, and it was eventually available in both 2-cell (3 volt) and 3-cell (4.5 volt) sizes.[6] The cast iron transmitter arm was replaced by a short stamped-steel bracket holding the new No. 323 transmitter. The writing shelf was tilted at a steeper angle, giving the phone a trimmer profile. The slow but continued trend toward simplicity is apparent in this version with its plain features and shorter cabinet. A 2-cell example of this phone is shown in Fig. 9-5.

Even within a model year, numerous electrical options were available in the No. 317. Table 9-1, based on Western Electric Catalog No. 9 (1935), shows these options. The 2-cell types, as seen in the table, were only supplied with 3-bar generators making possible an overall reduction in the width of the cabinet compared with the 3-cell types.

Fig. 9-3. Western Electric No. 317 wall phone of 1909 with a plain top and enclosed electric terminals.

Fig. 9-4. Western Electric No. 317 wall phone of 1911 with a plain front and new flexible stranded wiring.

Fig. 9-5. Western Electric No. 317 wall phone of 1916 with a smaller cabinet, a shorter transmitter arm, and a more slanted writing shelf.

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[5] In 1908 Western Electric was in the process of changing receivers from the external-terminal No. 122 to the concealed-terminal No. 143. Both were listed as available in the 1908 Western Electric catalog and in several Western Electric circulars issued that same year. The later No. 144 receiver shown in Fig. 9-3 is nearly identical to the No. 143 (see Chapter 3).

[6] The 2-cell type appears in the Western Electric 1918 catalog, but the 3-cell type in that catalog is the older style with the long transmitter arm. The 3-cell type with the short transmitter arm appears in later catalogs. See Fagen/AT&T (1975, 131) for additional dates.

Table 9-1. Variations of the Western Electric No. 317 magneto wall phone available in 1935

Model	Ringer	Resistance[a]	Magneto	Type[b]	Condenser[c]	Line Load
Three-Cell Type						
317AH	38AG	1000	22A	3-bar	No	Light
317N	38FG	1600	48A	5-bar	No	Medium
317R	38FG	1600	48A	5-bar	Yes	Medium
317P	38BG	2500	48A	5-bar	No	Heavy
317S	38BG	2500	48A	5-bar	Yes	Heavy
317BA[d]	38FG	1600	48A	5-bar	No	Medium
Two-Cell Type						
317CH	53AG	1000	22BA	3-bar	No	Light
317CN	53FG	1600	50F	3-bar	No	Medium
317CR	53FG	1600	50F	3-bar	Yes	Medium
317CP	53BG	2500	50F	3-bar	No	Heavy
317CS	53BG	2500	50F	3-bar	Yes	Heavy

[a] dc resistance of ringer in ohms.
[b] 60 volts ac for 3-bar magneto; 80 volts ac for 5-bar magneto.
[c] A 1-microfarad condenser was supplied as noted.
[d] Same as 317N except equipped with push button for secret signaling of central office.

Line loadings, shown in the table, were defined by Western Electric, as follows. Light-loaded lines were less than 15 miles in length, connected to no more than twelve telephones. Medium-loaded lines were between 10 and 30 miles in length, connected to 10 to 30 telephones. Heavy-loaded lines were up to 40 or 50 miles long or equipped with up to 40 telephones.

Fig. 9-6. Western Electric No. 417 wall phone of 1938 with the bulldog mouthpiece for a new transmitter and an anti-sidetone circuit.

Originally, condensers were supplied in magneto wall phones for just one purpose: to permit ringing when the receiver was inadvertently left off the hook. The operation of this sure-ring condenser is described in Chapter 15. By the 1920s, however, a second purpose had arisen. Common-battery systems were by then so prevalent that provisions were made to accommodate both common-battery and local-battery phones on the same line. Instructions were thus provided (pasted inside the door) for using the condenser to facilitate connection to a common-battery line, and this use of a ringer condenser is also described in Chapter 15. The same 1-microfarad condenser was used for either purpose.

Just before World War II, a final model of the magneto wall phone was produced by Western Electric. The No. 417 set shown in Fig. 9-6 was also produced with an olive drab paint job for the military during the war, and it was manufactured again briefly after the war.[7] This magneto wall phone with its more modern-looking transmitter is sometimes called a railroad phone, because the railroads tended to maintain this older type of equipment for a long time.

The No. 417 contained the new modular F1 transmitter and HA1 receiver elements that were developed for the F1 handset, which made its debut in 1936 (see Chapter 13). Although the external appearance

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[7] In the 1920s, Western Electric started marking the manufacturing date in small red numerals somewhere inside the instruments. Thus, the numerals IV45 inside the door of the No. 417 shown in Fig. 9-6 mean that the set was manufactured in the fourth quarter of 1945. The No. 417 first appeared in Western Electric's Catalog No. 10 in 1939.

of the receiver (now the No. 706) was not changed much, the appearance of the transmitter (now the No. 635) was altered significantly. The stubby shape of this mouthpiece lead to its bulldog nickname. Consequently, with its improved transmitter and anti-sidetone circuit, the No. 417 produces a signal unsurpassed by today's telephones (its superior performance can be seen in measurements reported in Chapter 18).

Most other components of the No. 417, including cabinet, ringer, magneto, and condenser, were unchanged from the latest version of the No. 317. The 6-terminal No. 113 coil was, of course, different from the 4-terminal No. 13 coil to facilitate the anti-sidetone circuit. Interestingly, a third purpose for a condenser was introduced in the No. 417: to provide a better capacitance balance under certain line conditions to adjust the sidetone level (sidetone balance).

Generally, the same variety of No. 417 sets was available as listed in Table 9-1, and the suffix designations (AH, N, R, etc.) retained the same meanings. However, one further model was made, and that was the SP417, which used the F1 handset instead of a separate transmitter and receiver. Like most of the Western Electric sets, a single wiring harness was used for all model variants, so all of the 417s have electrical provisions for the handset. The full conversion to an SP417 was accomplished with a replacement switch hook to cradle the handset and a blank, made like the base of the transmitter mounting bracket, to cover the transmitter mounting holes. The handset also fits adequately on the standard switch hook, so a less formal conversion could also be made.

Although Western Electric did not produce any further magneto wall phones, there was a continuing need for this type of equipment in Canada, and Canadian Bell's Northern Electric Company produced two later models. One, the No. N517, was like the Western Electric SP417 (just described), except there was no transmitter hole in the door requiring a blank cover. The other, the No. N717, was a smaller phone without a battery compartment. This compact wall phone is described in Chapter 12.

Stromberg-Carlson Magneto Wall Phones

Stromberg-Carlson made magneto wall phones that evolved much like the Western Electric instruments. One of the earliest Stromberg-Carlson single-box wall phones is shown in Fig. 9-7. This is the model No. 101 with a cathedral top and a picture-frame front. This phone is of the same vintage (i.e., around 1907) as the Western Electric No. 317 in Fig. 9-2. Like its Western Electric counterpart, bare solid wires were used throughout, with many routed through saw cuts in the rear of the backboard. Wiring was soldered to the four door hinges to make the connections to the door-mounted components, and external terminals were used on the cathedral top.

Stromberg-Carlson was also switching from an external-terminal receiver to a receiver with enclosed terminals, so this early model was produced with an enclosed No. 27A receiver on some units as shown in Fig. 9-7.[8] This No. 110 wall phone used the No. 15A coil. The ringer in this early set was not provided with an adjustment on bell spacing to control loudness as provided on its Western Electric counterpart. On most later Stromberg-Carlson ringers, however, this adjustment is made by merely rotating the bells, which were manufactured with off-center screw holes.

Fig. 9-7. Stromberg-Carlson No. 110 wall phone with nickel-plated hardware and a cathedral top.

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[8] Early catalog information can be found on the internet in the library of Telephone Collectors International.

Although there were minor electrical differences between this phone and the Western Electric No. 317 (described in Chapter 15), the only significant difference was the lightning arrester on the Stromberg-Carlson phone. This carbon-block device can be seen on the cathedral top as an integral part of the terminal arrangement. The lightning arrester holds two pairs of carbon blocks (one block connected to each line and the remaining blocks connected to ground), and each pair is separated by a thin mica sheet to prevent shorting out of the circuit and to provide the gap for discharge.

Kellogg Magneto Wall Phones

Kellogg also produced a similar line of magneto wall phones. A more recent model, the Kellogg No. F2884, is shown in Fig. 9-8. This phone is the counterpart of the plain (long transmitter arm) Western Electric No. 317 that was made between 1911 and 1916. Insulated stranded wiring was used on this Kellogg set as well, and these flexible wires also went directly to the door without being soldered to the hinges. Whereas the Western Electric phones of that period still used a cast iron transmitter arm and base, this Kellogg phone has a long stamped-steel arm and a clover-leaf base that are characteristic of the Kellogg sets.

There are some interesting electrical differences (mostly in signaling) between this phone and the Western Electric phones, and these are described in Chapter 15. The basic telephone circuit is, however, the same standard local-battery circuit used in most magneto wall phones. This Kellogg F2884 used the No. 41A receiver and the No. 28C coil. This Kellogg coil was a little different from most as it had both soldering terminals and screw terminals to permit rewiring in the field. The bell spacing in the Kellogg ringers is adjusted by moving a pivoting bracket that is similar to the Western Electric design. Like the Stromberg-Carlson phone, this Kellogg phone has a lightening arrester right on the phone. This round carbon-and-mica device is on the upper left side of the cabinet, just above the receiver (not visible in the figure).

Fig. 9-8. Kellogg No. F2884 wall phone with a plain top and a plain front.

American Electric Magneto Wall Phones

In 1926, Automatic Electric's parent company, the Gary Group, acquired the American Electric Company and the Monarch Telephone Manufacturing Company to manufacture manual (non-dial) telephones under the American Electric Company name (McCarthy 1990, 38; Telephony 1926, 38). This sister company with the same AE initials subsequently marketed manual telephones seamlessly with Automatic Electric's dial telephones, and basic designs were shared. The Type 200 wall phone shown in Fig. 9-9 is one of the few magneto wall phones made by American Electric.[9] It was equipped with a Type 6 transmitter and a Type 23 receiver. A later version of the Type 200 was made with a short transmitter arm, which held a Type 42 capsule-type bulldog transmitter, and a Type 42 capsule-type receiver. The cabinet on this phone is rather small (only 15½-inches high), and this compact size was achieved by the unusual placement of the ringer on the rear of the door inside the battery compartment. Metal louvers were provided on the sides of the cabinet near the ringer to let the sound out. The No. 31D coil in this early version of the phone has two pins that fasten into screw terminals to both support the coil and make electrical connections (a third screw terminal is provided on the coil frame). The later version was equipped with a more conventional No. MC-2888 induction coil.

Fig. 9-9. American Electric Type 200 wall phone with the ringer hidden inside the battery compartment.

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[9] This particular telephone is an early version of the Type 200 and just happens to have a Julius Andrae & Sons name tag on it.

Chapter 10
Candlestick Desk Stands

Desk stands, which hold only a transmitter, receiver, and hook switch, continued to grow in popularity. They were particularly well-suited for common-battery service, which was becoming more prevalent. Neither a magneto nor a battery was required for common-battery service, so the remaining components (ringer, coil, and condenser) could be placed in a small box and mounted in an out-of-the-way location.

Of course, desk stands held the same components needed for any type of telephone, and could be used for local-battery service as well as common-battery service. In local-battery service, however, a larger wall-mounted box with the magneto would have to be placed in an accessible location for cranking. The ringer and coil were usually placed in the box with the magneto, but additional space was required for the batteries, generally in a remote location.

The trend toward simplicity, which accompanied the drive to universal service, also affected the design of desk stands. In particular, the ornate machined castings used for stands in the 1890s were replaced by a simple brass tube. That tube and its plain round base were about the size and shape of a candle in a holder; hence the name candlestick. It should be noted, though, that the transmitters and receivers of the desk stands were exactly the same as those used on the wall phones of the same vintage. Further, a desk stand, together with a subset or ringer box, comprise a whole telephone.[1] The type of subset or ringer box used with the desk stand determines the telephone's circuit, and these boxes are described in Chapter 12.

Fig. 10-1. Western Electric No. 20-B nickel-plated desk stand of 1904 with uninsulated metal parts and exposed receiver terminals.

Western Electric Candlestick Desk Stands

The first tubular-shaft Western Electric candlestick desk stand in widespread service was the model No. 20-B, often referred to as the 1904 candlestick because of the patent date stamped prominently on its perch. This desk stand is shown in Fig. 10-1. Like other phones of this vintage, the metal parts were nickel-plated brass. Also, like its contemporary cathedral top wall phone (No. 317, which was described earlier), the No. 20-B desk stand used the old-style No. 122 external-terminal receiver and a No. 229 solid-back transmitter.

Another primitive feature of this 1904 candlestick was the electrical connection of the transmitter. One wire was routed externally through a hole in the transmitter cup, and then reentered through the central hole in the perch. The other electrode of the transmitter was in contact with the metal parts of the candlestick so that those parts served as the second conductor.

The No. 20-B (and later) Western Electric candlesticks used a simple mechanical design in which the transmitter and perch are fastened to a flat steel stem that extends through the length of the tubular stand. The hook switch lever acts directly on the main spring of the switch, which is also mounted on the stem. The entire stem is released for easy access by removing one of the three screws in the base. Other manufacturers used more complicated arrangements, which are mentioned in the following paragraphs.

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[1] Later, when more compact condensers and ringers were designed, the entire telephone was contained in a desk set. Those are called desk phones or combined telephones, rather than desk stands, to indicate that they are complete telephones.

Fig. 10-2. Western Electric No. 20-AL painted brass desk stand of 1915 with electrically insulated metal parts and enclosed receiver terminals.

Two later models of the non-dial candlestick desk stand were made by Western Electric: the No. 20-AL and the No. 40-AL. Figure 10-2 shows the No. 20-AL, which bears a patent date of 1915, and was manufactured for more than a decade. Construction of this set is more modern and all electrical connections are safely insulated from the metal base of the desk stand. The perch has a streamlined shape, with both transmitter wires routed internally. This desk stand uses the later No. 323 transmitter and the No. 144 receiver with enclosed terminals.

The metal parts of the No. 20-AL desk stand and the dial candlesticks were made of brass and were painted with a black "rubber finish" japan (Arlt 1930). Japans are asphalt-like varnishes that are baked to produce a durable surface. The term rubber finish, coined by its Western Electric manufacturer, refers to its semi-dull black appearance that looks like a polished piece of hard rubber; the japan contains no rubber.

The No. 40-AL candlestick is identical in shape and function to the No. 20-AL desk stand, but the base and shaft of the 40-AL were made of steel and were not painted at all. Those steel parts were given a chemical-scale finish produced by oxidizing their surface in the presence of steam and oil. This Bower Barff process produced a very hard finish with excellent corrosion resistance and a pleasant dark gray appearance. The finish can only be achieved on steel parts, and is not used for any other telephones described in this book. The No. 40-AL desk stand is often called the Bower Barff candlestick.

Two similar dial versions of the candlestick desk stand were also manufactured by Western Electric: the No. 50-AL (1918 latest patent date) and the No. 51-AL (1920 latest patent date). These all-brass desk stands are similar to the non-dial desk stands, except that the shaft has been moved off center to accommodate the dial. Figure 10-3 shows one of them, the No. 51-AL candlestick with a No. 2AA dial. This particular dial has only numbers on its porcelain number plate, because it was intended for rural service (the No. 2AB dial has both numbers and letters for metropolitan exchanges with names). The No. 50-AL desk stand is identical in external appearance.

Fig. 10-3. Western Electric No. 51-AL desk stand of 1920 with off-center shaft to accommodate a dial.

With the advent of dial telephones, a new problem arose. The repetitive making and breaking of the dc transmitter current caused radio interference. To combat this problem, a No. 61 radio-frequency filter was provided as an option. This little radio interference filter, in a can about 1-inch square by a half-inch thick, was mounted in the base of the desk stand. The filter's operation is described in Chapter 16.

Fig. 10-4. Western Electric No. 150-AL desk stand of 1938 with the bulldog mouthpiece for a new transmitter and switching for an anti-sidetone circuit.

One final variant of the Western Electric candlestick desk stand was manufactured – or more precisely remanufactured – in the late 1930s, long after the handset desk stands had been introduced (next chapter).[2] At that time, the new HA1 receiver and F1 transmitter with the bulldog mouthpiece were backfitted to models mentioned previously, and a circuit modification was made to facilitate use with an anti-sidetone subset. This modification involved the addition of an extra contact on the hook switch and the use of a 4-conductor cord from the desk stand to the subset, rather than the 3-conductor cord used with the original candlesticks. These desk stands were re-designated No. 120-AL, No. 140-AL, No. 150-AL, and No. 151-AL, respectively. They are thus counterparts of the No. 417 magneto wall phone, whereas the unmodified candlesticks are counterparts of the No. 317 magneto wall phones. Figure 10-4 shows a No. 150-AL desk stand with a No. 2AB dial. This remanufactured 50-AL can be compared with the No. 51-AL in Fig. 10-3, which is identical in appearance except for the transmitter face and the receiver.

Stromberg-Carlson Candlestick Desk Stands

The independent companies also manufactured desk stands in the traditional candlestick style, while maintaining some of their own mechanical design characteristics. Figure 10-5 shows a typical Stromberg-Carlson desk stand of the 1920s. A full inch shorter than the Western Electric candlesticks, this No. 986 Stromberg-Carlson desk stand retained much nickel plating, reminiscent of earlier designs. The nickel-plated parts were made of brass, whereas the black-painted tube and base are steel. The transmitter position in this desk stand is adjustable over a limited range with a ball-and-socket joint that is locked in place by the knurled socket piece. A 3-contact switch in the base is actuated by a pushrod from the switch hook lever.

Fig. 10-5. Stromberg-Carlson No. 986 painted steel desk stand with nickel-plated brass parts.

Mechanically, the Stromberg-Carlson desk stand is more complicated than the Western Electric models, but electrically it is the same (except for the re-manufactured Western Electric 100-series models with 4-contact switches). Although Stromberg-Carlson did not manufacture its own dials until after World War II, a dial version of this desk stand (Model No. 1150, not shown) was available and could be fitted with dials manufactured by Automatic Electric, Kellogg, North Electric, and Western Electric.[3] The No. 986 and No. 1150 desk stands use Stromberg-Carlson's No. 27A receiver. Other candlestick desk stands were made by Stromberg-Carlson in the 1930s and 1940s.

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[2] The earliest reference to this type of desk stand is in Jones (1938, 339).

[3] Desk stand models No. 986 and No. 1150 are both listed in the 1925 Stromberg-Carlson catalog.

Fig. 10-6. Kellogg No. F301 painted steel desk stand with a mar-proof bakelite sleeve on the shaft.

Kellogg Candlestick Desk Stands

A typical Kellogg candlestick desk stand of the 1930s is shown in Fig. 10-6. This Model F301 with a dial has a non-dial counterpart (Model F118) that is not shown here.[4] The desk stand shown is equipped with a Kellogg dial, but a similar dial manufactured by Automatic Electric was also used on Kellogg telephones. Intermediate in height between the Western Electric and Stromberg-Carlson candlesticks, this desk stand has a Kellite (bakelite) sleeve around the upright tube that "will not chip, mar, or discolor," according to the manufacturer.[5]

Like the Stromberg-Carlson desk stand, the F301 also uses a pushrod to actuate a hook switch located in the base. However, Kellogg had already introduced a handset desk stand by this time, and handsets generally require a 4-contact hook switch (see Chapter 15). Because the early Kellogg handset desk stands used the same base as this candlestick, it is not surprising that Kellogg used the 4-contact switch in this candlestick – even though it was not necessary. The pushrod that activates this switch is articulated and is even more complicated than the Stromberg-Carlson model. With internal spring washers to provide friction for the tilting transmitter, and with all-steel construction (except for transmitter cup and face plate) that tends to rust, the Kellogg candlesticks were not as serviceable as the others.

The F301 is a contemporary of the Kellogg magneto wall phone described earlier, and it also used the No. 41A receiver. Because of its 4-contact hook switch, this Kellogg desk stand is compatible with the standard circuits and the anti-sidetone circuits without any modification.

Automatic Electric Candlestick Desk Stands

An Automatic Electric Type 21 candlestick desk stand is shown in Fig. 10-7. American Electric made a non-dial version of this phone with a centered shaft and also called it a Type 21 desk stand. The Automatic Electric Type 21, like the Stromberg-Carlson and Kellogg candlesticks, is a little shorter than the Western Electric desk stands. But like the Western Electric candlesticks, the hook switch contacts in the Type 21 are mounted on a steel stem that extends through the length of the tubular stand. The entire stem can be released by loosening a single screw just above the receiver hook, once the base has been removed. A four-conductor switch assembly is employed such that this desk stand can be used with the standard circuits or the anti-sidetone circuits without any modification. This desk stand uses the same Type 6 transmitter and Type 23 receiver as used on the Type 200 magneto wall phone described earlier, although capsule-type transmitters and receivers were available later. Notice that the dial on this phone is fitted with an optional cut-away finger wheel, which was said to admit a greater amount of light and make it easier to keep the number plate clean.[6]

Fig. 10-7. Automatic Electric Type 21 desk stand with cut-away finger wheel.

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[4] Desk stand models F118 and F301 are both listed in Kellogg's catalog No. 9 (1935).

[5] By 1935, Kellogg had begun an extended period of manufacturing of handset desk stands and telephones out of their own brand of bakelite called Kellite. Bakelite is a phenolic-resin plastic that was developed around 1905 by Hendrik Baekeland.

[6] Automatic Electric catalog No. 4055-D.

Chapter 11
Handset Desk Stands

The convenience of a handle that contained both a transmitter and a receiver was recognized quite early. In 1877, British patents on such handsets were issued to two Englishmen, C. E. McEvoy and G. E. Pritchett (Fagen/AT&T 1975, 138; Frederick 1934; Jones and Inglis 1932). In 1878, Robert Brown, of Western Union's Gold and Stock Exchange, developed and introduced a practical handset, later obtaining the first U.S. patent on a handset.[1] Brown's patent drawing is shown in Fig. 11-1. Brown later went to France, where handsets based on his design were widely used. This resulted in telephones with such handsets being known as French phones. But handset telephones were not widely used in the United States for many years because the Bell System would not accept their poor performance.

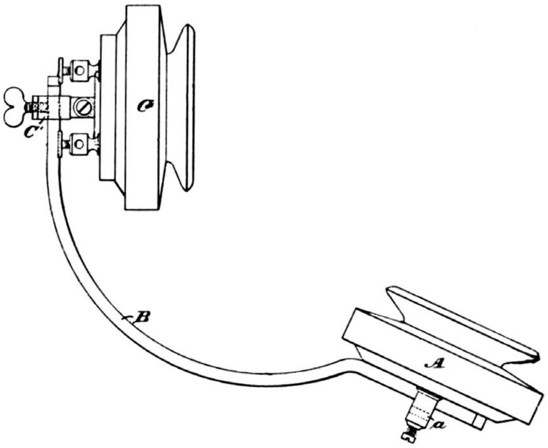

Fig. 11-1. Drawing of handset from Brown's patent, applied for in 1879.

Beginning in 1890, Western Electric produced several handset designs that were used in limited applications, including the No. 2 handset designed in 1902 and shown in Fig. 11-2. This handset has a switch in the handle, which opens when hung by the ring, and the handset could be used with a ringer box or a subset. However, the first handset desk stand placed in general service in the U.S. was made by Kellogg. That desk stand, known first as a micro-telephone and later as the Grabaphone, was introduced in 1905. A Grabaphone model No. F111, still being marketed in Kellogg's 1918 catalog, is shown in Fig. 11-3. This desk stand, also available with a dial, was an adaptation of the base of a candlestick desk stand (like Kellogg Nos. F118 and F301) with a rather crude cradle for the handset. The set shown in Fig. 11-3 has a No. 16A retardation coil and a 0.5-microfarad condenser mounted in the base together with a switch and terminal strip.

Fig. 11-2. Western Electric No. 2 handset designed in 1902 with an internal switch, activated by the ring at the top.

Although Western Electric manufactured handsets throughout this period, the Bell System did not place them in widespread service because of two inherent problems. First, handsets incorporating a transmitter of the solid-back type were susceptible to performance variations as the transmitter was moved around or tilted from its normal position. Second, the closeness of the receiver and transmitter sometimes resulted in a howling noise as the sidetone in the receiver would be picked up by the transmitter and amplified (acoustic feedback).

The Kellogg Grabaphone was less susceptible to these two problems for reasons that are not altogether commendable. First, the transmitter was mounted sideways so that the ordinary motion of moving one's head up and down would not cause the carbon granules to fall away from an electrode (the electrodes remained in a vertical plane).[2] The price for this improvement was that sound

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[1] Robert G. Brown, "Electric Speaking-Telephone," Patent No. 224,138, dated February 3, 1880; application filed September 29, 1879.

[2] Western Electric also made handsets of this style, including the lineman's handset of 1895 and the No. 5B handset of

waves did not impact directly on the diaphragm, thus lowering its efficiency. Second, Kellogg used a retardation-coil circuit in these phones, rather than the Western Electric booster circuit (which Kellogg adopted later). The retardation-coil circuit did not have the objectionably large sidetone of the booster circuit; unfortunately, it did not put a strong signal on the line, as the booster circuit did quite well. The absence of a large sidetone, combined with its overall low signal level, made the Grabaphone's handset less susceptible to acoustic feedback.

Fig. 11-3. Kellogg No. F111 Grabaphone desk stand of the type introduced in 1905.

Western Electric Handset Desk Stands

In 1918, Western Electric initiated a major research and development program to overcome these inherent problems and produce an acceptable handset. George Campbell's work on anti-sidetone circuits had just been published, and it was believed that the suppressed sidetone would eliminate the acoustic feedback problem (Campbell and Foster 1920; see Chapter 17 for more on sidetones). A non-positional transmitter had not yet been developed, but work was underway that would lead to such a device (the No. 395 transmitter). That transmitter and a variation of a watchcase receiver (the No. 557 receiver) were used in the new handset.[3] Further, extensive measurements of head dimensions of adults were made to help determine the exact shape and size of the handset, introducing the technology of human factors into the design.

After field testing and numerous modifications, the handset, now known as the E-type, was ready for commercial service in early 1927. It is interesting that the anti-sidetone circuit, for which this handset had been intended, was not yet ready, but that the solid bakelite material used in constructing the handset was adequate to eliminate the acoustic feedback problem – most previous handsets had hollow handles. Consequently, the E-type handset with an A-type handset mounting was placed in service with the old booster circuit. This desk stand, shown in Fig. 11-4, is seen to be very similar to a No. 50-AL or 51-AL candlestick base, with the shaft shortened and fitted with a cast-aluminum cradle-style hook switch.[4] Like most of the candlesticks, the base of this A-type desk stand is all brass. Also, like the candlesticks, a

Fig. 11-4. Western Electric A-type desk stand of 1927 with a cast-aluminum cradle on a shortened brass candlestick base.

1915.

[3] Arthur F. Bennett and Charles R. Moore, “Intelligence Signaling Apparatus,” Patent No. 1,719,645, dated July 2, 1929; application filed August 20, 1925.

[4] George K. Thompson, “Design for a Desk Stand for Hand Telephones,” Patent No. Des. 65,204, dated July 15, 1924; application filed December 28, 1922.

No. 2 dial is mounted on the surface of the base, although this is a No. 2H dial (rather than a 2A dial) with an extra electrical terminal for use with a handset (see Chapter 16).

Fig. 11-5. Western Electric A-type desk stand with handset resting on a cradle ear.

Notice that the patent for the A-type desk stand is a design patent, and the only part of the desk stand that was of a new design was the handset cradle. This patent can therefore be viewed as a patent for the design of the cradle, and there was a mistake in this design by George Thompson. As seen in Fig. 11-5, the handset can accidentally rest on one of the ears on an A-type desk stand, leading to a receiver-off-hook (ROH) hang-up error. Although infrequent, an ROH error was a big problem because it could not be corrected at the central office and it would disable all the phones on a party line – and most phones were on party lines in the 1920s.

Thus, a short time later, the A-type handset mounting was replaced by the B-type mounting shown in Fig. 11-6. The cradle was redesigned by William Scharringhausen, and the objective to eliminate the ROH error is clearly described in his patent document.[5] In the B-type mounting, the base was still round like the candlestick base, but the short remnant of the candlestick shaft had been eliminated by adding smooth contours of the single-piece stamped steel body. This construction was undoubtedly less expensive than the brass A-type body, providing additional incentive for the change. Like the A-type desk stand and the candlesticks, a surface-mounted No. 2H dial was still used.

Fig. 11-6. Western Electric B-type desk stand with a round footprint and a surface-mounted dial.

By the late 1920s, the Bell System was actively pursuing aesthetic designs, and in 1929 they held a competition for artists to re-design the B-type desk set (Dreyfuss 1955, 102-103; Clarke 1998, 178-180). The Bell System rejected all of the designs that were submitted and turned back to Bell Labs for the re-design. In 1930, the round-base B-type mounting was thus replaced by the oval (actually elliptical) D-type mounting shown in Fig. 11-7. The housing was a metal casting that was initially aluminum but later changed to a zinc alloy. This D-type housing was the configuration that continued in production for the remainder of the lifetime of the E-type handset.

At that time, Western Electric started assigning assembly code numbers to desk stands. A D-type handset mounting with the E-type handset and cords for connecting to a subset with the common-battery booster circuit was called a No. 102 desk stand. The same handset mounting and handset with cords for

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[5] William H. Scharringhausen, “Telephone Desk Set,” Patent No. 1,788,747, dated January 13, 1931; application filed November 22, 1927.

connecting to a common-battery anti-sidetone subset was called a No. 202 desk stand.[6] Other code numbers were assigned when the D-type desk stand was fitted for party line service or local-battery service.

Aside from its oval base, which provides better stability and a distinctive appearance, it should be noticed that the dial (now a No. 4H) is recessed into a cavity in the base, whereas the B-type and earlier candlestick varieties used a surface-mounted No. 2H dial. In 1934, the improved and less expensive F1 transmitter element was backfitted into the E-type handset, further improving the performance of these desk stands. Thus a late model No. 202 desk stand with its lower, trimmer profile, with its anti-sidetone circuit, and with its non-positional F1 transmitter represented a truly major advance in telephone design

Fig. 11-7. Western Electric D-type desk stand of 1930 with an oval footprint and a recessed dial.

Several further observations about the Western Electric handset desk stands are interesting. Designs of the dial versions and the non-dial versions (still in considerable demand) had converged. The non-dial desk stand, shown in Fig. 11-8, is exactly the same as its dial counterpart, except that the dial has been replaced by a blank cover. Also, the later production E-type handsets had attractive grooves along the length of the handle and around the transmitter and receiver caps. These grooves were in fact functional, as they were machined into the molded pieces to disguise fabrication seams (Huxam 1939). The grooves, seen in Figs. 11-7 and 11-8, would persist in the later F-type and G-type handset designs.

Another interesting observation has to do with the construction of the handset desk stands. Like the candlesticks, all wiring and components (including a dial-pulse filter when needed) were mounted in the body of the desk stand. The fabric-covered base served merely as a cover. Later, this construction style was completely reversed in the 500-type phones, where all components and wiring would be mounted on the base, and the housing would serve merely as a cover. The generation of phones in between, namely, the combined phones described in Chapter 13, are of mixed construction.

Fig. 11-8. Western Electric D-type non-dial desk stand, made by substituting a blank cover for the dial.

Kellogg Handset Desk Stands

Similar handset desk stands were also introduced by the independent companies. A Kellogg No. 700 desk stand, called a Masterphone, is shown in Fig. 11-9. This set, introduced in 1930 and made of bakelite, was the first in a series of bakelite Masterphones produced by Kellogg with stylish lines of the art deco period. However, the dial version of Kellogg's handset desk stand, the No. 730 shown in Fig. 11-10, was built on a steel candlestick base. No modern-looking dial deskstand was made by Kellogg during this period.

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[6] Notice that 100 was added to the model number of the set with the booster circuit to get the model number for the anti-sidetone set, just as had been done for the anti-sidetone candlesticks.

Fig. 11-9. Kellogg No. 700 bakelite Masterphone desk stand of 1930 with no provision for a dial.

Fig. 11-10. Kellogg No. 730 Masterphone desk stand with a bakelite cradle on a shortened candlestick base.

In 1933, Kellogg started supplying George Eaton's non-positional transmitter in the Masterphone handset (Eaton 1933, 14). Hence, Kellogg introduced the first high-quality non-positional transmitter one year before Western Electric did, and this Kellogg transmitter remained in use in all Masterphone handsets through the No. 1000 "red bar" telephone (Chapter 13). A capsule-type No. 89A receiver was also backfitted in the Masterphone handset and was used in later models through the No. 1000 telephone.

Automatic Electric Handset Desk Stands

Automatic Electric in 1925 was first to introduce a modern looking handset desk stand, which they called the Monophone (Automatic Electric 1925, 66). This No. 1 Monophone with a surface-mounted dial and a long neck on the handset cradle is shown in Fig. 11-11. Automatic Electric, American Electric, and Monarch also supplied the Monophone handset on a modified center-shaft candlestick base for non-dial applications. The bakelite base of the No. 1 Monophone was later modified to shorten the neck on the cradle and recess the dial into the base, and minor modifications were also made in the design of the handset. This later Type 1A Monophone is shown in Fig. 11-12, and it is the Monophone that is most commonly found. The handset on this desk stand contains the Type 38 receiver, and starting in 1935 the old solid-back transmitter was replaced by the Type 35A7 non-positional transmitter (Telephony 1935, 50).

Fig. 11-11. Automatic Electric No. 1 Monophone desk stand with a surface-mounted dial and a long cradle neck.

Fig. 11-12. Automatic Electric Type 1A Monophone desk stand with a recessed dial and shortened cradle neck.

Fig. 11-13. Automatic Electric Type 32A Monophone desk phone with a step-base to house other components.

A third modification of the Monophone is shown in Fig. 11-13. This modification has different transmitter and receiver caps and usually contains the induction-coil receiver, an element-style transmitter, and a large ring to raise the base and make room for a small buzzer or a single-coil ringer. This step-base Type 32A set was thus a complete telephone, but its electrical properties made it more suitable for use on isolated private exchanges (see Chapter 17).

Stromberg-Carlson Handset Desk Stands

By 1929, Stromberg-Carlson had a handset that was mounted on modified candlestick bases and the transmitter in this handset was the older solid-back transmitter.[7] The No. 1177 used a non-dial candlestick base and the No. 1178 utilized a candlestick base with a dial. Later, however, Stromberg-Carlson also produced bases that were specifically designed for a handset and were similar in appearance to the Western Electric sets. Figure 11-14 shows a Stromberg-Carlson No. 1198 desk stand with a partially recessed dial, and its counterpart No. 1197 desk stand without a dial is shown in Fig. 11-15. Stromberg-Carlson's non-positional No. P-24562 transmitter was introduced in the handset of these desk stands.[8] These two desk stands are made of molded bakelite, but it can be seen that each is formed in a different mold. Although Stromberg-Carlson has made the desk stands to look alike, they have not quite made the transition to a unified design. For Stromberg-Carlson, this would come in the next generation of telephones.

Fig. 11-14. Stromberg-Carlson No. 1198 bakelite desk stand with a partially recessed dial.

Fig. 11-15. Stromberg-Carlson No. 1197 bakelite desk stand without a dial.

Space Savers

A wall-mounted analog of the handset desk stand, often referred to as a space saver, was produced by a number of manufacturers. The Western Electric C-type space saver is shown in Fig. 11-16 and is seen to have the same No. 2H dial and E-type handset as the early handset deskstands. When the C-type space saver was fitted for common-battery anti-sidetone service, it was given the code No. 201, and other code numbers were used for other classes of service. The hook switch is functionally the same as the switch in the desk stands, but the mechanical layout is different. A very compact non-dial space saver (Fig. 11-17) is

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[7] Stromberg-Carlson 1929 switchboards and telephones catalog.

[8] This transmitter screws into the handset whereas most others are simply held in place by the cap on the handle.

obtained by removing the dial and its mount and snapping the dial card holder into the opening where the dial mount was attached. As with the desk stands, the space savers require a ringer box or a subset, and can be used for either local-battery or common-battery service.

Fig. 11-16. Western Electric C-type wall-mounted space saver with a surface-mounted dial atop a cast-steel pedestal.

Fig. 11-17. Western Electric C-type non-dial space saver with the number-card holder covering the dial-mount opening.

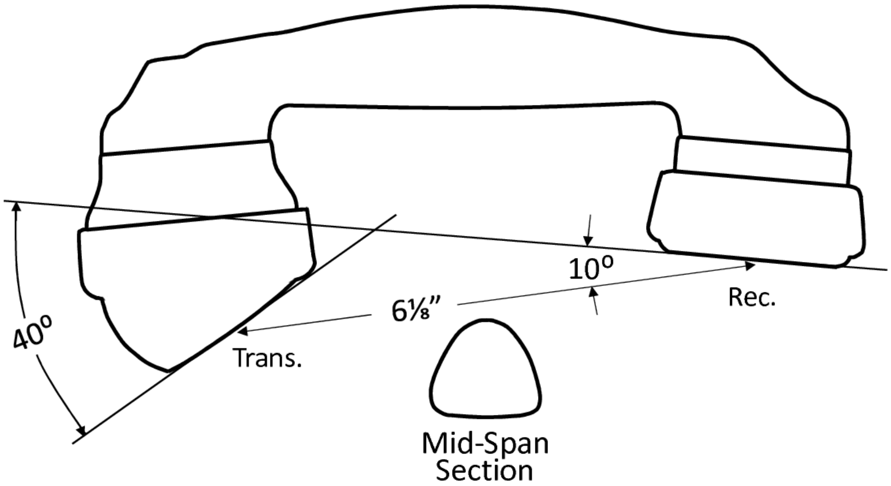

Fig. 11-18. Outline of E-type handset with critical dimensions.

Chapter 12
Ringer Boxes, Subsets, and Compact Wall Phones

Neither a candlestick desk stand nor a handset desk stand was a complete telephone, and provisions had to be made for housing the remaining components. Thus, a separate box was used to house the ringer, coil, condenser, and magneto (when used). These boxes were usually called subsets or ringer boxes, although the latter term was used most often for local-battery sets with magnetos.[1] The desk stands just described were designed to work equally well in either local-battery or common-battery applications. Further, during the lifetime of these desk stands, anti-sidetone circuits were introduced in both local-battery and common-battery systems. Thus, there were two varieties of local-battery ringer boxes and two varieties of common-battery subsets, and in principle, any one of these four boxes could be used with any of the desk stands. In practice, however, the Western Electric candlestick desk stands with 3-contact hook switches could not be wired to the common-battery anti-sidetone circuits (see Chapter 17).

It is easy to see that a desk stand's transmitter, receiver, and hook switch could be mounted directly on one of these subsets or ringer boxes to make a complete telephone – and this was done. Such compact wall telephones, sometimes called hotel phones, are described at the end of this chapter.

Fig. 12-1. Western Electric No. 300 local-battery ringer box with a large magneto, a long crank, and large nickel-plated bells.

Local-Battery Ringer Boxes

Western Electric manufactured two prevalent local-battery ringer boxes, the No. 300 and the No. 315. Both boxes were available in oak and walnut cabinets. Figure 12-1 shows a No. 300 ringer box in an oak cabinet with large (3-inch) nickel-plated bells. The smaller No. 315 ringer box is shown in Fig. 12-2; this particular ringer box has a walnut cabinet with the smaller (2½-inch) black painted bells that were typical of later sets. The No. 300 came with a 5-bar magneto in its slightly larger cabinet, while the No. 315 came with a 3-bar magneto and a shorter crank. The general appearance of these ringer boxes is quite similar to the No. 317 magneto wall phones, and indeed these ringer boxes were equipped with exactly the same coil, ringers, magnetos, and other hardware as the No. 317 wall phones.

Fig. 12-2. Western Electric No. 315 local-battery ringer box with a small magneto, a short crank, small painted bells, and a smaller cabinet.

A variety of electrical options was available in the No. 300 and 315 ringer boxes, depending on the type of service desired. Table 12-1 lists the options available in 1935 based on Western Electric Catalog No. 9. The optional condenser, as in the No. 317 magneto wall phone, was supplied for sure-ring purposes. Although in principle the condenser could be used to adapt the set to combined local-battery and common-battery lines (as done with the No. 317 wall phone), this would not normally be done, as a common-battery subset could be merely substituted for the ringer box without replacing the desk stand.

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[1] The term subset is shorthand for subscriber's set and is really a misnomer in this common usage. A subscriber's set in the trade language refers, in fact, to the whole telephone apparatus at the customer's location -- not just the box with the ringer.

Table 12-1. Variations of the Western Electric No. 300 and 315 magneto ringer boxes available in 1935

Model	Ringer	Resistance[a]	Magneto	Type[b]	Condenser[c]	Line Load
300K	38BG	2500	48A	5-bar	No	Heavy
300L	38FG	1600	48A	5-bar	No	Medium
300M	38FG	1600	48A	5-bar	Yes	Medium
300N	38BG	2500	48A	5-bar	Yes	Heavy
300AA	38BG	2500	50A	3-bar	No	Heavy
300AB	38FG	1600	50A	3-bar	No	Medium
315E	52AG	1000-3000	22E	2-bar	No	Light
315H	38AG	1020	22A	3-bar	No	Light
315J	49BG[d]	2500	22E	2-bar	No	Light

[a] dc resistance of ringer in ohms.
[b] 60 volts ac for 3-bar magneto; 80 volts ac for 5-bar magneto.
[c] A 1-microfarad condenser was supplied where noted.
[d] Four-party selective ringing (divided and biased).

The Western Electric No. 300 and 315 ringer boxes used the standard local-battery circuit with a No. 13 induction coil (see Chapter 15). Using exactly the same wooden boxes and hardware, except substituting a No. 113 coil (or the equivalent No. 104A closed-flux coil) and appropriate wiring, Western Electric produced the counterpart No. 400 and 415 anti-sidetone ringer boxes. Some of these were actually remanufactured No. 300 and 315 ringer boxes. The No. 400 and 415 boxes used the local-battery anti-sidetone circuit described in Chapter 18.

Figure 12-3 shows a very similar Kellogg No. F2370 ringer box with a No. 108A coil, and Fig. 12-4 shows a Stromberg-Carlson No. 1180 ringer box with a No. 44-A coil; both use the standard local-battery circuit. The Kellogg box, which is smaller and much like the Western Electric No. 315, contains a 5-bar magneto with closely spaced magnets. The Stromberg-Carlson box also has a 5-bar magneto, but it is in a larger oak cabinet like Western Electric No. 300

Fig. 12-3. Kellogg No. F2370 local-battery magneto ringer box.

Fig. 12-4. Stromberg-Carlson No. 1180 local-battery magneto ringer box.

Fig. 12-5. American Electric Type 200 local-battery magneto ringer box with the ringer on the inside of the door.

American Electric also made local-battery ringer boxes that were counterparts of their magneto wall phones. Figure 12-5 shows the Type 200 ringer box that has a 5-bar magneto and features like the Type 200 wall phone shown in Fig. 9-9. The ringer is mounted on the inside of the door, and the louvers on the sides let the sound out. This ringer box is a later version than the wall phone in Fig. 9-9; it has black painted hardware, rather than nickel plated hardware, and it contains the later No. MC-2888 induction coil.

Common-Battery Subsets

Although Western Electric did not modernize the cabinet style of its ringer boxes for the declining local-battery market, the cabinet style of its common-battery subsets went through quite an evolution. The first such subset of this century was the wooden No. 295 introduced around 1902. This subset, in a walnut cabinet with markings stamped in the wood, is shown in Fig. 12-6. It incorporates the No. 20 induction coil in Western Electric's booster circuit (see Chapter 16).

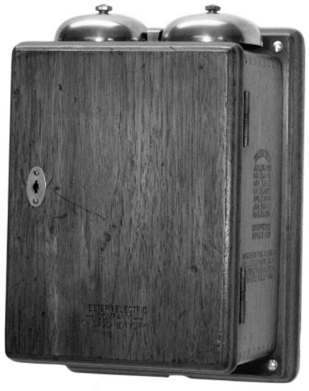

Fig. 12-6. Western Electric No. 295 common-battery subset of 1902 in a small wood cabinet with external nickel-plated bells.

Around 1912, the wood box was replaced by a black metal box, which resulted in the No. 334 subset shown in Fig. 12-7. Keeping in mind that the telephone was the first electronic device ever made, the No. 334 was in all likelihood the original electronic black box. The electrical circuit in the No. 334 is identical to that in the No. 295, and it continued to use the No. 20 coil.

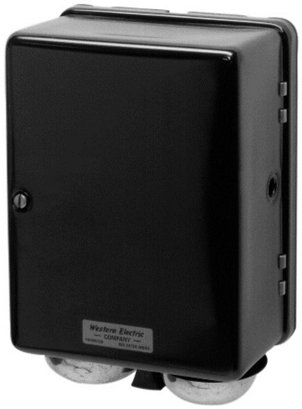

Fig. 12-7. Western Electric No. 334 common-battery subset of 1912 in a small metal cabinet with external nickel-plated bells -- the original electronic black box.

Though the No. 334 subset was more modern looking than the old wooden box, it left a lot to be desired in terms of manufacturing economy. It was made of copper-plated steel; its external bells required complex cutouts; and the ringer mount and clapper cover were separate parts riveted to the base. All of these manufacturing features were simplified in the No. 534 subset that was introduced around 1918. The No. 534, shown in Fig. 12-8, also used the booster circuit, but an improved No. 46 coil was substituted for the older No. 20 induction coil.

Fig. 12-8. Western Electric No. 534 common-battery subset of 1918 with bells enclosed in a larger louvered metal cabinet.

The final cabinet style appeared in 1930 when Western Electric introduced the No. 584 subset shown in Fig. 12-9. While the booster circuit and No. 46 coil remained unchanged, several mechanical changes were made to produce a smaller, less expensive subset (Lohmeyer 1931). A more compact layout was achieved by using smaller ringer gongs and mounting them parallel to the base, rather than at right angles as was previously done. And a tight fitting bakelite cover was substituted for the generous steel cover. Bakelite had two advantages here: (1) a steel cover that was tight-fitting would have acted as a magnetic shunt, affecting the ringer's performance, and (2) bakelite was cheaper to fabricate because no finishing operations were required.

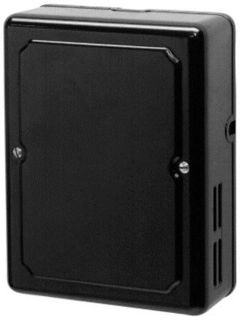

Fig. 12-9. Western Electric No. 584 compact common-battery subset of 1930 with a louvered bakelite cover.

Western Electric did not discontinue the No. 534 subset when the compact No. 584 was introduced, because they needed the roomier cabinet for two applications. First, they were making compact wall phones from these subsets, and there was insufficient room in the 584 for a hook switch. Second, a relay or vacuum tube was required in subsets for four-party selective ringing applications, and a relay or vacuum tube would not fit in the compact No. 584.

When Western Electric finally produced their anti-sidetone circuit around 1930, it was installed in the boxes of both the No. 534 and 584 subsets, and the boxes were renumbered No. 634 and 684, respectively. Originally, these anti-sidetone circuits used a No. 146 coil, which was effectively a No. 46 coil with an extra winding wound around it.[2] Two condensers were required for this circuit instead of one, but they were encased in the same envelope (can). The ringer and remaining hardware were the same as in the 534 and 584 subsets, so the booster subsets and the anti-sidetone subsets looked almost identical inside and out. A short time later, the cylindrical No. 146 coil was replaced by the closed-flux No. 101A coil that resembles a small transformer (which it is). This coil and anti-sidetone circuit remained in use in Western Electric subsets and the 300-type combined telephones until after World War II. The circuit is described in Chapter 17.

As with the local-battery ringer boxes, a large variety of electrical options was available within a given common-battery subset model, depending generally on the type of signaling desired. Table 12-2 lists the options available in 1923 based on Western Electric Catalog No. 5. Model suffixes used for the No. 534 subsets generally have the same meaning for the later No. 584, 634, and 684 subsets, although the coil and circuit would, of course, be different in the 600-series subsets.

Table 12-2. Variations of the Western Electric No. 534 subset available in 1923

Model	Ringer	Kind of Ringing	Coil
534A	8AG	Single or 2-Party (divided)	46
534AR	42AG[a]	4-Party (divided and biased)	46
534E	41SG	Harmonic (33-1/3 cycles)	46
534F	41TG	Harmonic (50 cycles)	46
534G	41UG	Harmonic (66-2/3 cycles)	46
534H	41RG	Harmonic (16-2/3 cycles)	46
534K	8AG	Single or 2-Party (divided)	None[b]
534C	None	None	46
534D	8AG	Single or 2-Party (divided)	None[c]
534Y	8AG	Single or 2-Party (divided)	13[d]
534R	8JG	(high resistance ringer)	46

[a] Used a No. 85J relay in the ringer circuit.
[b] Common-battery series circuit for very light local service.
[c] Used only as a bell box without a phone.
[d] Local-battery talking with common-battery signaling.

Automatic Electric also made their early Type 21 common-battery subsets in a large metal box with a distinctive raised oval shape on the cover (Fig. 12-10) and their later Type 32 subsets in a smaller bakelite box (Fig. 12-11). Both subset types were available with the booster circuit, an anti-sidetone circuit, or with no induction coil at all for use as just a ringer.

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[2] The full scope of a pattern can now be seen in Western Electric's model numbering scheme. Anti-sidetone counterparts of earlier sidetone components were given the old model number -- plus 100. Thus, the No. 13 and No. 46 coils were replaced by the No. 113 and No. 146 anti-sidetone coils. The No. 317 magneto wall phone was replaced by the No. 417 anti-sidetone wall phone. The Nos. 20, 40, 50, and 51 candlesticks were replaced by the remanufactured Nos. 120, 140, 150, and 151 anti-sidetone candlesticks. The No. 102 handset desk stand was replaced by the No. 202 anti-sidetone desk stand. The No. 300 and No. 315 ringer boxes were replaced by the No. 400 and No. 415 anti-sidetone ringer boxes. And the No. 534 and No. 584 subsets were replaced by the No. 634 and No. 684 anti-sidetone subsets.

Fig. 12-10. Automatic Electric Type 21
common-battery subset with bells
enclosed in a louvered metal cabinet.

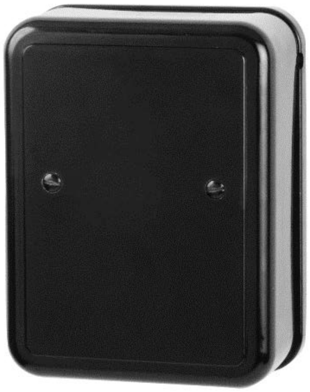

Fig. 12-11. Automatic Electric Type 32
compact common-battery subset
in a louvered bakelite box.

Kellogg and Stromberg-Carlson made similar common-battery subsets. Figure 12-12 shows a Kellogg No. F602 subset with a No. 99-A coil, and Fig. 12-13 shows a Stromberg-Carlson No. 1156 subset with a No. 44B coil. Both of these subsets have the same booster circuit, which was developed and used by Western Electric, and even the terminal markings are similar (see Chapter 16). Kellogg and Stromberg-Carlson also introduced anti-sidetone circuits in these same metal boxes. Kellogg's No. F610 anti-sidetone subset used a No. 103-A coil in a circuit that Kellogg called the Triad. Stromberg-Carlson's No. 1230 anti-sidetone subset used a No. 46A coil in yet a different circuit. Although not identical to the Western Electric circuits, the Automatic Electric, Kellogg, and Stromberg-Carlson circuits were similar to Western Electric's. All are described in Chapter 17.

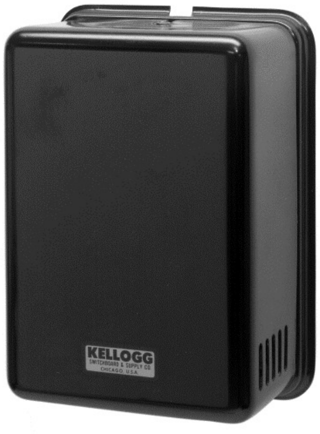

Fig. 12-12. Kellogg No. F602
common-battery subset with bells
enclosed in a louvered metal cabinet.

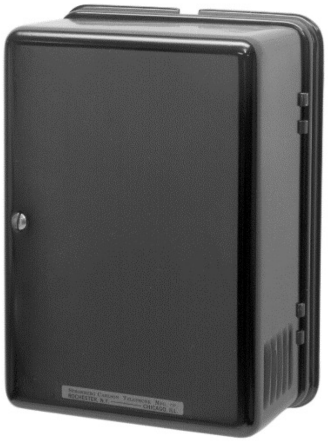

Fig. 12-13 Stromberg-Carlson No. 1156
common-battery subset with bells
enclosed in a louvered metal cabinet.

Compact Wall Phones

Wall phones were also made from most of the ringer boxes and subsets just described, and these are sometimes called hotel phones. Figure 12-14 shows a Western Electric No. 305 local-battery phone made from a No. 300 ringer box. This telephone was available with a 3-bar or a 5-bar magneto as no counterpart wall phone was made from the smaller No. 315 ringer box because there was no room in that box for a hook switch. The telephone shown in Fig. 12-14 has a 3-bar magneto and its characteristic short crank. Although similar to the single-box magneto wall phones, the compact wall phones did not house their own batteries, which had to be placed in another location on the premises.

The Western Electric No. 293 common-battery phone shown in Fig. 12-15 is the counterpart of the No. 295 subset with the booster circuit. This particular telephone is also housed in a walnut cabinet. Figure 12-16 shows a later Western Electric No. 653 anti-sidetone phone based on the No. 634 subset. This phone has the same bulldog transmitter (F1 capsule) and element-style receiver (HA1) as the 100-series candlesticks and the No. 417 magneto wall phone.

Figure 12-17 shows a Kellogg No. F817 telephone that was derived from the Kellogg No. F602 subset. This particular phone has the earlier No. 79A coil. In all cases, the transmitters and receivers on these compact phones are exactly the same ones used on the candlestick desk stands that are normally paired with the corresponding subsets.

Fig. 12-14. Western Electric No. 305 local-battery magneto phone based on the No. 300 ringer box.

Fig. 12-15. Western Electric No. 293 common-battery phone with the old transmitter and booster circuit based on the No. 295 wooden subset.

Fig. 12-16. Western Electric No. 653 common-battery phone with bulldog transmitter and anti-sidetone circuit based on the No. 634 subset.

Automatic Electric made several phones of this type and one is shown in Fig. 12-18. This Type 60 wall phone uses the box of the Type 21 subset plus a raised base to house a complete telephone with both a dial and a magneto. This is a rather recent phone that uses the Type 41 handset, which appeared first on the popular Type 40 desk telephone (next chapter). Several local-battery circuits were available in the Type 60 wall phone, and the circuits are described in Chapter 18. This arrangement, with both a magneto and a dial, was often used in railroad systems. Code ringing with the magneto could be used to signal other parties on the line, and the dial could be used to make connections through the central office.

Fig. 12-17. Kellogg No. F817 common-battery phone based on the F602 subset.

Fig. 12-18 Automatic Electric Type 60 local-battery phone in the box of a Type 21 subset with a raised base, a magneto, and a dial.

Finally, Fig. 12-19 shows the Northern Electric No. N717 local-battery magneto wall phone, which is the counterpart of the N500 anti-sidetone ringer box (not shown). This phone uses the F1 handset, the No. 104A induction coil, a B-type ringer, and the little 41BN magneto. This is also a rather recent phone, which uses the F1 handset and B-type ringer that were designed by Western Electric for their No. 302 telephone (next chapter).

Fig. 12-19. Northern Electric No. N717 local-battery phone based on the No. N500 ringer box.

Western Electric's Specialty Phone

Western Electric manufactured a portable local-battery telephone for use by radio broadcasting personnel and other field technicians who needed temporary communications. The earlier No. 331A version of this phone is in a textured olive-colored metal box and uses components very similar to those in the N717 just described. The F-type handset has a push-to-talk switch to save battery current, the B-type ringer is installed without gongs for muted signaling, and a bee-hive neon signaling lamp is provided for silent signaling. The No. 104 induction coil is used in the usual bridge-type anti-sidetone circuit. The later No. 331B specialty phone, manufactured after April, 1978, is in a similar metal box that is painted light blue and is shown in Fig. 12-20. This phone has a G-type handset with a push-to-talk switch, a bee-hive neon lamp for silent signaling, and a P-type ringer like that used in the Trimline telephone (see Chapter 14). This phone uses a very interesting circuit, also borrowed from the Trimline, and the circuit is on a small printed circuit board (see Chapter 18). Both sets use the small Canadian 41BN magneto generator with modified switch contacts; both sets are equipped with a switch to turn off the ringer; and either set can be equipped with a No. 52 operator's headset instead of a handset. These sets use two regular D-size flashlight batteries (3 volts) instead of the large dry cells.

Fig. 12-20. Western Electric No. 331B portable telephone with a neon lamp for silent signaling.

Chapter 13
Combined Telephones of the 1930s and 1940s

Until the mid-1930s, telephone components were still too large to fit inside a single desk set. However, some progress in size reduction had been made in the small subsets of 1930. And, as manufacturing techniques improved, condensers continued their trend toward smaller sizes, compared with the large turn-of-the-century condensers. Ironically, it was the size of the condenser that was a major impediment. To overcome this, the Bell Laboratories made a surprising change in ringer design that permitted the use of a smaller condenser.

As the industry moved into the era of more compact telephones, common-battery systems were becoming dominant. The generation of desk telephones that combined the features of a desk stand and a subset was thus designed principally for common-battery service, although models for local-battery service were provided.

Western Electric Desk Telephone

Three components had to be moved from the subset into the base of the new No. 302 “combined” telephone (Fig. 13-1): the coil, the ringer, and the dual condenser. The previous common-battery, anti-sidetone circuit was left unchanged, so the No. 101A induction coil, which was already rather compact, was used without modification. The ringer, however, was completely redesigned, and the new B-type ringer (see Chapter 6) was somewhat more compact. Interestingly, though, most of the reduction in ringer dimensions was caused by the smaller gongs (1¾-inch diameter compared with 2 5/16).

Fig. 13-1. Western Electric No. 302 combined telephone of 1937
with a die-cast metal housing, ***U.S. Postal Service photo***.

The surprising change in the new design was in the ringer's coil impedance, which was more than doubled. By roughly doubling the inductive impedance of the ringer, a condenser half the previous size could be used in the ringing circuit (see Chapter 6). Thus, the previous dual condenser (2 microfarad for the receiver circuit, 1 microfarad for the ringer circuit) was replaced by a new, smaller dual condenser (2 microfarad for the receiver circuit, ½ microfarad for the ringer circuit). Because the ringer circuit sees a high voltage, which requires a heavier insulation in its condenser, most of the bulk was in that part of the dual unit. The net result was a 60-percent reduction in size from a little over 5½ cubic inches to a scant 2¼ cubic inches in volume for the new dual-condenser unit.

The No. 302 combined telephone was installed on a trial basis in 1936 and went into production in 1937 (AT&T Bell Labs 1936; Jones 1938). The three transposed components (coil, ringer, and condenser) were mounted on the base as in the subsets, whereas the 5H dial (which was interchangeable with the earlier handset dials), the hook switch, and a dial-pulse radio interference filter (when needed) continued to be mounted in the housing as in the earlier desk stands. This mixed method of construction required the base and the housing to be connected by wires. To prevent damage to these wires, a cloth strap, or strain relief, was used to loosely hinge the housing and base together.

The Bell System continued an interest in the appearance of its telephones, and in 1930 a young industrial designer, Henry Dreyfuss, was hired as a consultant to help with the design of the new combined telephone (AT&T Bell Labs 1967, 18). Although some of the features of the new design may have been influenced by Dreyfuss, the designs of both the No. 302 and the F-type handset were done in-house by George R. Lum, who was issued design patents for both.[1] Previous editions of this book as well as numerous other publications – including a 2011 U.S. Postal Service postage stamp – incorrectly give Dreyfuss credit for these designs. For a more complete description of Dreyfuss's work for the Bell System, see Flinchum and Meyer 2017. Dreyfuss went on to design such other famous objects as the Big Ben alarm clock, the Singer sewing machine, the John Deere tractor, and the 20th Century Limited streamlined train.

Early versions of the No. 302 were fitted with cloth cords, used a die-cast metal housing, and were very heavy (the metal 302 in Fig. 13-1 weighs 6¼ pounds, a full 2 pounds heavier than the later plastic 500-type telephones). Later versions of the 302 phone were fitted with rubber cords and used a lighter, organic thermoplastic housing. The new F1 handset was much simpler in construction than the previous E1 handset, because it had only three bakelite parts: a solid handle with simple transmitter and receiver covers. Tools were not usually required for disassembly as for the E1. The F1 transmitter capsule, which had been backfitted to the E1 handset in 1934, continued in use; however, a new HA1 receiver element was used in the F1 handset. Both the transmitter and receiver elements simply slipped into place under their respective covers and did not require extra screw threads or fittings as before.

Special attention had even been given to the gongs on the new B-type ringer (Wiebusch 1942). To achieve a pleasing sound with these smaller gongs, a frequency ratio of five:four was chosen (a major-third musical interval of 2,000 and 1,600 cycles per second). And an optional gong attachment called a Helmholz resonator could be used to increase the sound level of the fundamental frequencies because the normally louder overtones are beyond the range of good hearing sensitivity. The amount of research at the Bell Laboratories going into all aspects of telephone design by the 1930s was impressive.

Non-dial telephones were still in large demand. As with the handset desk stands before, the non-dial version of the 300-type telephone, shown in Fig. 13-2, was made by merely replacing the dial with a blank cover. In a continuing trend toward standardization of the product line, the new dial blank contained a terminal strip underneath, and the terminals were marked just like those on a dial. When the wiring leads for the dial were connected to those terminals, the non-dial circuit resulted.

Fig. 13-2. Western Electric No. 302 non-dial telephone, made by substituting a blank cover for the dial.

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[1] George R. Lum, "Desk Stand for a Hand Telephone," Patent No. Des. 95,765, dated May 28, 1935; application filed March 27, 1935. George R. Lum, "Hand Telephone," Patent No. Des. 95,915, dated June 11, 1935; application filed April 25, 1935.

Fig. 13-3. Western Electric No. 299F hand generator -- a large magneto in a wood cabinet.

Although non-dial sets were widely used on common-battery lines with manual switchboards, some local-battery service was still maintained with these sets. Substituting appropriate wiring and a No. 104A coil, produced the No. 307 local-battery desk telephone. The No. 104A coil used the same closed-flux frame and mounting hardware as the No. 101A coil, yet it is electrically similar to the No. 113 local-battery anti-sidetone coil (properties of all of these coils are described in Part Three). A No. 299 hand generator box with the large No. 48A magneto is shown in Fig. 13-3 and was used with the 307 telephone to provide for outbound signaling.

An interesting variation of the No. 307 local-battery telephone was used on long common-battery lines. For those lines, a mixed mode of local-battery talking and common-battery signaling was often used, and the No. 307 telephone for that service had a dial. Relays at the central office were able to respond to the weak dc current pulses from dialing, but the direct current was too small, because of high line resistance, to produce a strong voice signal. Further, the local-battery circuit produced a voice signal that was almost twice as large as that of the common-battery No. 302, even under ideal circumstances. Thus, the No. 307 (with local batteries) made a powerful phone for remote locations. To accommodate this type of service, the Western Electric 307 incorporated several extra condensers and a No. 266A retardation coil to keep direct current out of the receiver. This circuit is described in Chapter 18.

One other variant of this new phone was the No. 250 desk stand. This was, in effect, an empty No. 302 -- no coil, ringer, or condenser. It was made as a replacement for the earlier candlestick and handset desk stands and could be used in either common-battery or local-battery service.

Western Electric Wall Phone

Western Electric also introduced a handset wall phone using the smaller components of the 300-type telephone.[2] This Western Electric No. 354 wall phone is shown in Fig. 13-4. By the time this telephone was introduced, all Western Electric telephones were being made with thermoplastic housings. The dial was now a model No. 6, which is still interchangeable with earlier handset dials. A dial blank could also be used here to produce a non-dial version of the 354 wall phone. It is interesting to see that the louvers in the side of this wall phone are identical to those in the small bakelite subsets, showing again the Bell System's tendency toward standardization.

A precursor to the No. 354 wall phone was made by Western Electric in 1932 and used the E1 handset.[3] That early wall phone had the same general format as the 354, although its bakelite housing was rather large (2½ inches taller) because of the large ringer and condenser. This phone was a field-trial model, and examples of it are rarely found today.

Finally, just as Western Electric had provided the No. 250 replacement desk stand, they provided a counterpart upgraded space saver with the F1 handset. This G-type space saver is shown in Fig. 13-5. Like the earlier C-type space saver, a very compact non-dial version is made by removing the dial and its mount and snapping the number-card holder into the exposed hole as shown in Fig. 13-6.

Fig. 13-4. Western Electric No. 354 handset wall phone with a thermoplastic housing.

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[2] George R. Lum, "Wall Mounting for a Hand Telephone," Patent No. Des. 152,276, dated Jan.4, 1949; application filed Dec. 9, 1947.

[3] George R. Lum, "Wall Mounting for a Hand Telephone," Patent No. Des. 85,107, dated Sept. 15, 1931; application filed Aug. 1, 1931.

Fig. 13-5. Western Electric G-type wall-mounted space saver with a surface-mounted dial atop a die-cast metal pedestal.

Fig. 13-6. Western Electric G-type non-dial space saver with the number-card holder covering the dial-mount opening.

Automatic Electric Combined Telephones

Fig. 13-7. Automatic Electric Type 34 combined telephone of 1934 with a bakelite housing.

Automatic Electric introduced a combined desk telephone in 1934 utilizing the handset from the Type 1A Monophone, and this Type 34 telephone with a bakelite housing is shown in Fig. 13-7. It is sometimes called the Shirley Temple telephone because of a prominent 1938 advertisement celebrating the local telephone company's 100,000th phone installation in the home of the famous child star. The companion Type 35 wall phone was introduced in 1935 with the new Type 35A7 non-positional transmitter. This phone is shown in Fig. 13-8, and it is sometimes called the juke-box phone because of its shape. Both of these phones used an open-core cylindrical coil with a Triad-type circuit that is described in Chapter 17.

Just prior to World War II, Automatic Electric introduced updated versions of these phones with a new Type 41 handset. The handset contains a re-packaged version of Automatic Electric's non-positional transmitter and a new drop-in Type 41 receiver element. A Type 40 desk phone with optional chrome features is shown in Fig. 13-9 and a relatively plain Type 50 wall phone is shown in Fig. 13-10. A new semi-closed-core coil was used in these phones with a circuit that is like Western Electric's anti-sidetone circuit. Because these phones were frequently used on party lines, a mechanical latch on the hook

Fig. 13-8. Automatic Electric Type 35 handset wall phone of 1935 with a bakelite housing.

switch was available such that one could listen to determine if the party line was busy before drawing dc transmitter current. Such an optional device (chrome plated) can be seen under the handset in Fig. 13-10.

Fig. 13-9. Automatic Electric Type 40 combined telephone with a new handset, improved circuit, and a bakelite housing.

Fig. 13-10. Automatic Electric Type 50 wall phone with the new handset, improved circuit, and a bakelite housing.

Automatic Electric also made a Type 43 space saver that used the new Type 41 handset as shown in Fig. 13-11. This space saver was housed in a die-cast metal case. Unlike Western Electric's space saver, the Automatic Electric Type 43 contains all the components except the ringer. It is thus a complete telephone and does not require a subset, although a nearby ringer would be needed in another phone or in a separate extension ringer box.

Fig. 13-11. Automatic Electric Type 43 space saver with all components except a ringer in a die-cast metal housing.

Local-battery versions of the Type 40 and Type 50 telephones were also available. Anticipating that local-battery service would soon be converted to common-battery service, these telephones had a clever circuit modification that permitted conversion to the usual common-battery circuit by simply relocating one wire. This circuit is described in detail in Chapter 18. A local-battery Type 40 or Type 50 would usually be provided with a dial blank instead of a dial, and a special magneto box was required. This box, with a plastic cover, is shown in Fig. 13-12 and contains a small magneto like Northern Electric's No. 41BN, a retardation coil, and two dry cell batteries. The magneto box was simply removed when the phone was converted to common-battery service.

Fig. 13-12. Automatic Electric magneto box with a retardation coil, batteries, and a plastic cover.

Kellogg Combined Telephones

Kellogg, during this period, produced several telephones that used variations of the handset first introduced on their No. 700 desk stand. All of the phones with this handset were called Masterphones and contained Eaton's non-positional transmitter and the No. 89A receiver. The first of Kellogg's combined telephones were the No. 900 non-dial telephone (called the pyramid phone) shown in Fig. 13-13 and the No. 925 dial telephone (called the ash tray phone) shown in Fig. 13-14. Both used a rather large closed-flux No. 106 induction coil, although the No. 106 coil in the 925 telephone has an extra terminal for adjustment purposes. As with earlier Kellogg desk stands, the dial and non-dial models were built with different housings, both of which were a little larger than Western Electric's No. 302.[4] These phones were introduced in 1933 and 1935, respectively, somewhat earlier than when Western Electric introduced its first combined telephone.

Fig. 13-13. Kellogg No. 900 Masterphone combined telephone of 1933 with a bakelite housing and no provisions for a dial.

Fig. 13-14. Kellogg No. 925 Masterphone combined telephone of 1935 with a bakelite housing and a dial.

In addition to their distinctive art-deco style, these Kellogg telephones were distinguished by their all-bakelite construction. However, a consequence of their heavily sculptured lines was the loss of some useable interior space for components and wiring. Further, the ringer in these phones was of the older standard design (not like Western Electric's B-type ringer), with small diameter gongs and a 1-microfarad condenser. Thus, the inside of these two telephones was very crowded. This problem was remedied in Kellogg's next design.

A final model of the Masterphone series was the Kellogg 1000 telephone, which went into full production in 1947. Figure 13-15 shows this telephone with a dial, and Fig. 13-16 shows a non-dial version; finally, Kellogg had produced a single telephone housing with interchangeable parts for its dial and non-dial telephones. The No. 1000 telephone, also with a bakelite housing, was known as the Kellogg red-bar phone because of the bright red bar that operated the hook switch (instead of the more familiar round plungers). This red bar is quite visible when the handset is off the hook, as shown in Fig. 13-16.

Several features of the Kellogg 1000 telephone are noteworthy. First, its simple shape provides more interior space than the previous two models, and this space is used more efficiently. To avoid the tangle of wires present in those earlier models, a molded one-piece interconnecting block was used.[5] The plunger-operated hook switch and all interconnections were located inside this block, but this was not like the networks that were to come later; both the coil and the condenser were external components that plugged into the connecting block in the same manner that vacuum tubes plug into an old radio.

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[4] However, Kellogg did use a dial blank in some of its No. 925 telephones to make an equivalent non-dial telephone.

[5] Western Electric avoided this problem substantially by mounting the connecting terminals right on the coil, rather than running multiple coil wires to a common terminal block.

Fig. 13-15. Kellogg No. 1000 Masterphone combined telephone of 1947 with a bakelite housing.

Fig. 13-16. Kellogg No. 1000 non-dial Masterphone with handset removed to show the red bar hook switch plunger.

The second notable feature of the wiring of the Kellogg 1000 was that two different coils were available. The No. 113 coil produced a common-battery, anti-sidetone circuit, whereas the No. 114 coil produced a local-battery, anti-sidetone circuit. Thus, the non-dial telephone shown in Fig. 13-16 could be converted for local-battery service by plugging in the No. 114 coil and using the phone in conjunction with a No. 1200 hand generator (magneto) box. This box, shown in Fig. 13-17, is actually made of wood, but it is painted black to match the black bakelite finish of the telephone.

The Kellogg 1000 was available in two additional styles: a wall phone, and a desk set with a small magneto in the base. The latter was almost identical to the phone in Fig. 13-16 (except for a hole in the housing for the magneto crank), perched on top of an additional 1¾-inch base. This arrangement is similar to the Stromberg-Carlson telephone in the following section.

Fig. 13-17. Kellogg No. 1200 hand generator -- a large magneto in a black painted wood cabinet.

Stromberg-Carlson Combined Telephones

Stromberg-Carlson's first combined telephone, the No. 1212 shown in Fig. 13-18, was introduced around 1936 using the same handset as on the No. 1197 and No. 1198 desk stands. Like the early Kellogg combined telephones, the No. 1212 used a standard ringer with relatively small gongs and a 1-microfarad condenser. To hold all the components, the bakelite housing was made rather large, giving rise to its nickname, fat Stromberg.

Similarities to the earlier Stromberg-Carlson No. 1198 desk stand are apparent, and the same single-plunger (in the center) handset cradle was used on both. The No. 1212 phone contained the very small No. 45A induction coil of the closed-flux type and had an anti-sidetone circuit that was not used in subsequent models. This phone was not very popular, especially after the No. 1222 came out, because the bakelite ears of the handset cradle were prone to breaking if

Fig. 13-18. Stromberg-Carlson No. 1212 combined telephone circa 1936 with a bakelite housing.

the phone was dropped. The earlier desk stands that used this cradle were lighter (no coil, condenser, or ringer) and were less susceptible to breakage.

Fig. 13-19. Stromberg-Carlson No. 1243 combined telephone of 1946 with a die-cast zinc housing.

Around 1940, Stromberg-Carlson developed the very successful No. 1222 to answer Western Electric's No. 302. The No. 1222 is identical in external appearance to the later No. 1243 shown in Fig. 13-19. Its housing was made of die-cast zinc and it is, except for some corner cutting, quite similar in appearance to the Western Electric 302. The new handset on the No. 1222 is very similar to Western Electric’s F1 handset and contains a non-positional transmitter and a new No. P-34230 drop-in receiver. The No. 1222 contains a No. 46A coil that is small and similar to the No. 45A coil in appearance; however, the 46A provides a different circuit that is used in several later models as well. This circuit, as can be seen in Chapter 17, is almost identical to the Western Electric anti-sidetone circuit. With these similarities in circuit design and appearance, it is not surprising that the Bell System bought many of these No. 1222s after World War II when their exclusive supplier, Western Electric, was unable to meet the demand for 300-type telephones.

The No. 1222 and later 1200-series models all had a hinged plate in the cradle under the handset. This plate could be used for two-step hook switch operation for party lines, just as with the Automatic Electric hook switch latch. On the Stromberg-Carlson phones, activation of this feature required bending a tab on the mechanism and making a wiring change to form a complete circuit through the receiver before transmitter current was established.

In early 1946, Stromberg-Carlson updated the No. 1222 with a true network circuit, forming the No. 1243 telephone. Wall-mounted models of this phone were also available. Stromberg-Carlson thus produced a network circuit a full three years before Western Electric would do so in their 500-type telephone. Several variations of this network were used in the No. 1243 phone and the later No. 1543 phone (described in the next chapter). At least two of those networks (the No. 200595 and the 210558) have an extremely clever design. The coil in those networks has an extra tap and is wound in such a way that one combination of tap connections results in a common-battery anti-sidetone circuit, whereas another combination results in a local-battery anti-sidetone circuit. Therefore, the very same telephone -- with no parts substitutions whatsoever -- could be connected for either common-battery or local-battery service, thus simplifying the company's parts inventory.

Stromberg-Carlson made the same provisions for a magneto as did Kellogg; that is, either a separate magneto box (No. 1268, not shown) could be used with the No. 1243 telephone, or a base-mounted magneto could be provided, as shown in Fig. 13-20. The combined desk set and base-mounted magneto is called the No. 1248 desk telephone.

It is interesting to observe, at the end of this art-deco period of great diversity, that all the phones began to look alike -- the Western Electric 302, the Automatic Electric Type 40, the Kellogg 1000, and the Stromberg-Carlson 1243. This is particularly noteworthy because many were to become exactly the same (i.e., standardized) in the following post-war period.

Fig. 13-20. Stromberg-Carlson No. 1248 local-battery desk telephone with a compact magneto in an enlarged base.

Chapter 14
Standard Rotary Dial and Touchtone Telephones

Western Electric 500-Type Telephones

By the end of World War II, advances in scientific principles and new materials had been sufficient to justify integrating these features in a new model (AT&T Bell Labs 1949a and 1949b). Thus, the new 500-type telephone set was introduced in 1949; it is shown in Fig. 14-1 and its non-dial configuration is shown in Fig. 14-2. With technical developments provided by the Bell Laboratories and exterior design provided by Henry Dreyfuss, this telephone became the industry standard in more ways than just a figure of speech.

The 500-type telephone incorporated a number of innovative features -- including a user-friendly dial, a smaller handset, a volume control on the ringer, a plastic housing that served only as a cover (exposing, when removed, all components mounted on the base), and a network package containing most of the electrical components of an improved circuit (Neisser 1951).

Fig. 14-1. Western Electric 500-type telephone introduced in 1949 with removable thermoplastic housing, outboard dial numbers, and metal finger wheel (later clear plastic).
Photo courtesy of the Gregg Museum of Art & Design.[1]

The new network package, called the No. 425A, was just 2½ inches long, 1⅞ inches wide, and 1½ inches high and is shown in Fig. 14-3. This network contains the coil, a resistor, and condensers for the talking circuit, the ringing circuit, and the dial-pulse radio interference filter. Gone are discrete components mounted individually on the base. The components in the network are mounted on the bottom of a plastic terminal plate, which is permanently fastened to a heavy steel can. After assembly, the can is filled with a moisture-excluding, vibration-damping silicone compound. This compound, however, precludes disassembly and replacement of individual components, so the network is treated as a replaceable unit.

The physical size of the condensers again played a key role in achieving compactness of the 425 network. Because the new circuit in the 425 network was similar to the circuit in the No. 302 telephone, it

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[1] Gregg Museum of Art & Design, North Carolina State University, Raleigh.

still required a 2-microfarad condenser in the talking circuit and a 0.5-microfarad condenser in the ringing circuit. Although significant size reduction had been achieved in the No. 302 telephone, those condensers were still rather bulky. A new technique of fabricating condensers was used to achieve further size reduction (Wehe 1949; Evenson 1951). Rather than using foil separated by paper, the new metallized paper condensers had a thin film of metal, vacuum deposited directly on one side of the insulating paper. The metallizing process had been developed by the Germans during World War II and was seen by Bell System engineers during a post-war inspection tour. The resulting metallized paper condensers made by Western Electric were less than half the size of the conventional foil-and-paper condensers.

Fig. 14-2. Western Electric non-dial 500-type telephone, made by substituting a blank plastic cover for the dial.

The C-type ringer in the 500 telephone was also new (see Chapter 6). One design objective of the C-type ringer was the reduction of maintenance visits to adjust the loudness of the bell (Bredehoft 1951, 471). This was accomplished with a subscriber-operated control wheel, which protruded through a slot in the base, to change the gong spacing. Renewed attention was given to the sound of the gongs, again using the musical interval of a major third to produce a pleasing sound (Jenkins 1957). However, the standard frequencies for the 500 set were fixed at 1610 and 1280 cycles per second and were produced by brass gongs (other materials were used to produce different tones for multi-phone office settings). These frequencies are lower still than those in the No. 302 telephone, making the new ringer even more audible. A resonator shell (now standard) was again used to enhance the loudness of the fundamental frequencies relative to their overtones.

The exterior design of the 500-type telephone was produced by the New York firm of Henry Dreyfuss, with Dreyfuss himself still in command (Flinchum and Meyer 2017). A decade later, this telephone would be recognized as one of the ten "best designed products of modern times" in a poll of leading industrial designers (AT&T Bell Labs 1959a). More recognition would come to later Dreyfuss-designed telephones.

The dial in the 500-type phone was arranged to improve dialing accuracy and speed. To accomplish this, the numbers and letters were moved outside of the fingerwheel where they would no longer be obscured by portions of the wheel itself. In principle, a dialer could take aim at the next number while the fingerwheel was still moving, thus accelerating the whole dialing process (Prescott 1952; Donovan 1991). Ironically, extensive tests with the early design of this type showed that the dialing time was actually slower than with the older 302 set (Black and Cunningham 1954). From observing participants in the tests, it was found that the time loss occurred at the end of the period when the fingerwheel was returning to its rest position. The dialer was slow to recognize when the dial had come to rest, because no frame of reference was provided by the black fingerwheel revolving over an all-black background. This was remedied by placing a white dot at the center of each finger hole so the dialer could tell when rotation had stopped.

Fig. 14-3. Western Electric No. 425A network containing most electrical components for the talking and ringing circuits.

Incidentally, an imaginative method was used to manufacture a plastic number ring so its numbers would not be rubbed off or scratched by frequent use (porcelain on metal had previously been used). Numbers were die cut completely through a black plastic ring, and white plastic was extruded into the

Fig. 14-4. Later version of Western Electric 500-type telephone with clear plastic fingerwheel, built-in number card holder, and lighter thermoplastic handset.

cutouts. Thus, no matter how much material is rubbed away or scratched, clean number outlines remain. The dial blank for non-dial applications was a similar, simple plastic ring with no markings. No electrical terminals were mounted under this blank, as was done on the No. 302 telephone, because No. 7 dials had pigtail wires rather than screw terminals, and all connections were made on the network. Relocating just one wire on the network produced the non-dial circuit.

The handset for the 500-type telephone was all new, incorporating the T1 transmitter and the U1 receiver. The handset itself was shorter, lighter, and had a flat surface on the handle that made it easier to hold -- all important human factors considered in the Dreyfuss design. The original G1 handset for the 500-type telephones was made of bakelite with a small diameter channel (about ¼ inch minimum) running through the handle to accommodate the wiring. The later G3 handset used a thin shell of molded thermoplastic with a large open channel through the handle. With the hollow handle of the G3 handset and the higher efficiency receiver and transmitter elements, the old problem of acoustic feedback returned. To reduce this unwanted feedback, a cotton ball was inserted into the handle, and it is said that the size and weight of the cotton ball were tightly specified by Western Electric.

A minor modification was made to the 500-type telephone shown in Fig. 14-1 to produce the later, more commonplace version of this phone shown in Fig. 14-4. First, the No. 7A dial, which sounded like it had gravel in its gears, was replaced with a smooth operating No. 7C dial. This dial was fitted with a clear plastic finger wheel, and the finger wheel was soon modified to include a built-in number card holder that gave a slightly lower profile to that part of the set. The lighter G3 handset, mentioned above, was added at this time, and small round plastic feet, set back from the edges, replaced the old-style protruding pads. And in 1954, the 500-type telephone was made available in a range of decorator colors with matching spring cords (Brown 1966, 12). Surprisingly, these minor changes gave a much more modern feel and appearance to today's 500-type telephone.

Wall phones had remained popular, so in 1956 a wall phone version of the 500-type telephone was made that utilized all of the components developed for the desk set. This wall phone, the No. 554, is shown in Fig. 14-5, and a non-dial version with a dial blank was also available. An interesting design detail of this phone is the pair of creases in the top surface of the housing. These shoulder creases, absent from the earliest version, were added at the Dreyfuss firm by a student intern, Donald Genaro, whose major design achievement was still in the future. The creases were added to provide an off-hook rest for the handset, a fact that is little known because user instructions were never provided.

Fig. 14-5. Western Electric No. 554 wall phone with shoulder creases on top of a removable plastic housing to provide an off-hook rest for the handset. ***Gregg Museum of Art & Design.***

Industry Standardization

After three-quarters of a century of fierce competition between the Bell System and the independent companies -- and, not incidentally, after two world wars and a raging Korean conflict -- an event took place that lead to much standardization in the American telephone industry. Heralded only by a two-paragraph note in Telephony magazine, a cross-licensing patent agreement was concluded on June 7, 1951, between Western Electric (for itself and AT&T) and International Telephone & Telegraph Company (ITT and its subsidiaries) (Telephony 1951a).[2] The agreement was intended "to strengthen the technical leadership of the free world" and it permitted each company to use the other's patents.[3]

Two months later on August 9, 1951, ITT made a large purchase of Kellogg stock, eventually acquiring control of that company (Telephony 1951b). Kellogg briefly manufactured a K-500 look-alike set (described below), but soon Kellogg produced a completely standardized 500-type telephone like the Western Electric phone shown in Fig. 14-4. The Kellogg telephone has a mixture of ITT and Kellogg markings on the housing, the handset, and the dial, but its parts are identical in appearance and interchangeable with those in the Western Electric 500-type telephone. Even the cotton ball is present in the G3 handsets of the non-Western Electric telephones.

Stromberg-Carlson also produced a 500-type look-alike phone (see below), but eventually switched over to a standard 500-type telephone in the 1960s. From this point on, the distinction between Western Electric telephones and many of its competitors' sets largely disappeared.

Fig. 14-6. Northern Electric No. 41BN compact magneto in a small wall-mounted plastic housing.

Northern Electric, Western Electric's counterpart in Canada, generally made equipment that was like Western Electric's. However, long rural lines were still widespread in Canada, so Northern Electric made a line of local-battery, 500-type telephones. Desk sets (No. 500Q1A, 500Q2A, and 500Q3A) and wall phones (No. 554Q1A, 554Q2A, and 554Q3A) were available with and without dials for either ringing with a magneto or for common-battery signaling. In fact, some service used both a magneto and a dial. For that kind of service, code ringing with the magneto was used for other parties on the line, while the dial was used for parties connecting through the central office.

The same circuit was used for the 500-type local-battery phones as for the Western Electric No. 307 telephone, but most of the components were mounted in a network, appropriately designated No. 425Q1A. The companion No. 41BN wall-mounted magneto (less than 4 inches high) is shown in Fig. 14-6 with a plastic housing for separate mounting. The local-battery desk set and the wall phone look just like the standard 500 and 554 telephones.

Fig. 14-7. Western Electric No. 5302 conversion of a No. 302 telephone, made to look like a 500-type telephone.

500-Type Look-Alikes

Early Western Electric telephones had an engineered service life of twenty years, so when the 500-type telephone was introduced in 1949 many of the older 302s were still quite serviceable. To satisfy the post-war demand for a

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[2] No mention at all was made in another national telephone magazine, Telephone Engineer and Management.

[3] A pending anti-trust suit against Western Electric and AT&T filed by the U.S. Department of Justice in 1949 might have also played a role in this matter.

modern-looking telephone and protect their investment, in August 1955 Western Electric started converting its 302s to make them look like 500s (AT&T Bell Labs 1956a). Figure 14-7 shows one of these converted telephones, called the No. 5302. At first glance this phone is hard to distinguish from the phone in Fig. 14-1, but all of the working parts are those of a 302. The handset is a modified G-type handset that accommodates the earlier F1 transmitter and HA1 receiver. Even the dial is the older No. 6 dial surrounded by a plastic ring carrying outboard numbers that make it look like a No. 7 dial. The body of the 5302 is a little shorter than the 500-type body (chopped off at the back) because the 302 set had a smaller footprint.

Fig. 14-8. Stromberg-Carlson No. 1543 update of the No. 1243 telephone, with a new dial to look like the 500-type telephone. Alternate hook switch plungers convert this desk set to a wall phone.

Similarly, Stromberg-Carlson had a good durable design in its No. 1243 telephone. It had circuitry inside a network, not unlike the Western Electric 425 network, and its circuit was equivalent to that of the Western Electric 302 telephone. Thus, there was no problem of impedance matching with Western Electric equipment, and Stromberg-Carlson's first response to the Western Electric 500 was rather superficial. An outboard-number ring was added to their dial along with a new plastic housing that rounded out the lines of the No. 1243. This Stromberg-Carlson No. 1543, shown in Fig. 14-8, looks similar to the 500 telephone, although retaining some of the old Stromberg-Carlson style (such as the clipped corners on the base). However, other components are the same as those of the No. 1243 telephone.

It is worth noting that Stromberg-Carlson achieved a degree of versatility with this phone that was not reached by others. With an alternate set of hook switch plungers (shown beside the phone in Fig. 14-8), this desk phone could be converted to a wall phone (dial on top, handset on bottom). Further, like the No. 1243, the network circuit could be changed from a common-battery type to a local-battery type by merely reconnecting hook-up wires to different terminals. This concept did not catch on, though, and the No. 1543 eventually gave way to the standard 500 design.

Kellogg's situation was different. Although the K-1000 red-bar phone is remembered as a classic design, it had its practical shortcomings. Its bakelite body was susceptible to breaking, it did not have a compact network circuit, and its circuit was not quite as good as the others (see Chapter 17). Thus, Kellogg switched quickly to all-500 technology, but interestingly, used a thermoplastic housing and a bakelite handset that were shaped differently from the 500 telephone. Figure 14-9 shows this Kellogg K-500 telephone (this particular set was manufactured in 1954) with its bulges around the dial and its bulbous handset. While Kellogg tried to retain some of its own identity on the outside, every working part inside the K-500 was of the Western Electric design: T1 transmitter, U1 receiver, No. 7 dial, No. 425 network, and C-type ringer. Even the base was identical in all respects to the base of a Western Electric 500 and could have been fitted with a 500-type plastic cover. Kellogg soon transitioned to the standard 500-type design for the entire phone.

Fig. 14-9. Kellogg K-500 telephone, a genuine 500-type telephone underneath, with a different plastic housing and handset handle to distinguish it from the Western Electric telephone.

Fig. 14-10. Automatic Electric Type 80 telephone with many 500-type similarities.

Fig. 14-11. Automatic Electric Type 90 wall phone with many 500-type similarities.

Automatic Electric's Type 80 telephone is also very similar in appearance to the Western Electric 500-type phone, but it contains a mixture of Automatic Electric and Western Electric technologies (see Fig. 14-10). Automatic Electric retained its transmitter and receiver designs, but housed them in a handset that is very similar to Western Electric's G1 handset. Early Type 80s used the same dial as the older Type 40 telephone and added a separate extended number ring in a manner similar to Western Electric's 5302 telephone. The Type 80 had a network circuit in a package that was quite different from the package for Western Electric's 425 network, but the circuit inside was basically the same with minor modifications (see Chapter 19). Automatic Electric's companion wall phone was called the Type 90 and is shown in Fig. 14-11. Automatic Electric produced later versions of the Type 80 telephone, but they never switched to the standard 500-type design.

Standard Touchtone Telephones

Fig. 14-12. Western Electric No. 1500 touchtone telephone, introduced in 1963 with 10 buttons (later, with 12 buttons, redesignated the No. 2500).

Touchtone telephones were introduced into general service in 1963 after several years of development. The push-button unit with its transistor oscillator was originally designed to fit into the shell of the 500-type telephone, and experimental units with a round touchtone key pad were placed in trial service in 1959 (AT&T Bell Labs 1959b). Subsequent market trials conducted over a two-year period were very successful and the new desk set, as shown in Fig. 14-12, was introduced in the latter part of 1963 (Hiatt 1963). Although this telephone retained most of the design features of the 500-type phone, the front portion was redesigned by Donald Genaro at the Dreyfuss firm and received a removable flat plate that surrounded the touchtone dial. The set in Fig. 14-12 (manufactured in 1965) was typical of the early touchtone sets having just 10 buttons, replacing, one for one, the 10 finger holes in a rotary dial. The 10-button desk sets (No. 1500) were later replaced by 12-button sets (No. 2500). The touchtone desk set used the same handset, ringer, and similar No. 425 network as in the 500-type telephone; only the rotary dial was replaced, and the housing was slightly re-shaped to fit the square outline of the touchtone key pad.

Fig. 14-13. Western Electric No. 2554 wall phone with 12 buttons (introduced in 1963 with 10 buttons as the No. 1554). ***Gregg Museum of Art & Design photo.***

By the end of 1963, the Bell System also introduced a touchtone wall phone (AT&T Bell Labs 1963b). This phone is significantly smaller than the No. 554 rotary dial wall phone. The size reduction was achieved by re-configuring the electrical components of the No. 425 network in a No. 4010 network (broader, with a lower profile) and using a smaller M-type ringer. This little ringer can be described as a miniature version of the C-type ringer with a single gong. Later, the M-type ringer in this phone was replaced by the P-type ringer that was designed for the Trimline telephone. The wall phone was first introduced with a 10-button key pad (No. 1554). A later version of this phone with a 12-button pad (No. 2554) is shown in Fig. 14-13. Notice that this design also provides a way of parking an off-hook handset.

Kellogg and Stromberg-Carlson also made touchtone desk phones and wall phones that were identical in appearance to Western Electric's No. 2500 and No. 2554 phones, and the parts were all interchangeable. There were some minor manufacturing differences, though, as both Kellogg and Stromberg-Carlson tended to use more printed circuit boards with push-on connectors, rather than potted networks with screw terminals. It is interesting to observe that standard telephone spade lugs, which are used with screw terminals, also push into the female push-in connectors, which grip the spade lugs on their sides.

Two variants of the standard wall phones were also made. A touchtone version of the larger No. 554 rotary dial phone was made by Stromberg-Carlson (No. 554 TD), Kellogg (No. 3554), and Western Electric (No. 2554 CONVERTED). This touchtone version has the same housing as a No. 554 wall phone, but there is a round plastic insert in the dial location with cutouts for the buttons of a standard touchtone dial pad. The Stromberg-Carlson touchtone telephone is shown in Fig. 14-14. Stromberg-Carlson additionally made a rotary dial version (No. 1654) of the smaller touchtone wall phone (Nos. 1554 and 2554). The housing of this rotary dial version has a 3-inch round cutout for the dial, although the housing is otherwise the same as that of the touchtone telephone. This Stromberg-Carlson rotary dial telephone is shown in Fig. 14-15.

Fig. 14-14. Stromberg-Carlson No. 554 TD touchtone version of the standard No. 554 rotary-dial wall phone.

Fig. 14-15. Stromberg-Carlson No. 1654 rotary-dial version of the standard No. 1554 and No. 2554 touchtone wall phones.

Fig. 14-16. Automatic Electric Type 80 touchtone telephone with many 2500-type similarities.

Automatic Electric did not conform to industry standardization that was underway at that time, and they manufactured their own touchtone design. This touchtone phone, also called a Type 80, is shown in Fig. 14-16 and it is very similar in external appearance to the Western Electric design. The touchtone dial, which they called a touch-calling unit, uses the Western Electric circuit. As with other parts, however, the touchtone dial is not interchangeable with the Western Electric dial. Automatic Electric later made a light-weight plastic telephone with the squared-off shape of the touchtone Type 80 and called it the Type 80E. The Type 80E was available with either a touchtone dial or a rotary dial. Automatic Electric's counterpart to the compact No. 2554 touchtone wall phone was a variant of their Princess-type telephone, which is described in the next section.

Western Electric made a chrome-plated switch hook for their G-type space saver (see Fig. 13-5) to hold the new G-type handset. They also made a touchtone dial package that would fit on top of the G-type space saver. These updated G-type space savers were used with a No. 685 subset that had a No. 425 network, a C-type ringer, and a plastic cover without any louvers. Other manufacturers made similar space saver phones of this vintage, but when the compact touchtone wall phones came out, the space savers lost their special place in the market.

Princess-Type Telephones

Although the Bell System had paid a lot of attention to human factors in its telephones over the years, all its phones had been utilitarian in appearance since the turn of the century. The Princess telephone changed that tradition (Fig. 14-17). This graceful little telephone, introduced in 1959, was intended for the bedroom and had a lighted dial for nighttime use (Brown 1966, 13). The light was powered by a plug-in transformer located on the premises, and the two spare wires (yellow and black) of a standard line cord were used to connect this power supply to the telephone.

Fig. 14-17. Western Electric No. 701 rotary dial Princess telephone, introduced in 1959 with a clear plastic finger wheel, indented panels (front and rear), and non-modular cords.

The appearance of the Princess telephone was a radical departure from tradition, but the telephone did not depart at all from the technology of the time. The set used a standard G-type handset, a No. 495A network that was merely a re-packaged No. 425 in a more compatible shape, and a No. 8 dial that was electrically and mechanically similar to the standard No. 7 dial of the 500-type telephones. The Princess dial used the same clear plastic fingerwheel as the 500 set, but the dial numbers were brought back under the finger holes to save space.

Interestingly, the early Princess telephones did not have a ringer because there was simply no ringer available at the time that was small enough. Without a ringer, the Princess phone was very light, and lightness was desired. But in pre-production tests, it was found that the telephone was too light and would slide across a table when being dialed, so a half-pound lead weight was added for stability.

Fig. 14-18. Western Electric No. 2702 touchtone Princess telephone with indented panels (front and rear), modular cords, and 12 buttons (earlier No. 1702 with 10 buttons).

No small ringer was being developed for the Princess at that time as the phone was to be accompanied by a little wall-mounted box with an E-type ringer. That ringer was, in effect, a full-size C-type ringer with a single gong. However, the wall-mounted box was not well-received and early sales suffered, so the small M-type ringer mentioned above was eventually incorporated in the Princess phone.

The early Princess telephone shown in Fig. 14-17 had a rotary dial (model No. 701) and non-modular cords. This particular set, manufactured in April 1962, still had no ringer, about three years after introduction of the model. Later, Princess phones were made with touchtone dials (first the No. 1702 with a 10-button pad, and later the No. 2702 with a 12-button pad) and with modular cords. Figure 14-18 shows a 12-button touchtone version with modular cords manufactured in 1978.

It should be noted here that a No. 4228 network of somewhat smaller dimensions was subsequently developed as a universal replacement for the various preceding networks. And around 1983 yet another, lighter weight, No. 4293 network was produced by Western Electric. These networks can be found in later versions of the standard phones -- 500-type, 2500-type, and Princess -- but it will be seen in Chapter 19 that the same basic circuit is present in all of them.

Exterior design of the Princess was again provided by the Dreyfuss firm. Although Henry Dreyfuss was still personally involved, the lead designer for the Princess telephone was Robert Hose, with other members of the design team contributing. Genaro, who had added shoulder creases to the No. 554 wall phone, left his impression on the Princess phone as well. Indented panels in the housing (front and rear) of the Princess were added by Genaro to provide an overhang, or lip, to prevent slipping so the entire phone could be picked up with one hand straddling the handset.

Kellogg and Stromberg-Carlson, which had already started manufacturing Western Electric designs, continued the trend with their Princess-type telephones. While the design was available to the independent companies, the Princess name was a registered trademark and could not be used. Therefore, Kellogg called its Princess-type phone the Cinderella while Stromberg-Carlson called its similar phone the Petite (see Table 14-1 for a summary of the names). Model numbers were also about the same (e.g., No. K701 for Kellogg's Cinderella and No. S-C701 for

Table 14-1. Princess-type telephones

Manufacturer	Name
Western Electric	Princess
Kellogg	Cinderella
Stromberg-Carlson	Petite
Automatic Electric	Starlite

Stromberg-Carlson's Petite rotary dial phones without ringers). There were some manufacturing differences, however, and although Western Electric and Kellogg parts were interchangeable, that was not the case for some of the Stromberg-Carlson parts. Stromberg-Carlson's Petite phone was a few percent larger than Western Electric's Princess phone and none of the plastic parts were interchangeable, although the T1-type transmitter and U1-type receiver were used. The only readily noticeable appearance difference was the orientation of the dial, which was rotated about 30 degrees clockwise in the Stromberg-Carlson phone (finger stop at the 6-o'clock position).

Fig. 14-19. Automatic Electric Type 182 Starlite desk phone with an electroluminescent panel for a dial light and a power cord (110 volts ac).

Automatic Electric's similar Starlite phone was not an exact copy of the Western Electric design, but had the same general format. An early Type 182 without a ringer is shown in Fig. 14-19. This phone has an electroluminescent panel for a dial light with a power cord that plugs into a standard 110-volt ac outlet. The wheel of a rheostat protrudes through the base such that the dial light can be dimmed. Indented panels below the edge of the overhanging electroluminescent panel provide a grip to prevent slipping so the phone can be picked up with one hand, just as in the Western Electric design. A large induction coil is mounted in one end of the base and the rest of the components are mounted in a network in the other end of the base to provide weight and balance without using a lead weight.

A later Type 182A version of the Starlite phone was made without the electroluminescent panel, but with an optional dial light. The light was an electroluminescent disc that required 110-volt ac power, which was supplied through extra wires in the line cord, rather than through a separate power cord. This phone was available with either a rotary dial or a touchtone dial. The Type 182A had a light-wieght plastic base with a network on a printed circuit board. A single-gong ringer was available in the Type 182A. A wall-mounted version of this phone was also available with either a rotary or touchtone dial. A rotary dial version of this Type 192A Starlite phone is shown in Fig. 14-20. The touchtone Type 192A wall phone (not shown) was Automatic Electric's counterpart of Western Electric's small No. 2554 wall phone. The modular connector on the back of the Type 192A was not standard, however, and does not plug into an RJ11-type wall jack.

Fig. 14-20. Automatic Electric Type 192A Starlite wall phone with a ringer and a light-weight plastic base and cover.

Trimline-Type Telephones

Fig. 14-21. Western Electric Trimline desk telephone introduced in 1965 with a rotary dial and in 1966 with a touchtone pad.

Fig. 14-22. Western Electric Trimline telephone resting on the high-rise shoulders of a wall-mounted base.

It is fitting that the Trimline telephone -- the last of the standard telephones designed before the Bell System breakup -- was so successful. This loaf-shaped sculpture, shown in Fig. 14-21, is still being produced by a number of manufacturers, and has been widely acclaimed by the industrial design community.[4] The production Trimline's design was done by Donald Genaro at the Dreyfuss firm and, as might be expected, the Trimline design includes several features that can be considered Genaro trademarks. The base of the desk set has a reverse slope (wider at the top than the bottom), functionally like the panels on the Princess phone, so the entire phone can be picked up with one hand without slipping. And the wall-mounted base has high-rise shoulders that provide an off-hook perch for the handset, like the shoulder creases on the No. 554 wall phone (see Fig. 14-22). The rotary dial version of the Trimline (model No. 220) was introduced in 1965, two years after touchtone dialing was introduced, so design work on the touchtone Trimline was done in parallel. The touchtone Trimline was introduced in 1966 with a 10-button key pad (No. 1220) and later with a 12-button key pad (No. 2220) (Brown 1966, 18).

The Trimline's design, as successful as it was, was a long time in coming (AT&T Bell Labs 1963a; AT&T Bell Labs 1965; Sentenne 1965; Krumreich and Mosing 1966; Flinchum and Meyer 2017). The basic concept was borrowed from the lineman's test set, which had a small dial in the handle. The objective was to put all parts that needed to be reached by the user within the handset so the base could be kept

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[4] The Trimline phone is, for example, in the permanent collection of the Museum of Modern Art in New York, in the Smithsonian's Cooper-Hewitt Museum in New York, and in the Philadelphia Museum of Art. It was featured as one of twenty-five products, chosen as "classic" designs internationally, in Fortune magazine (May, 1977). And it is also featured in a number of books on design: Jay Doblin, ***One Hundred Great Product Designs***, (New York, 1970); Nada Westerman and Joan Wessel, ***American Design Classics***, (New York, 1985); and Kathryn Hiesinger, ***Design Since 1945***, (Philadelphia, 1983).

in an out-of-the-way place, like under a kitchen shelf. Five different models, nicknamed Demitasse, Schmoo, Contour, Trimline-I, and Trimline-II, were field-tested during a period from 1958 through 1963 before the design was ready for production.

Fig. 14-23. Western Electric Trimline touchtone and rotary dial handsets with their common desk base.

To achieve public acceptance, the size of the dial had to be reduced, but that would be difficult. Reduction of the dial's overall diameter could not be accomplished by reducing the size of the fingerholes, as that would leave holes that were too small for the average finger. The solution was ingenious. The normal space between the 1 and 0 (see for example Fig. 14-4) was eliminated, and the finger-stop was mounted on a pivot so it would move down to the location of the 9 during dialing, thus providing the required rotation. By closing up the circle of finger holes, the dial diameter was reduced to produce the trim lines that were sought. This small dial can be seen in Fig. 14-23.

Developing a small dial was just a small part of the design job, however, as only one of the standard components was used in the Trimline's design envelope. That lone component, not insignificantly, was the transmitter (the standard T1 element). Even a new smaller LA2 receiver element was developed for the Trimline telephone.

Other innovations were required. The electrical circuit was laid out on a flexible printed circuit board that could be bent to follow the handset's contour. Illumination for the rotary dial and the touchtone key pad was provided in the early Trimlines by an incandescent bulb that used the same external transformer as the Princess telephone. In the later Trimline telephones, dial illumination was provided by light-emitting diodes (LEDs) that took their power from the telephone line, thus eliminating the need for a separate power source and extra wires.

A small P-type ringer was located in the Trimline's base with the hook switch. The P-type ringer is similar to the M-type ringer, having a single gong and a miniature motor that resembles the C-type motor. However, in the P-type ringer, the motor is actually located inside the gong. A plastic resonance chamber is located outside the gong to enhance the sound level. Although the components of the Trimline had been substantially reconfigured, functionally the Trimline is like the other standard phones described in this chapter, as is seen more clearly in Chapter 19.

Table 14-2. Trimline-type telephones

Manufacturer	Name
Western Electric	Trimline
Kellogg	Trendline
Stromberg-Carlson	Slenderet
Automatic Electric	Styleline

Kellogg and Stromberg-Carlson followed suit. As with the Princess, the design was available but the trademarked name was not. Kellogg called its Trimline-type phone the Trendline while Stromberg-Carlson called its the Slenderet. Table 14-2 summarizes the names of these phones. Again, there were minor manufacturing differences. Kellogg used a rotary dial that connected to the circuit board with pigtails although the others used screw connections. Stromberg-Carlson used a standard U1-type receiver instead of the smaller LA2 receiver. Otherwise, most parts were interchangeable between these phones and they were virtually indistinguishable from the outside except for different logos on the dial centers and screw covers. Model numbering also followed the Western Electric numbers (e.g., K220 was the rotary Trendline and S-C220 was the rotary Slenderet).

Automatic Electric's entry into the dial-in-handset field was called the Styleline. The Type 980 handset with either a Type 981 desk base or a Type 982 wall base was available with either a rotary dial or a touchtone dial. A rotary dial Styleline handset and both bases are shown in Fig. 14-24. Although it is very similar in appearance to Western Electric's Trimline phone, none of the parts are the same. The Styleline uses the transmitter and receiver from the Type 80 handset, and those are not like Western Electric's T1 transmitter and U1 receiver. The dial has a moveable finger-stop, just like the Trimline's, but the Styleline's dial otherwise follows Automatic Electric's construction style. The voice circuit, which is borrowed from Western Electric, is on a little printed circuit board that is not like the flexible circuit board used in the Trimline. The Styleline was available with an optional electroluminescent dial light that required power from a standard 110-volt ac outlet. Thus, Automatic Electric's telephones remained unconventional to the end.

Fig. 14-24. Automatic Electric Type 980 Styleline rotary-dial handset with a Type 981 desk base and a Type 982 wall base.

The Design Line Series of Telephones

In 1968, a tri-company project team was formed consisting of AT&T marketing and customer services specialists, Western Electric merchandising and manufacturing experts, and Bell Labs engineers (Hall 1975). The team's purpose was to develop "antique/decorator" concepts into new products and find ways to reduce the product introductory time. The design requirements specified by the team were straightforward: The telephones must, of course, be unusually attractive; they must use standard, available components; and they must appeal to a broad range of customers interested in decorator-styled telephones, from the low-price mass market to the high-fashion, exclusive market.

Bell Labs engineers then called on Dreyfuss's firm to develop a series of new-style telephones in unique shapes, materials, and colors (Flinchum and Meyer 2017). Other designers were later brought into the program. The new products were called the Design Line telephones. For these phones, the customer would purchase a Bell System-approved housing from a retail outlet, but the Bell System would own the components necessary to make it a working telephone set. The customer was then charged the regular monthly extension rate for service, where applicable. Although the housings were made by a variety of contractors, the telephones were assembled by Western Electric and equipped with Western Electric working parts.

The total number of eventual designs and variations in the Design Line series is not known by the author, but there were more than 50 – eventually including candlesticks, Disney characters, Snoopy, and Kermit the Frog. The Dreyfuss designers did not consider these phones to be a high-water mark of consumer taste as they critiqued the lineup from candlesticks to phones in the likeness of mice and dogs (Mickey and Snoopy).

Fig. 14-25. Western Electric's Design Line "Sculptura." ***Gregg Museum of Art & Design.***

Fig. 14-26. Western Electric's Design Line "Exeter." ***Gregg Museum of Art & Design.***

Individual designs ranged from the whimsical, such as the Sculptura in Fig. 14-25 to the practical, namely the Exeter shown in Fig. 14-26 – both of these designs were done by the Dreyfuss firm. The Exeter was the most practical of the Design Line offerings and shows a lasting example of the Dreyfuss firm's work. Desk versions (No. 900 rotary, 2900 touchtone) and wall versions (No. 953 rotary, 2953 touchtone) were available. Many later business phones were variations of this design theme. The K-type handset on the Exeter and some other Design Line phones was designed by Genaro and manufactured by Western Electric, although the rest of the housing was made by an independent contractor. The K-type design with its carbon transmitter was patented and eventually morphed into the similar-looking R-type handset with an electret transmitter that was used on many later business sets.[5]

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[5] Donald Michael Genaro and John Niel McGarvey, "Telephone Handset," Patent No. Des. 229,837, dated Jan. 8, 1974; application filed Apr. 13, 1973.

End of an Era

On January 1, 1984, the Western Electric Company, then older than the telephone itself, ceased to exist (Hochheiser 1991, 143).[6] On that day of court-ordered divestiture, the Bell System was broken into seven regional operating companies (the Baby Bells) and a more compact AT&T. AT&T retained the long-distance part of the business, its venerable research organization (Bell Laboratories), and its manufacturing operations (which could no longer have exclusive supply arrangements with the operating companies). A newly created AT&T Technologies, Inc. assumed the corporate charter of Western Electric and continued making 500-type, 2500-type, and Trimline telephones under the AT&T Technologies label for several years at plants in Indianapolis and Shreveport. However, to become competitive in the market, AT&T shifted residential telephone manufacturing to the Far East, beginning in Hong Kong in late 1985, Singapore the following year, and later in Bangkok and elsewhere. Thus ended U.S. production of rugged electromechanical telephones, and though phones similar to the 500-type, the 2500-type, the Princess, and the Trimline are still made today, they are products of the modern electronics age, rather than a bygone culture.

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[6] See also the AT&T 1983 Annual Report, p. 4.

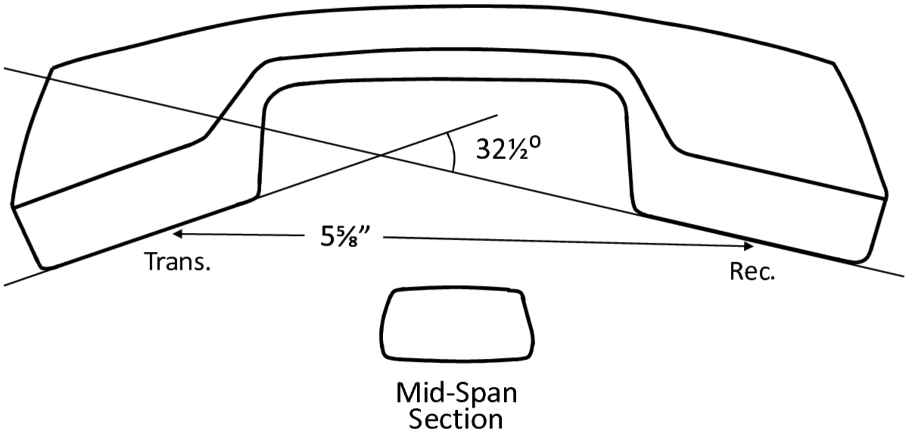

Fig. 14-27. Outline of K-type handset with critical dimensions.

Part Three
Technology

Chapter 15
The Standard Local-Battery Circuit

Principles of the Standard Local-Battery Circuit

The original local-battery circuit described in Chapter 4 and shown in Fig. 4-4 was so simple and so effective that no change was needed when local-battery telephones went into widespread service. Adding to that circuit the bridging arrangement for a magneto and ringer, as described in Chapter 6 and shown in Fig. 6-4, produced the complete local-battery circuit that was used universally until the late 1930s. This complete circuit is shown in Fig. 15-1. In this circuit, direct current is confined to the transmitter current loop (transmitter, coil primary winding, and battery).[1] A battery voltage of 3 volts (2 dry cells) or 4.5 volts (3 dry cells) was used to produce a direct current of about 30 milliamperes, but this dc current varied considerably because of the temperamental nature of a carbon-granule transmitter. Direct currents ranging from 20 to 100 milliamperes are not uncommon. However, no direct current or dc voltages appear in the receiver circuit (receiver, coil secondary, ringer, magneto, and line) because of the isolation provided by the coil. The ringer and magneto can thus be connected directly to the line without regard for their dc properties.

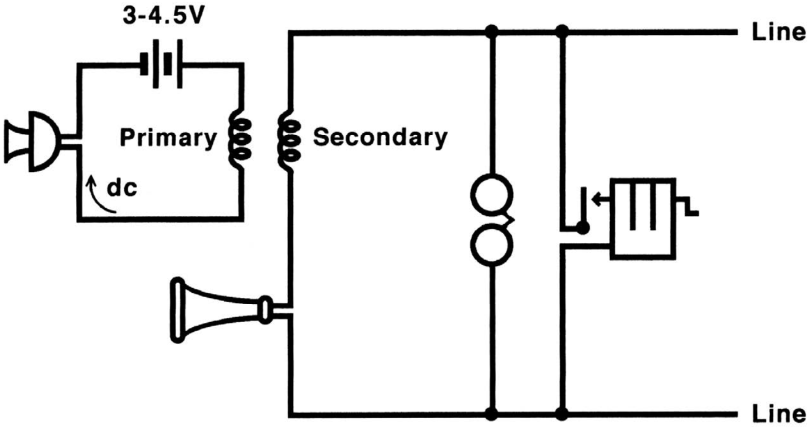

Fig. 15-1. The standard local-battery circuit with bridging ringer and magneto.

Although dc behavior of this and other telephone circuits is the same when transmitting and receiving, ac operation is not the same when transmitting and receiving. Thus, transmitting and receiving will be discussed separately for alternating currents (the voice signal). Before covering ac operation, however, it will be helpful to discuss the characteristics of several coils that are used in the standard local-battery circuit.

The characteristics of these local-battery coils are given in Table 15-1. The coil resistances and turns ratios in Table 15-1 and in all other such tables in later chapters were measured on two or more coils of each type. For a given type, variations in measured resistances were generally ± 2 to 3 percent -- except for

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[1] The coil winding through which direct current (dc) flows is called the primary winding in most telephone circuits.

these early coils in Table 15-1, where the variations were ± 10 to 15 percent. In many cases, resistance values in the tables have been rounded to agree with manufacturers' catalog values.

Table 15-1. Characteristics of induction coils used in the standard local-battery circuit.

Characteristic	**Primary**	**Secondary**
Western Electric No. 13		
Terminal Markings	P-P	S-S
Resistance, ohms	1.4	17
Turns Ratio, to primary	1.0	4.1
American Electric No. 31D		
Terminal Markings	P-SP	SP-S
Resistance, ohms	0.6	38
Turns Ratio, to primary	1.0	6.9
American Electric No. MC-2888[a]		
Terminal Markings	P-PS	PS-S
Resistance, ohms	1.8	14
Turns Ratio, to primary	1.0	4.0
Kellogg No. 28-C[b]		
Terminal Markings	P-P	S-S
Resistance, ohms	0.8	52
Turns Ratio, to primary	1.0	8.7
Kellogg No. 108-A		
Terminal Markings	P-P	S-S
Resistance, ohms	1.3	11
Turns Ratio, to primary	1.0	3.4
Stromberg-Carlson No. 15A		
Terminal Markings	None	None
Resistance, ohms	0.8	66
Turns Ratio, to primary	1.0	8.1
Stromberg-Carlson No. 44A		
Terminal Markings	P1-P2	S3-S4
Resistance, ohms	2.2	13
Turns Ratio, to primary	1.0	4.1

[a] These are catalog values (American Electric Bulletin 100) which differ a little from the measured 17-ohm secondary and 3.8 turns ratio.

[b] This coil was later made with a 1.6-ohm primary and 22-ohm secondary, but it was still called No. 28-C (see Kellogg Catalog No. 9).

The turns ratios shown in Table 15-1 (and in later chapters) are taken as the ratio of measured primary and secondary voltages,

$$\text{Turns Ratio} = V_{\text{Secondary}} / V_{\text{Primary}},$$

with a 1,000-cycle-per-second voltage applied to the primary winding and with the secondary winding open. The measured values generally vary by only ± 1 percent for coils of the same type. These values, deduced from voltage measurements, are very close to the ratios of the actual numbers of turns in each winding.[2] The effective turns ratio under operating conditions varies because of resistive losses when

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[2] See Abbott (1904, 238-239) and Eppes (1981, 22) where the actual number of turns can be found for Western Electric's No. 13, 20, and 101A coils. The differences in actual turns ratios are only ± 2 or 3 percent when compared with ratios deduced here from voltage measurements.

current is flowing, and will be found to be slightly less than the open-circuit value when transmitting, and slightly greater than that when receiving.

Several observations about these coils are worth noting. First, the ratio of the resistances of the windings is different from the ratio of the numbers of turns. This is caused by two factors, both intended to keep the resistance in the dc loop very low. (1) Heavier wire was used for the primary winding (typically, No. 26 gage B&S) than for the secondary winding (No. 28). (2) The primary winding was wound first, and the secondary winding was wound on top of it, so the secondary winding has a larger diameter with more inches of wire per turn.

It can be seen that the early American Electric coil (No. 31D), the early Kellogg coil (No. 28-C), and the early Stromberg-Carlson coil (No. 15A) do not provide good impedance matching (see Appendix) because their turns ratios are too high. Later, these manufacturers made coils (also shown in the table) more like the well-designed Western Electric No. 13 coil.

For the discussion that follows, two electrically identical Western Electric local-battery telephones in normal working order were connected together by a short line. Each telephone had a No. 323 transmitter, a No. 144 receiver, a No. 13 coil, and a 3-volt battery. Properties of the transmitter and receiver were given in Chapters 2 and 3. Actual measured voltages are used in the following discussion to illustrate how the circuit works, thus avoiding mathematical analysis.[3] As with the previously covered direct current, the ac voltages shown in the following figures are typical values, and large variations are to be expected because transmitter output is quite variable. Nevertheless, for a given transmitter output voltage (normalized to 75 millivolts for the discussions in this and later chapters), the rest of the values in these figures will be accurate to about ± 10 percent, which is quite good and is typical of the precision in most electronic circuits.

Transmitting (ac)

Figure 15-2 shows this circuit with typical ac voltages, measured while transmitting, but with the ringer, magneto, and battery removed from the diagram for simplicity. Because the magneto is normally switched off the line and the ringer impedance is so high at audio frequencies (see Table 6-1 of Chapter 6), neither has any effect on ac (voice) operation of the phone and they can be literally removed from the circuit. Batteries, on the other hand, have a very low resistance to current flow, so little of the ac voltage generated by the transmitter is lost in the battery; in these tests, the actual ac voltage measured across the battery was

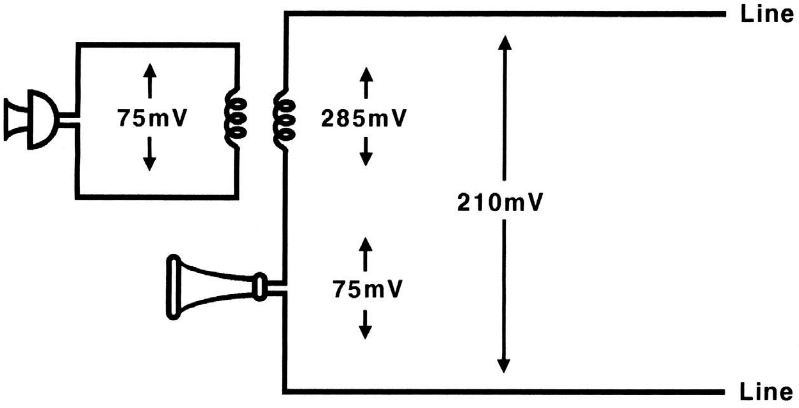

Fig. 15-2. Typical ac voltages in the standard local-battery circuit when transmitting.

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[3] Measurements reported here and in later chapters were made with an electronic digital multimeter with a sensitivity of 0.1 millivolt ac. An audio tone of approximately 1,000 cycles per second was placed in front of the transmitter of the transmitting telephone for the measurements. Two independent and consistent sets of measurements were always made -- one with each phone, in turn, operating as the transmitting telephone.

less than 1 millivolt. Thus, the battery can be treated as a short circuit and left out of the diagram for the purpose of ac circuit analysis, but, of course, the battery cannot be physically removed from the circuit.

During normal operation, the transmitter generates a voltage of about 75 millivolts. The transmitter voltage is stepped up to about 285 millivolts by the transformer action of the coil. This 285-millivolt voltage is thus the ac voltage source for transmitting, and its power is dissipated (or dropped) in the receiver and in the other (receiving) telephone connected to the line. About 75 millivolts is dropped across the receiver in the transmitting phone, putting about 210 millivolts directly on the line. Notice that the effective turns ratio of the coil is 3.8 (285 / 75 = 3.8), which is only slightly less than the open-circuit value of 4.1 shown in Table 15-1.

Receiving (ac)

Figure 15-3 shows this circuit with typical ac voltages that are measured while the phone is receiving. The voltage source for the receiving phone is, of course, the 210-millivolt line voltage that is generated by the transmitting phone. Of this, about 75 millivolts are dropped across the receiver and about 135 millivolts are dropped unproductively across the coil secondary winding. The coil steps down this voltage to about 30 millivolts in the transmitter circuit, where the power is dissipated in the idle transmitter. Now the effective turns ratio of the coil is 4.5 (135 / 30 = 4.5), which is slightly greater than the open-circuit value of 4.1 in Table 15-1.

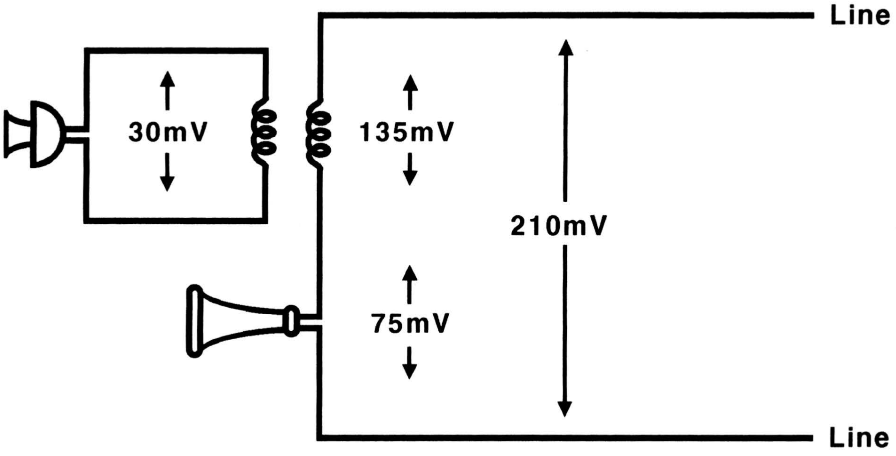

Fig. 15-3. Typical ac voltages in the standard local-battery circuit when receiving.

Several performance characteristics of this circuit can be noted. First, more than two-and-a-half times the transmitter voltage is placed on the line when transmitting. Second, about 35 percent (75 / 210 = 0.36) of the line voltage appears across the receiver when receiving. Finally, the receiver voltage is the same in the transmitting phone (sidetone) and in the receiving phone. This final characteristic is a consequence of the simple series nature of the circuit; the same ac current flows through the line and both receivers. The performance characteristics of the original local-battery circuit (circa 1881) are hard to match in common-battery circuits, which are covered in following chapters.

Examples of the Standard Local-Battery Circuit

The standard local-battery circuit was used in single-box and compact wall phones, and in candlestick desk stands, handset desk stands, and space savers with ringer boxes. Examples of complete wiring diagrams for several of these phones are described in the following sections to illustrate additional electrical features that were commonly used.

Wall Phone with Primitive Hookup

An example of the purest, most straight-forward application of the standard local-battery circuit is found in the cathedral top Stromberg-Carlson No. 101 wall phone, circa 1907. The complete wiring diagram for this phone is shown in Fig. 15-4. None of the terminals in this phone is marked, and wires are soldered to the four door hinges to supply current to the transmitter and ringer, which are mounted on the door.

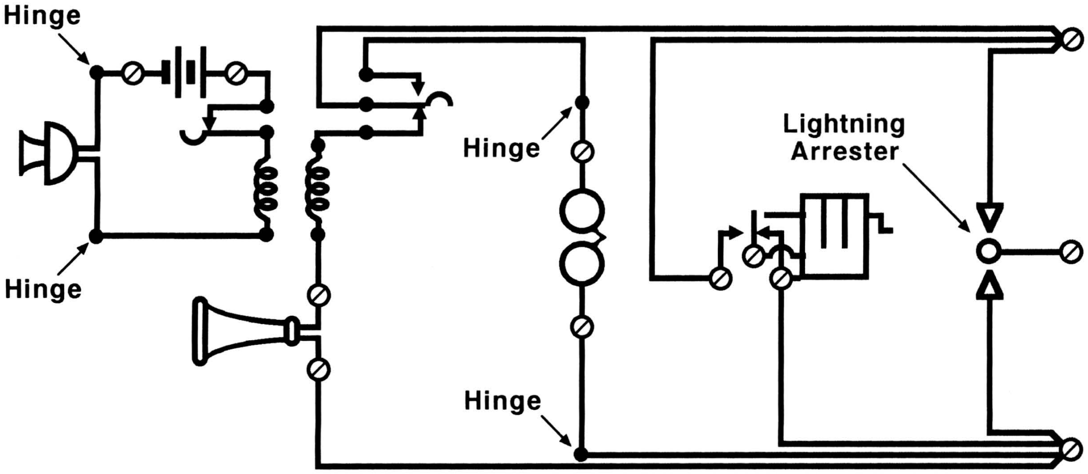

Fig. 15-4. Wiring of the Stromberg-Carlson No. 101 magneto wall phone, a primitive application of the standard local-battery circuit.

The similarity between Fig. 15-4 and the basic circuit in Fig. 15-1 is apparent -- only switches (and a lightning arrester) have been added.[4] One section of the hook switch opens up the transmitter circuit and prevents battery drain when the phone is not in use. The other section of the hook switch disconnects the receiver when the phone is not in use so that a ring signal will not be short circuited around the ringer through the receiver (magnetos are normally cranked with the receiver on the hook). A 3-contact (single-pole, double-throw, SPDT) section of the hook switch is used for this latter purpose, and it also switches the ringer out of the circuit for talking to prevent ac voice current from going through the ringer. (Disconnecting the ringers became unnecessary when higher-impedance ringers were introduced.) The ringer wire in this model was sometimes soldered directly to the center terminal of the switch. The switch on the magneto is also a 3-contact (SPDT) switch, but it is connected here as a simple 2-contact (single-pole, single-throw, SPST) switch (Fig. 15-4). This particular magneto, with its 3-contact switch, can be used in more complex signaling arrangements.

Finally, a carbon-block lightning arrester was built into the external terminals on the cathedral top of this telephone (see Fig. 9-7 of Chapter 9). Two pairs of carbon blocks were built into in the arrester, and the individual blocks in each pair were separated by a mica sheet. This insulating mica sheet prevents shorting of these terminals during normal operation and provides the small spark gap for arcing if the line is struck by lightning. A second spark gap is also provided by the saw-tooth shape of the metal frame that holds the carbon blocks. These saw teeth produce an enhanced electric field that promotes a discharge. The lightning arrester has no effect on the telephone during talking or signaling.

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[4] By convention, in the wiring diagrams that follow, switch contacts will be shown in their positions for talking (i.e., receiver off hook, no dialing, and no signaling).

Occasionally, an old circuit such as this will be found with an additional switch in the battery part of the circuit (not shown in the figure). This accessory, often available in the form of a small round oak base with a brass lever, could be mounted out-of-sight on the underside of the box. This switch was used to disconnect the transmitter circuit so that one could listen in on party line conversations silently (eaves dropping or rubbering) without running down the batteries.

Wall Phone with Western Electric's Standard Wiring

Shortly after introduction of the No. 317, wiring became rather standardized in the Western Electric magneto wall phones, and this standard wiring diagram is shown in Fig. 15-5. This diagram with its No. 13 induction coil would describe nearly all the phones listed in Table 9-1 of Chapter 9 with, perhaps, some minor change in terminal markings (e.g., LINE1 and LINE2 are often called L1 and L2).

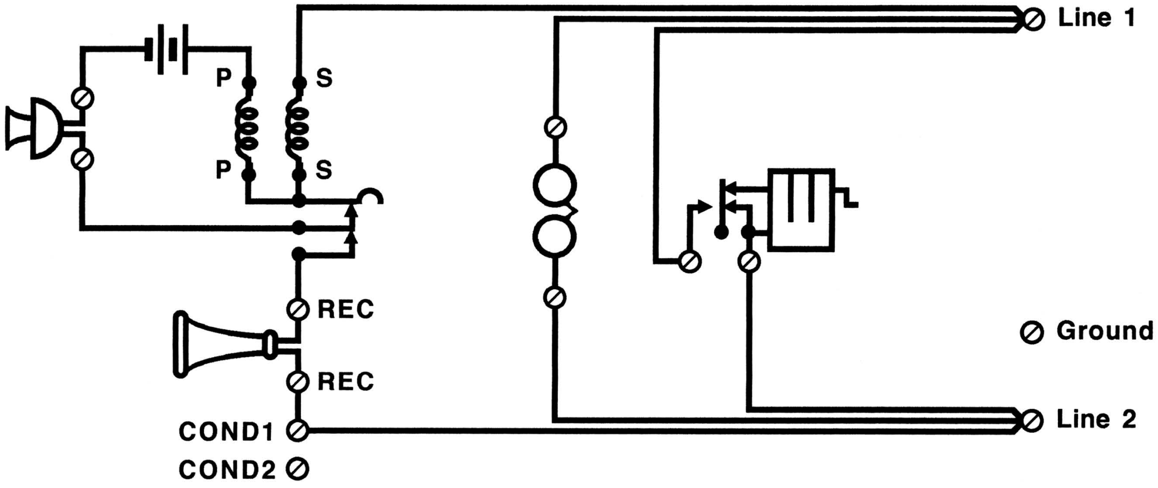

Fig. 15-5. Wiring of most Western Electric No. 317 magneto wall phones, showing inconsequential connection between primary and secondary loops.

The circuit in Fig. 15-5 is quite similar to the fundamental circuit in Fig. 15-1 with one major deviation. This deviation is a connection between the primary current loop and the secondary current loop, made near the hook switch. Because no new current loop is created by this connection, it has no effect on the operation of the circuit. This inconsequential single point of contact between the two current loops does, however, reduce from 4 to 3 the number of contacts required in the hook switch. Thus, in the name of economy, this connection is made in most, but not all, local-battery sets. You can see in the circuits covered below that this single point of contact between the current loops may be made elsewhere if desired.

A 3-contact hook switch thus provides switching for these two circuits. Further, the sequence of switching in this circuit is significant. Mechanically, a lever pushes on the first contact of the hook switch until it touches the second, and finally together they touch the third contact. The diagram shows that the first contacts to touch together connect the transmitter circuit, while the last contact to be touched connects the receiver circuit. Although completion of one circuit precedes the other by only a fraction of a second, this is ample time for the transient voltage pulse, which is generated by closing the circuit containing the battery, to die down before the receiver circuit is completed. This delay results in nearly silent operation (no receiver clicks) of the hook switch in these local-battery sets. In general, telephone circuits are designed to get all dc currents flowing before the receiver is switched into the circuit.

A 1-microfarad condenser was supplied in some variants of the Western Electric No. 317, and provisions for this condenser were included in the standard wiring harness -- whether that set had the condenser or not. The condenser could be used for one of two purposes. First, and by far the most common use of the condenser, was to permit ringing when the receiver was left off the hook. By simply moving to COND2 one of the two wires shown going to COND1, and then connecting the condenser to those terminals, the condenser is placed in series with the receiver to provide this sure-ring function.

To see how the sure-ring condenser works, first, consider the impedance for a ring signal (20 cycles per second) of the current path through the receiver without the sure-ring condenser and compare that with the impedance of the parallel path through the ringer. Based on information in Table 3-1 of Chapter 3 for a No. 144 receiver (typical) and on the general behavior of coils (see Appendix), it can be shown that the receiver has an impedance at 20 cycles per second that is very close to its dc resistance of 85 ohms. Further, a No. 323 transmitter (typical), as reflected in the induction coil secondary, will appear to have an impedance in the range of 400 to 1200 ohms, based a transmitter resistance of 25 to 75 ohms (see Table 2-1 of Chapter 2) and on a coil turns ratio of 4 (see Table 15-1 of this chapter). Therefore, at most, the impedance of the current path through the receiver is about 1,285 ohms, and this is to be compared with an impedance of 4,750 ohms for a No. 38A ringer (lowest typical impedance, see Table 6-1 of Chapter 6). Hence, the current path through the ringer has a substantially higher impedance than the path through the receiver, and most of the ring-signal current would take the path of least resistance through the receiver. Thus, if a single receiver were left off the hook, the ringers along the line would not work.

Now consider a 1-microfarad condenser wired in series with the receiver. At 20 cycles per second, a 1-microfarad condenser has an impedance of 7,960 ohms (see Appendix). This is so much larger than the other 1,285 ohms (maximum) in the receiver pathway, that when added together (even though these numbers do not add together algebraically) the impedance of this pathway is still about 8,000 ohms, due mostly to the condenser. In this case, the 4,750-ohm impedance through the ringer is the path of least resistance. Even for a ringer with a higher impedance, like the No. 53B (12,500 ohms), the receiver pathway with its sure-ring condenser merely looks like another 8,000-ohm ringer on the line, rather than a 1,285-ohm (maximum) short circuit. Consequently, the ringer will ring even with the receiver in the circuit (i.e., with a receiver off the hook).

The second purpose for a condenser was to keep direct current from flowing through the ringer "when the set is used in connection with common battery lines."[5] The next chapter on common-battery circuits shows that it is necessary to keep dc out of the ringer to avoid false off-hook signals and to avoid wasting battery power. For this purpose, the 1-microfarad condenser is connected to the COND terminals, and the lower ringer lead is moved from LINE2 to COND2. This puts the condenser in series with the ringer. As shown in Chapter 6 (following Table 6-1), the condenser's impedance subtracts from the inductive portion of the ringer's impedance, leaving a net impedance of several thousand ohms. This net impedance is in the same ballpark as the ringer's impedance without the condenser, so the ringer condenser has little effect other than to block direct current (dc). It is surprising, yet true, that a 1-microfarad condenser at 20 cycles per second prevents a short circuit when placed in series with the receiver, but it has little effect when placed in series with the ringer.

Another example of a local-battery circuit being used on a common-battery line will be discussed at the end of this chapter. In that example, the local-battery circuit is used for talking and the common-battery circuit is used for signaling. Connecting the receiver with the correct polarity is also discussed in that example.

Finally, in a Western Electric magneto wall phone, a ground terminal was always provided for divided ringing (i.e., placing the ringer between one line and ground for selective ringing purposes). This terminal is usually shown without any connection, and the ringer and magneto are shown across the line in bridging fashion.

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[5] Instructions including this note appeared on the door diagram of the No. 317 in the 1920s when common-battery systems had become prevalent. Although such instructions were not present earlier, this condenser connection could of course be made on earlier sets.

Western Electric Wall Phone with Special Signaling

Although most Western Electric magneto wall phones used the standard wiring arrangement shown in Fig. 15-5, some had special features, such as the one shown in Fig. 15-6. This is the wiring diagram for a Western Electric No. SP317S. There are a number of differences in this wiring diagram compared with the wiring diagram in Fig. 15-5, but these differences do not affect the talking circuit in any fundamental way. The essential similarity between Fig. 15-6, Fig. 15-5, and the basic circuit in Fig. 15-1 is still present.

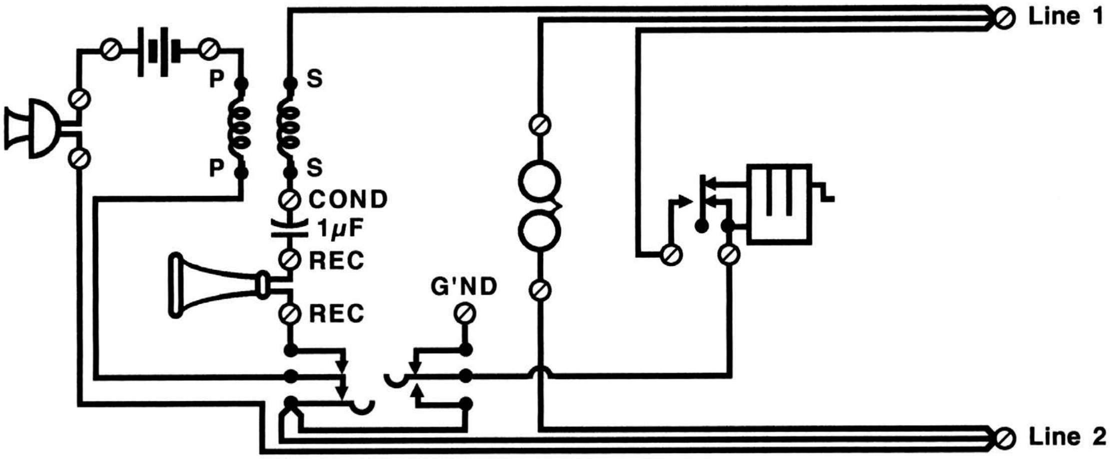

Fig. 15-6. Wiring of Western Electric No. SP317S magneto wall phone, with special signaling and a sure-ring condenser.

First, the inconsequential single point of contact between the transmitter circuit and the receiver circuit is present, but in a different location than in the previous case. This common point is now at the LINE 2 terminal, rather than at one end of the coil. Because a single point of contact has no effect on performance, the location of this point can be chosen arbitrarily.

Second, the receiver and the sure-ring condenser are in different relative positions (in Fig. 15-6 the condenser is above the receiver whereas in Fig. 15-5 it would be below). In a series circuit (i.e., in any portion of a circuit where components are connected one after the other, without any parallel pathways), the order in which the components are placed is immaterial. Consider two components, such as a condenser and a receiver. Each presents a known resistance (impedance) to current flow, and taken together these impedances add to give a total that does not depend on which component comes first. Mathematically, this is related to the fact that $a + b = b + a$. It follows that all other electrical considerations (voltages and currents) are unchanged by the order. Therefore, in the case of Fig. 15-6 versus Fig. 15-5, and in many other cases to be seen, the mere interchange of components in a string or series should not be viewed as an important difference -- usually just a wiring convenience.

Finally, and most noticeably, this telephone has a rather complex multi-contact hook switch. Three of these contacts perform the same function as the hook switch in the previous case. The other three contacts are extra and comprise a single-pole, double-throw switch that is used to reroute the magneto signal. If the magneto in this phone were cranked with the receiver on hook, which would be normal, the magneto would be connected between LINE 1 and LINE 2 (remember that all switches are being shown off-hook, so the pathway in this case would be through the contacts shown as open in Fig. 15-6). In this manner, the caller could signal other parties on the same line. However, if the magneto were intentionally cranked with the receiver off hook (contacts as shown in Fig. 15-6), the magneto would be connected between LINE 1 and G'ND (ground). For a bridging party line (as depicted), the caller could thus signal the operator secretly by cranking the magneto with the receiver off hook, provided that the operator had a signaling device connected between Line 1 and ground. Notice that the sure-ring condenser is required for this function, so it is wired permanently in this circuit, rather than being provided as an option as in Fig. 15-5.

Typical American Electric Wall Phone Hookup

American Electric's wiring arrangement is shown in Fig. 15-7 for the Type 200 wall phone shown in Fig. 9-9 of Chapter 9, and the wiring is very similar to the standard arrangement used by Western Electric (Fig. 15-5). The hook switch with its inconsequential single point of contact between the primary and secondary current loops has been moved to the other end of the coil with no effect on the way the circuit works. A loop of wire between coil terminal S and the receiver terminal was provided for installation of a sure-ring condenser. This wire could be cut and the two ends connected to a condenser, although none is present in this case.

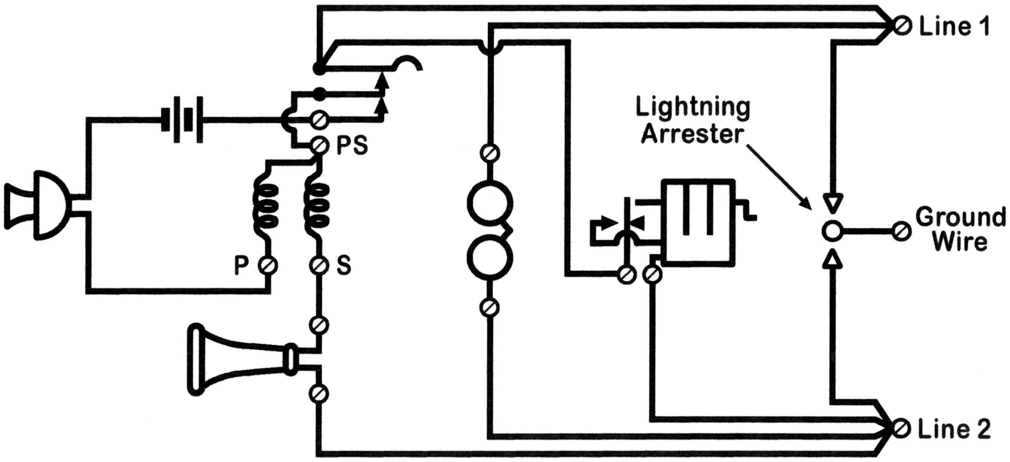

Fig. 15-7. Wiring of Automatic Electric Type 200 magneto wall phone, with incorrect hook switch sequencing.

The wall phone in Fig. 9-9 happens to be a relatively early version of the Type 200 wall phone, and a couple of details in the wiring of this phone were later modified. This particular phone used the No. 31D coil with too few turns of wire in the primary and too many in the secondary. Thus performance was not optimum and that coil was later replaced by the improved MC-2888 coil. Also, it can be noticed that the switching sequence is not correct, and it was hard wired in this set (not optional). The receiver circuit is closed first such that closing of the transmitter circuit can be heard as noisy hook switch operation. This was also corrected in later versions of the Type 200 wall phone.

Typical Kellogg Wall Phone Hookup

Kellogg provided a different wiring arrangement for its magnetos, and a typical Kellogg wiring diagram is shown in Fig. 15-8. This diagram is for the No. F2884 set shown in Fig. 9-8 of Chapter 9. Although the tangle of wiring associated with the ringer, magneto, and lightning arrester make this diagram a little difficult to follow, the basic talking circuit (shown on the left side of the figure) is again like Fig. 15-5 and similar to Fig. 15-1. It is, however, the ringer, magneto connection, lightning arrester, and one other feature, that make this Kellogg wiring interesting.

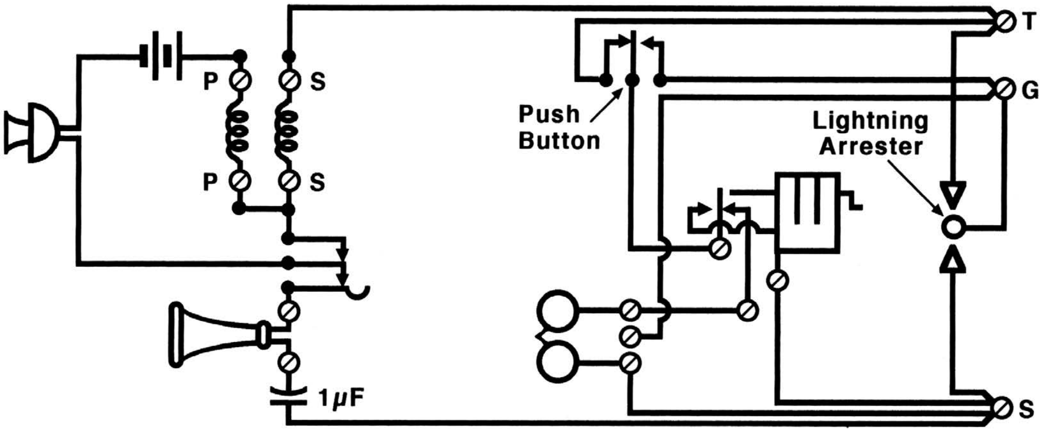

Fig. 15-8. Wiring of Kellogg No. F2884 magneto wall phone, with push button for secret signaling and magneto switching for silent ringing.

That other interesting feature is related to screw terminals, which appear on the coil in addition to solder terminals. Using these terminals to make wiring changes, this local-battery set could be converted in the field to common-battery operation. Wiring instructions were provided by Kellogg for the conversion. See Chapter 16 for a discussion of common-battery circuits, including the local-receiver circuit that would have been used.

This Kellogg telephone provides a good example of the so-called universal wiring that was used by the independent companies. Universal-type wiring had loops of wire protruding from the wiring harness at strategic places, and these loops could be cut to insert optional features like sure-ring condensers and push buttons for secret signaling. In this particular set, all of the options provided for in the wiring harness are present.

First, Kellogg magnetos incorporate a full single-pole, double-throw (SPDT) switch that was arranged for silent ringing. Not only would this switch disconnect the magneto when the crank was not being turned, but it would also disconnect its own ringer when the crank was being turned, as can be seen by examining Fig. 15-8. This arrangement automatically eliminated the annoyance of listening to loud bells when calling out. Of course, if it was desired to have the bells ring when cranking, the ringer lead could be moved from the center terminal to the upper left terminal of the magneto switch.

Next, this telephone was equipped with a push-button switch to provide secret signaling of the central office. By pushing this switch while cranking, the magneto signal would appear between terminal S and G (ground) rather than across the line, S and T (Kellogg's short-lived notation). Thus the ringers in phones on the party line would not ring, but a device between S and ground at the central office would respond. This was a common accessory, also available on Western Electric phones as noted in Table 9-1 of Chapter 9, whose function was similar to that of the preceding circuit in Fig. 15-6.

This phone also had a lightning arrester that consisted of two semicircular metal discs, each connected to a line terminal. These discs were laid side by side (but not touching) against a grounded circular block of carbon, being separated from the carbon by a thin circular mica sheet. As in the carbon-block arrester described earlier, the mica sheet provided a spark gap for arcing in the event of a lightning strike.

Other electrical hazards were present with the proximity of telephone lines to power lines, so additional protective devices were also developed. Hammond Hayes, whose name will come up later in a prominent way, made a comprehensive study of the protection problem in 1890 (Fagen/AT&T 1975, 337-342; see also Miller 1903, 272-280; Rhodes 1929, 181-183; Lee 1985, 113-118). Protection devices were usually located remotely from telephone sets, and they will not be discussed further.

Candlestick Desk Stand with a Ringer Box

The wiring diagram for a Western Electric non-dial candlestick desk stand with a local-battery ringer box is shown in Fig. 15-9. As drawn, this diagram shows a No. 20-AL or 40-AL candlestick with a No. 300 ringer box with a sure-ring condenser.[6] The wiring for the earlier No. 20-B candlestick is also like Fig. 15-9 except that terminal markings are different (1, 2, 3, and 4 instead of W, Y, GN, and R). The smaller No. 315 ringer box does not have the COND terminal or a condenser (it was too big to fit in the box), but otherwise its wiring is identical to Fig. 15-9, also. And the wiring for the No. 305 compact wall phone (a derivative of the No. 300 ringer box) is the same as Fig. 15-9, except for the elimination of redundant terminals (R, Y, and GN) that accommodate the desk stand cord.

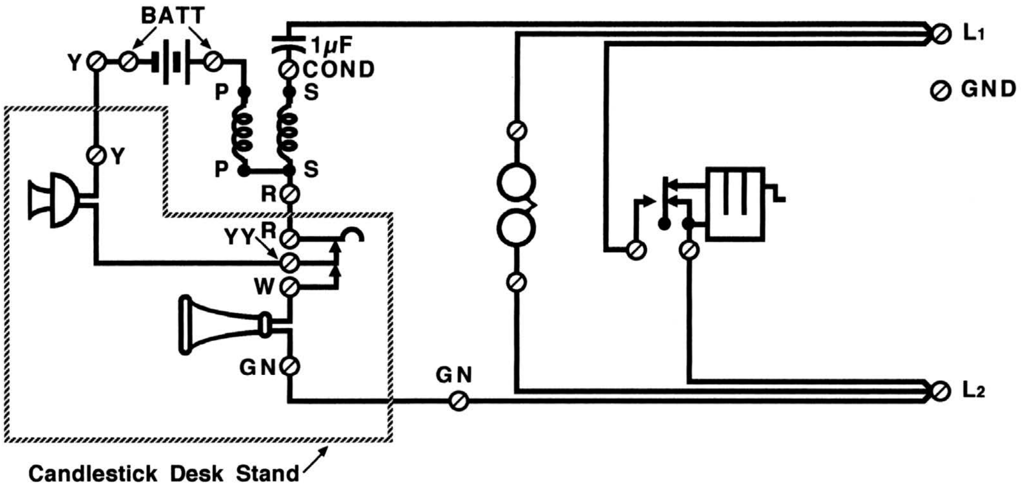

Fig. 15-9. Wiring of Western Electric candlestick desk stand and magneto ringer box, showing equivalence to magneto wall phones and the emergence of color-coded wiring.

The circuit in Fig. 15-9 is almost identical to that in Fig. 15-5 for the No. 317 magneto wall phone; only the location of the sure-ring condenser has been inconsequentially changed. However, color coding is seen for the first time in this circuit. A 3-conductor cord with red, yellow, and green leads connects the desk stand with the ringer box at terminals R, Y, and GN, respectively. And the receiver cord, with white and green leads, is connected to terminals W and GN. Color-coded terminal markings will be seen in all subsequent telephones.

Western Electric, American Electric, Kellogg, and Stromberg-Carlson desk stands and ringer boxes were interchangeable with each other and the same color coding was used in all. American Electric used a 4-contact hook switch in their candlestick although wiring of their ringer box was very similar to the Western Electric arrangement in Fig. 15-9. American Electric used loops of wire in the wiring harness for connecting to a condenser rather than using terminals. Kellogg also used a 4-contact hook switch in some of their candlesticks, and the Kellogg ringer box circuit was like Fig. 15-9 with two exceptions: (1) terminal markings were not identical, although similar, and (2) the magneto and ringer were connected as in Fig. 15-8. Stromberg-Carlson used a 3-contact hook switch in a candlestick with no terminal markings, and the Stromberg-Carlson ringer box had its inconsequential single point of contact between the battery and the transmitter, a somewhat unusual location. Nevertheless, if the green wire of the desk stand cord was connected to terminal GN in the ringer box, etc., all circuits would be equivalent to Fig. 15-1.

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[6] The wiring harnesses for the No. 300 ringer box and the No. 305 compact wall phone all have the COND terminal, and it is connected to the L1 terminal by a wire. If the set was ordered with a condenser, that wire would be cut out and the condenser leads connected to the COND and L1 screw terminals. Thus, standardization to simplify manufacturing is also evidenced in these sets.

Handset Desk Stand with a Ringer Box

The wiring diagram for a Western Electric non-dial handset desk stand with a local-battery ringer box is shown in Fig. 15-10. As drawn, this diagram depicts any of the mountings for the E1 handset (e.g., Figs. 11-8 and 11-17) with a No. 315 ringer box. The ringer box portion of Fig. 15-10 shows the simpler shunt switch arrangement of the small Western Electric 3-bar magneto, and the wiring does not have the COND condenser terminal. Otherwise, this portion of the figure is identical to Fig. 15-9, and the handset desk stand can obviously be used with either the No. 300 or 315 ringer box.

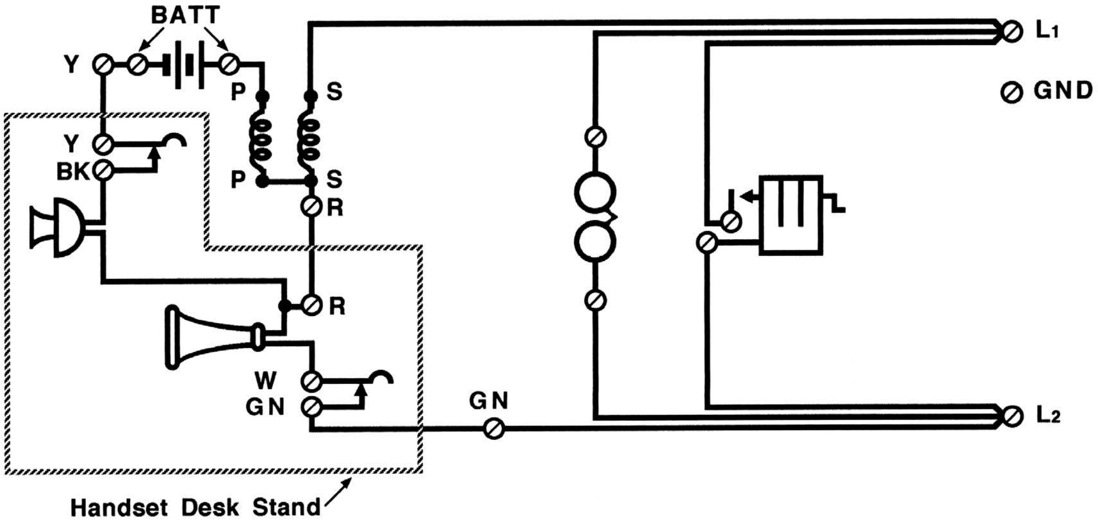

Fig. 15-10. Wiring of Western Electric handset desk stand and magneto ringer box, showing extra hook switch contacts required for a 3-wire handset.

The significant difference between Fig. 15-10 and Fig. 15-9 is in the desk stand. When Western Electric introduced the E1 handset, a decision was made to minimize the number of wires in the handset cord. This was accomplished by connecting one transmitter lead and one receiver lead together in the handset and using a cord with just three wires (red, black, and white). This common connection became the inconsequential single point of contact between the transmitter and receiver current loops, thus preventing the hook switch from being placed at that juncture as in the previous case (notice that all four transmitter and receiver leads had to be connected separately in Fig. 15-9). As a consequence of this decision, switches for the transmitter loop and for the receiver loop had to be separated, and a 4-contact hook switch (2 SPST switch sections) was required. The closing of these contacts is still sequenced such that Y and BK in the transmitter loop make contact first, and W and GN in the receiver loop make contact last, to ensure quiet hook switch operation.

There is a small condenser, which is permanently connected across the transmitter in the E1 handset, and is not shown in Fig. 15-10. This condenser is discussed in Chapter 16 and has no effect on the operation of the local-battery circuit. As with the candlestick desk stands, Western Electric, Automatic Electric, Kellogg, and Stromberg-Carlson handset desk stands can be used interchangeably with the various ringer boxes.

Western Electric Desk Stands and Subsets (LBTCBS)

It is shown in the next and later chapters that the common-battery circuits do not put as strong a voice signal on the line as the local-battery circuits. Further, a high line resistance reduces the current going through the transmitter. Therefore, near the end of some very long common-battery lines, it was advantageous to use a local-battery circuit for talking while using the common-battery features for signaling (LBTCBS). The No. 534Y black metal subset, which was used for this purpose, looked just like the No. 534A common-battery subset, but contained the No. 13 coil instead of the No. 46 coil. The No. 534Y in combination with a candlestick or a handset desk stand had a circuit identical to those shown in Figs. 15-9 and 15-10 except for (a) terminal markings, (b) a condenser in series with the ringer, (c) no condenser in series with the receiver, and (d) no magneto.

Referring again to Figs. 15-9 and 15-10, it is seen that direct current from local batteries is confined to the primary current loop containing the transmitter. When connected to a common-battery line, however, another direct current from batteries at the central office flows from L1 (usually the positive or tip terminal) through the secondary winding, through the receiver, and back to the line at L2 (usually the negative or ring terminal). This direct current in the line can be used, as with all common-battery sets, to signal the operator or to operate a dial. However, when direct current flows through the receiver in this manner, its performance can be affected by changing the polarizing magnetic field from its optimium value. On the No. 122 and 144 receivers, one of the terminals is marked with the letter Z. The letter Z stands for zinc, which is the negative (or ring) terminal of a zinc-carbon dry-cell battery. For candlestick desk stands (Fig. 15-9) with these receivers, installers were provided with the following instructions for obtaining the proper polarity to minimize the adverse effect of the direct current:

> Pole receiver by connecting so line current increases pull on diaphragm with receiver off hook. This pull is increased with “Z” terminal of receiver connected to switch-hook contact when ring of line is connected to L1. When line is reversed ....[7]

Although these instructions are a little confusing (L1 is assumed to be connected to the ring side of the line, which is not standard), it is clear that the Z terminal should be connected to the negative or ring line terminal, and this holds for magneto wall phones discussed earlier as well as the desk stands when they are used on common-battery lines. For handset desk stands with the E1 handset, instructions were provided as follows:

> After all connections have been made, remove the receiver cap and check the magnetic pull on the diaphragm. Reverse the line-wire connections on L1 and L2 of the subscriber set and recheck the magnetic pull. Restore connection of line wires to normal. The magnetic pull on the diaphragm should be greatest with the line wires normal. If not, make the following changes in the subscriber set:[8]

The changes, then described, had the effect of interchanging L1 and L2.

* * *

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[7] AT&T Specification 4566, Machine Switching Stations (February 1926), p. 91.

[8] For example, Bell System Practices, "Hand Telephone Sets Local Battery Connections," Section 510-120-403, AT&T Co. Standard, August 1957.

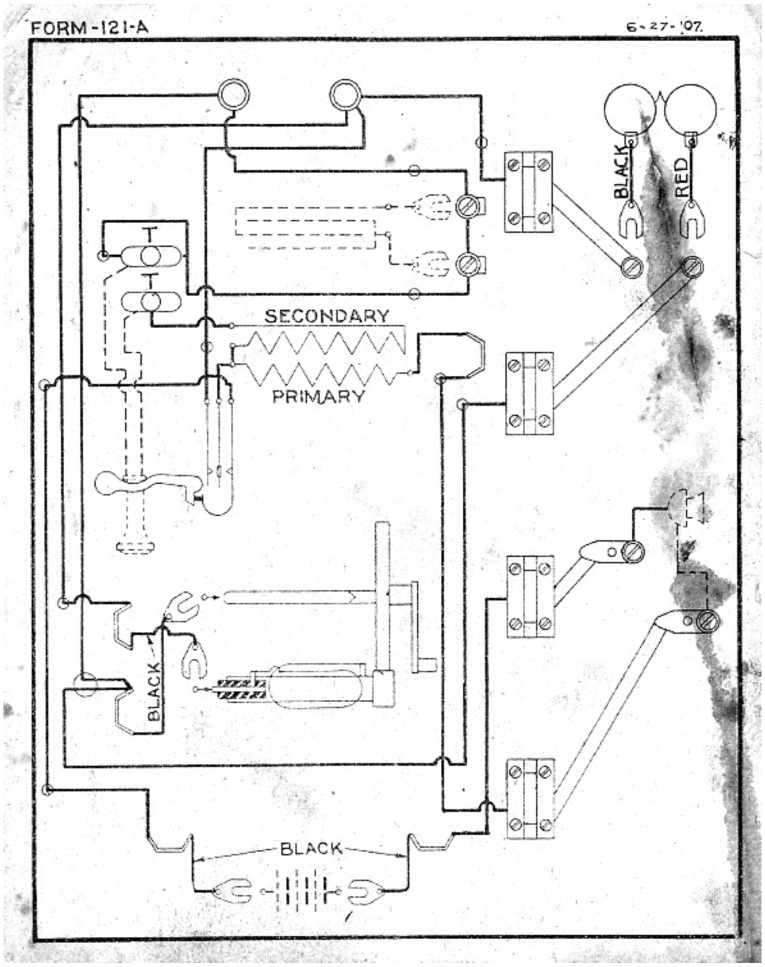

Fig. 15-11. Wiring diagram for early Western Electric No. 317 wall phone (see Fig. 9-2) on paper pasted inside the door of the phone.

Chapter 16
Early Common-Battery Circuits

Local-battery circuits were very effective, but every telephone needed batteries to provide transmitter current and a magneto to signal the operator. Common-battery systems (also called central-battery or central-energy systems) could provide transmitter current over the line. That current could also be used to signal the operator, eliminating the need for the magneto as well. Although common-battery systems reduced cost and maintenance of telephone instruments as desired, such systems gave rise to two new obstacles. One was the need for new circuitry at the central office, and the other was an inherently low voice signal that was subject to greater line loses and more noise pickup.

Central-Office Circuits

To supply current from batteries at the central office required the installation of an electrical circuit that was not needed at a local-battery exchange (often referred to merely as the switch). The circuit that came into common usage for this purpose was developed by Hammond Hayes in 1892, and Hayes's arrangement is shown in Fig. 16-1 (Miller 1903, 240; Fagen/AT&T 1975, 499).[1] The coils (isolation transformers) in this arrangement were called repeating coils by Hayes and others because, with their 1-to-1 turns ratio, they passed (repeated) an ac voice signal without either stepping up or stepping down the voltage.

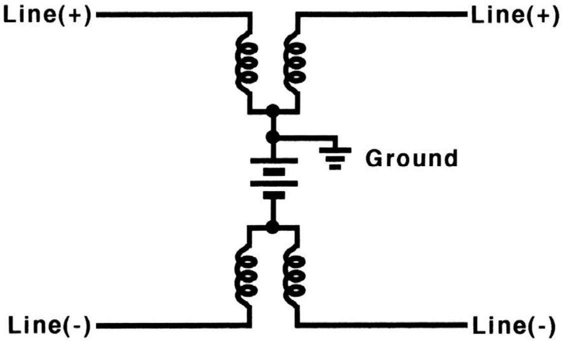

Fig. 16-1. Hayes common-battery supply circuit for the central office.

The dc resistance of each coil winding was very low (about 5 ohms) in early systems. Later systems typically used two 100-ohm coils and 24-volt batteries or two 200-ohm coils and 48-volt batteries. A subscriber with a 100-ohm (dc) telephone next door to a 48-volt central office (i.e., zero line resistance) would find a total loop resistance of 500 ohms (100 ohms for the phone and 400 ohms for the repeating coils) and a direct current of 96 milliamperes (48 volts = 500 ohms x 0.096 amperes). The off-hook voltage across that telephone would be 9.6 volts (9.6 volts = 100 ohms x 0.096 amperes). Subscribers located at distances from the central office would have additional line resistances, with correspondingly lower off-hook voltages. The on-hook voltage (no current and therefore no voltage drop across the resistances) at the subscriber's set would be the full 48 volts, regardless of the line resistance.

Today’s common-battery system has batteries that produce a nominal 48 volts. The coils and other components at the central office -- plus the line -- have an apparent resistance of about 1800 ohms, while the dc resistance of a modern telephone is around 200 ohms. The dc current in such an off-hook telephone is, therefore, about 24 milliamperes (48 volts = 2,000 ohms x 0.024 amperes). The off-hook voltage across the telephone is only about 4.8 volts (4.8 volts = 200 ohms x 0.024 amperes). One of the side benefits of a high resistance system is its inherent self-protection; even if the subscriber's lines become shorted together, the current would only rise to about 27 milliamperes in this case (48 volts = 1,800 ohms x 0.027 amperes), just slightly above the normal off-hook value.

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[1] Hammond V. Hayes, "Telephone-Circuit," Patent No. 474,323, dated May 3, 1892; application filed January 13, 1892.

The ac operation of the Hayes common-battery arrangement is straightforward. The transmitting signal from a telephone passes through one winding of each repeating coil and induces a like signal in the other winding of each coil. The resistance of a battery is very low, so its presence can be ignored for ac circuit evaluation. Thus, the location of the battery can be considered as one of those inconsequential single points of contact between two circuits that creates no new current loops and has no effect on operation.

In principle, a single repeating coil could be used, rather than using two repeating coils as in the symmetric arrangement in Fig. 16-1; in fact, Hayes's original patent used only one coil. In practice, however, one terminal of the battery is grounded, and the use of two coils isolates each line from this common point thereby reducing noise pickup. Using the Hayes arrangement, many circuits can be connected to a single battery without causing crosstalk, but each circuit requires its own repeating coils.

Principles of the Western Electric Booster Circuit

The original series circuit shown in Fig. 4-3 of Chapter 4 would, of course, be a common-battery circuit if the batteries were located at the central office. That simple arrangement was used in some early installations, but it had several major shortcomings. First, impedances of the transmitters and receivers were not matched, and this resulted in poor signal power delivery. Second, direct current flowed through the receiver, and this was undesirable because of the effect on the permanent magnetic field and because of loud switching noise.

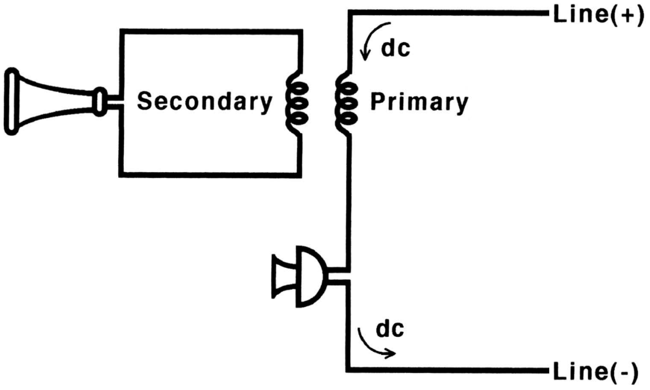

Fig. 16-2. The local-receiver (or local-secondary) circuit for common-battery systems.

Both of these problems could be solved by using an induction coil to couple the receiver to that circuit in much the same way as a coil is used to couple the transmitter to the local-battery circuit. The result is shown in Fig. 16-2 and is called the local-receiver or local-secondary circuit. In some respects, this circuit is similar to the local-battery circuit, and even the same coil would be used to produce matched impedances. However, the coil is not used to step up the transmitter voltage, as in the case of the local-battery circuit. Consequently, the ac voltage source in the common-battery circuit is the unaltered transmitter voltage, only about a quarter of the stepped-up voltage generated in the local-battery circuit. About a third of the transmitter's typical 75-millivolt signal would be dissipated in the coil's primary winding, leaving only about 50 millivolts across the line. Thus, another problem arises with this circuit: low ac line voltages that are subject to greater line losses and noise pickup.

Shortly after the Hayes common-battery system was developed in 1892, Bell engineers found a way to boost the transmitter voltage in the local-receiver circuit to get a larger ac voltage on the line when the telephone was transmitting. In a delayed application, Charles E. Scribner obtained a patent for this circuit and assigned it to the Western Electric Company.[2] By cleverly opening up the secondary current loop and connecting it across the transmitter as shown in Fig. 16-3, a voltage is induced in the primary winding that adds to the transmitter voltage. The transmitter voltage is thus boosted by the receiver circuit, rather than being reduced by it, and a larger ac voltage is placed on the line. The way this happens is described in the section on transmitting.

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[2] Charles E. Scribner, "Telephone-Circuit," Patent No. 669,710, dated March 12, 1901; application filed November 13, 1897 and renewed September 4, 1900.

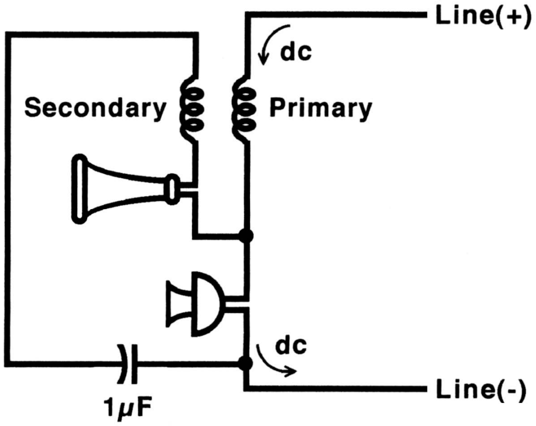

Fig. 16-3. Western Electric's booster circuit for common-battery systems.

To keep direct current out of the receiver in this circuit, a condenser was placed in the receiver loop. Ideally, one would like to use a large condenser with its correspondingly low ac impedance. Most sets used a 1-microfarad condenser (159 ohms at 1,000 cycles per second).[3]

The booster circuit, with its ringer, is shown in Fig. 16-4. In this customary arrangement, the condenser serves two purposes -- keeping dc out of the ringer as well as out of the receiver. Because the condenser is used in the ringing circuit, it requires heavy insulating paper in its construction to withstand the high-voltage ring signal. This contributes to its large dimensions, making it impractical to use a condenser with a capacitance greater than 1 microfarad. Later (see next chapter), when the ringer is given its own separate condenser, a 2-microfarad condenser with lighter insulation and smaller dimensions is routinely used in the receiver circuit.

The main direct current path in Fig. 16-4 is seen to be from Line (+), through the primary winding, through the transmitter, and to Line (-). As a consequence of using the lone condenser in both the ringer loop and the receiver loop, there is another dc path through the receiver, but it turns out to be insignificant. This circuitous path goes from Line (+), through the ringer, through the secondary winding, through the receiver, through the transmitter, and finally to Line (-). This path has such a high dc resistance (generally much more than 1,000 ohms, depending on the ringer) compared with its parallel pathway (the primary winding and the transmitter, generally less than 100 ohms) that its dc current is not significant. Furthermore, when the receiver is on hook, this pathway is opened by the hook switch, so the current is actually zero under those conditions.

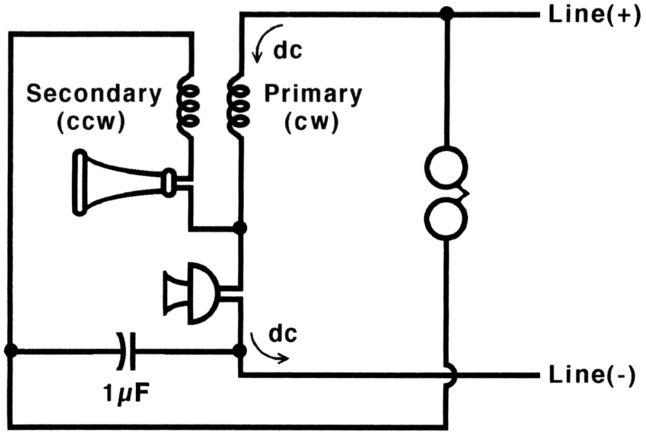

Fig. 16-4. The common-battery booster circuit with a ringer.

Western Electric, Kellogg, and Stromberg-Carlson made two generations of coils for this circuit, and they are described in Table 16-1 along with two similar coils made by Automatic Electric. The early coils had the secondary winding (smaller wire) on the inside and the primary winding (larger wire) on the outside. This was, from one point of view, a logical arrangement because the inside winding contained the ac voltage source when transmitting. In the booster circuit, this winding induces a voltage in the outside winding. This would be the normal way a transformer would be constructed, but the inside winding would be called the primary winding. Although Western Electric stuck to its definition that the winding with dc current would be called the primary winding (the outside winding in this case), Kellogg, Stromberg-Carlson, and Automatic Electric adopted the other definition.

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[3] Incidentally, the impedance of this condenser almost exactly cancels out the receiver's inductive impedance, leaving a very low net impedance in the receiver loop.

Table 16-1. Characteristics of induction coils used in the booster circuit

Characteristic	Primary[a]	Secondary[a]
Western Electric No. 20		
Terminal Markings	1-2	3-4
Resistance, ohms	16	27
Turns Ratio, to primary	1.0	0.80
Western Electric No. 46		
Terminal Markings	1-2	3-4
Resistance, ohms	14	9
Turns Ratio, to primary	1.0	0.62
Automatic Electric No. D280389 and D281897		
Terminal Markings	3-4	1-2
Resistance, ohms	14	27
Turns Ratio, to primary	1.0	0.82
Kellogg No. 79-A		
Terminal Markings	1-2	3-4
Resistance, ohms	15[b]	29[b]
Turns Ratio, to primary	1.0	0.82
Kellogg No. 99-A		
Terminal Markings	1-2	3-4
Resistance, ohms	25	8
Turns Ratio, to primary	1.0	0.65
Stromberg-Carlson No. 43A		
Terminal Markings	1-2	3-4
Resistance, ohms	11	27
Turns Ratio, to primary	1.0	0.87
Stromberg-Carlson No. 44B		
Terminal Markings	1-2	3-4
Resistance, ohms	14	9
Turns Ratio, to primary	1.0	0.63

[a] Automatic Electric, Kellogg, and Stromberg-Carlson used reversed definitions from those used here for the primary and secondary windings of their early coils.

[b] Kellogg catalog information on the No. 79-A coil lists resistances that are 2 to 4 ohms higher than actual measured values, as shown here. These are the only significant differences found between measured and listed values.

From another point of view, it would be more logical to put the primary winding (larger wire) on the inside to reduce resistance in the dc current loop and to reduce the overall size of the coil. In 1918, Western Electric made this change in the No. 46 coil, which was introduced to replace the No. 20 coil. The No. 46 coil also had a slightly lower turns ratio of 0.62. Kellogg and Stromberg-Carlson followed suit, not only putting the larger-wire winding on the inside (which they now called the primary), but also reducing the turns ratio to about 0.62. Automatic Electric did not make an improved version of their coil for the booster circuit and continued to supply D281897 into the 1940s (see Catalog #4055-D).

One final note about the hookup of coils in the booster circuit is very important. In Fig. 16-4, the primary winding of these coils is noted as being wound clockwise (cw) whereas the secondary winding is noted as being wound counterclockwise (ccw). In actuality, the two windings are wound in the same direction, and the leads of one winding are merely interchanged to effect the polarity reversal. The reason for the polarity reversal is explained in the section on transmitting. In the simpler local-battery and local-receiver circuits, coil polarity is not important.

For the discussions that follow, two electrically identical Western Electric telephones with the booster circuit were connected to the common-battery supply shown in Fig. 16-5. Each telephone had a No. 323 transmitter, a No. 144 receiver, a 1-microfarad condenser, and a No. 46 coil. Properties of the transmitter and receiver were given in Chapters 2 and 3. As with the local-battery measurements of the previous chapter, the direct current through the transmitter was about 30 milliamperes for the measurements to be described.

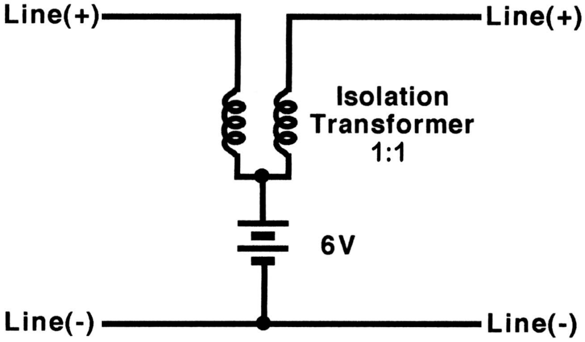

Fig. 16-5. Common-battery dc supply used for measurements made by the author.

Transmitting (ac)

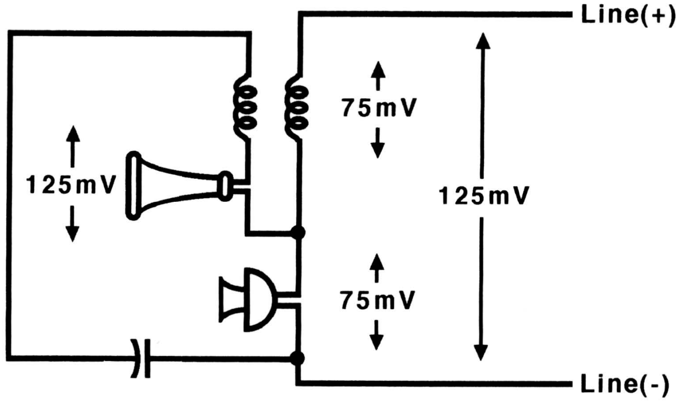

Fig. 16-6. Typical ac voltages in the common-battery booster circuit when transmitting.

Figure 16-6 shows this circuit with typical ac voltages measured when transmitting, but with the ringer omitted from the diagram as usual because the ringer does not affect the voice operation of the circuit. When transmitting, the ac transmitter voltage (typically 75 millivolts) drives a current through the receiver loop, as well as through the line circuit and hence the other (receiving) telephone connected to the line. The rather large ac current produced in the receiver loop flows through the coil secondary winding, inducing a stepped-up voltage of about 75 millivolts in the primary winding by means of the coil's transformer action.[4] This induced voltage adds to the transmitter voltage, boosting the output to almost double the transmitter voltage alone.[5]

In effect, there are now two voltage sources -- the transmitter and the coil's primary winding -- that add together to produce the line voltage of 125 millivolts. For these two voltages to add constructively, they must have the same phase relation; that is, the ac voltage of the primary winding must reach its maximum positive value at the same instant that the transmitter voltage reaches its maximum positive value. If, on the other hand, one reached its maximum positive value when the other reached its maximum negative value, the two voltages would subtract. To get these two voltages in phase so they will add together, the primary and secondary coil windings must have opposite polarities. Hence, the secondary must be connected in a counterclockwise sense if the primary is connected in a clockwise sense. If the coil windings are not connected in this way, the two voltages will subtract and the booster circuit will not work.[6]

The current in the receiver circuit, which has produced this nice boost in line voltage, unfortunately flows directly through the receiver and produces a large receiver signal in the transmitting phone. This receiver voltage of about 125 millivolts is as large as the line voltage, and represents an enormous sidetone (see Chapter 17 for a discussion of sidetone). This was a very undesirable side effect of getting a strong voice signal on the line.

Receiving (ac)

Figure 16-7 shows typical voltages in the booster circuit when it is receiving. The voltage source now is the line voltage (125 millivolts), which is dropped across the primary winding (90 millivolts) and the transmitter (35 millivolts). In this case, the 90 millivolts across the primary winding induces a stepped-down voltage in the secondary winding, and this combines with the other voltages in the receiver loop, leaving a net value of about 45 millivolts across the receiver.

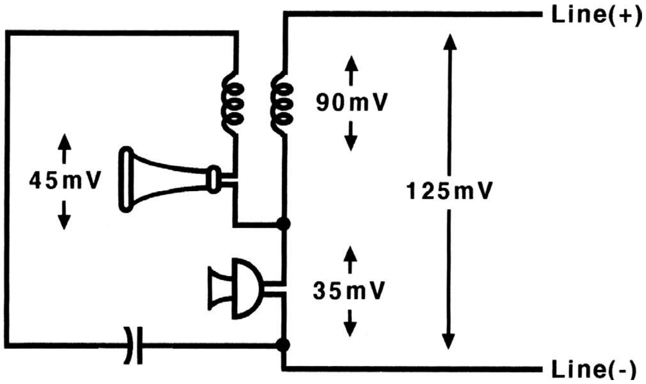

Fig. 16-7. Typical ac voltages in the common-battery booster circuit when receiving.

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[4] By convention, turns ratios are always given as the ratio of the number of turns in the secondary to those in the primary. Because the induction coil is functioning in reverse, so to speak, when transmitting, the step-up is given by the ratio of the turns in the primary to those in the secondary, the inverse of the value in Table 1 (i.e., 1 / 0.62 = 1.6).

[5] See Adding Voltages in the Appendix for the explanation of why these two measured voltages do not add up exactly.

[6] Miller (1933, 127) reports a 12-decibel, or four-fold, loss in signal strength when the coil polarity is wrong.

In summary, the booster circuit partially overcomes all three of the shortcomings of a simple series circuit. Essentially all of the direct current is kept out of the receiver, impedance matching is improved (yielding better power delivery), and the line voltage has been boosted (leading to lower line losses and less noise). However, the line voltage is still little more than half that put on the line by the standard local-battery circuit, and the large sidetone is objectionable. Thus, a price has been paid in terms of degraded performance for the economy of a common-battery system.

The sidetone in the booster circuit was, in fact, so objectionable that provisions were made for an alternate hookup for reduced sidetone operation for telephones that were installed on very short lines. This alternate hookup merely converts the booster circuit into a local-receiver circuit with its low line voltage and neutral sidetone. True sidetone suppression will come in circuit developments discussed in the next chapter.

Finally, another practical problem was created by the booster circuit in its customary hook-up. When the receiver is lifted off the hook, the condenser discharges, producing a large current pulse in the receiver circuit, and this current pulse is heard as a loud click in the receiver. More will be said on this subject when discussing particular wiring diagrams for handset desk stands.

Examples of the Booster Circuit

Two groups of telephones used the booster circuit: (1) candlestick desk stands with subsets, and their compact wall phone counterparts, and (2) handset desk stands and space savers with subsets. Examples of complete wiring diagrams for these phones follow.

Candlestick Without a Dial

The simplest and one of the earliest applications of the booster circuit was in the non-dial candlestick desk stands, and Fig. 16-8 shows this wiring diagram. In Fig. 16-8, the terminal markings, which are color-coded, correspond to a Western Electric No. 20AL or 40AL desk stand with a No. 334A, 534A, or 584A subset. With somewhat different terminal markings, this is also the wiring used for the Western Electric No. 20B desk stand, the Stromberg-Carlson No. 986 desk stand, the Western Electric No. 295A subset, the Stromberg-Carlson No. 1156BYZ subset, the Kellogg No. F602 subset, the Western Electric No. 293 compact wall phone, and others. Kellogg and Automatic Electric candlestick desk stands and compact wall phones generally had a 4-contact hook switch (two SPST switches), and were wired in a slightly different way; the wiring used with those switches will be shown below.

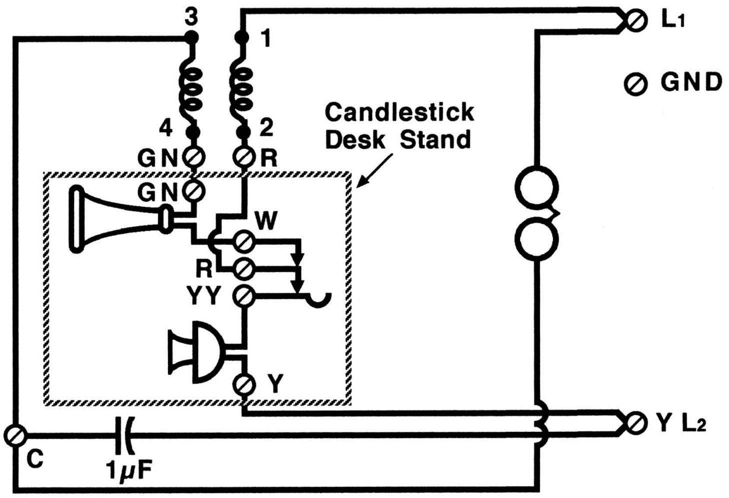

Fig. 16-8. Wiring of typical non-dial candlestick desk stand and booster subset, showing color-coded terminal markings.

The similarity to the basic circuit in Fig. 16-4 is apparent.[7] Notice that contacts YY and R of the hook switch make contact first, thus establishing stable direct current before the receiver is switched into the circuit (contacts W and R). This reduces receiver click, but it does not eliminate it because of further condenser discharge. Common-battery circuits, which have condensers in their direct current loops, have noisy hook switch operation compared with the quiet local-battery circuits. Also notice from Fig. 16-8 that extensive color-coding is being used. The receiver cord (white and green leads) and the 3-conductor subset cord (green, red, and yellow) all match the terminal markings. The later anti-sidetone circuits will require a four-conductor cord, and all future wiring is color-coded.

Hookup for Reduced Sidetone

Because the sidetone was so large in the booster circuit, provisions were made for an alternate hookup. The following instructions can be found inside the Western Electric subsets:

> For sidetone reduction reverse the yellow and red cord conductors at the desk set box terminals. This side tone reduction circuit should only be used in cases where there is annoyance from noise or side tone.

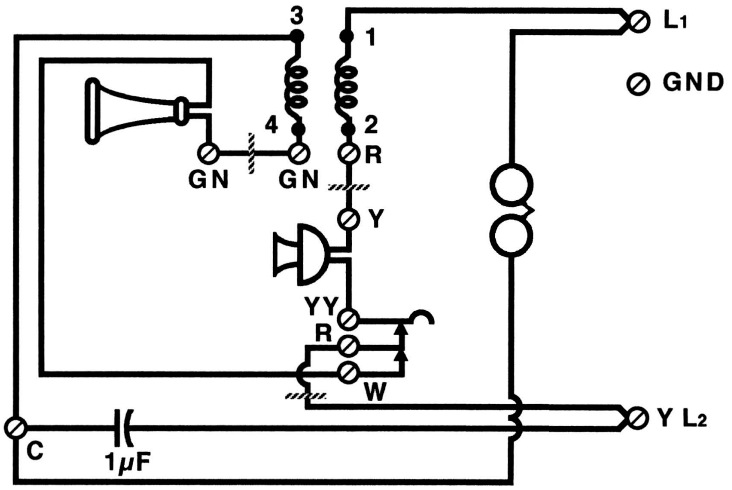

Fig. 16-9. Alternate hookup for a candlestick desk stand and booster subset to reduce sidetone.

A similar note can be found in Stromberg-Carlson and Kellogg subsets, and the same procedure was also used by Automatic Electric (Burden/AE 1948, 79). Following these instructions results in the circuit in Fig. 16-9. By comparing Fig. 16-9 with Fig. 16-2, the circuit is seen to be a local-receiver circuit with two modifications. First, there is a single inconsequential point of contact between the receiver circuit and the transmitter circuit at the hook switch. This is analogous to the connection in local-battery sets and has no effect on performance. Second, the condenser has been left in the receiver circuit, whereas the simple local-receiver circuit does not use a condenser. Although this has some effect on performance, the condenser completes the receiver circuit, forming a type of local-receiver circuit.

Candlestick Desk Stand with a Dial

The circuit for Western Electric candlestick desk stands and booster subsets was the first one used by the Bell System for dial service, and the wiring for these phones is shown in Fig. 16-10. The wiring of the subset for the dial candlestick is, of course, identical to that for the non-dial candlestick as shown in Fig. 16-8, and the wiring of the desk stand in Fig. 16-10 is like that in Fig. 16-8, except for the three switches of the dial. The dial switches in Fig. 16-10 are shown in the talking position, rendering the circuit equivalent to that of Fig. 16-8.

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[7] Early Western Electric sets with the No. 20 coil used a 2-microfarad condenser as did the Stromberg-Carlson No. 1156BYZ subset. Others used a 1-microfarad condenser.

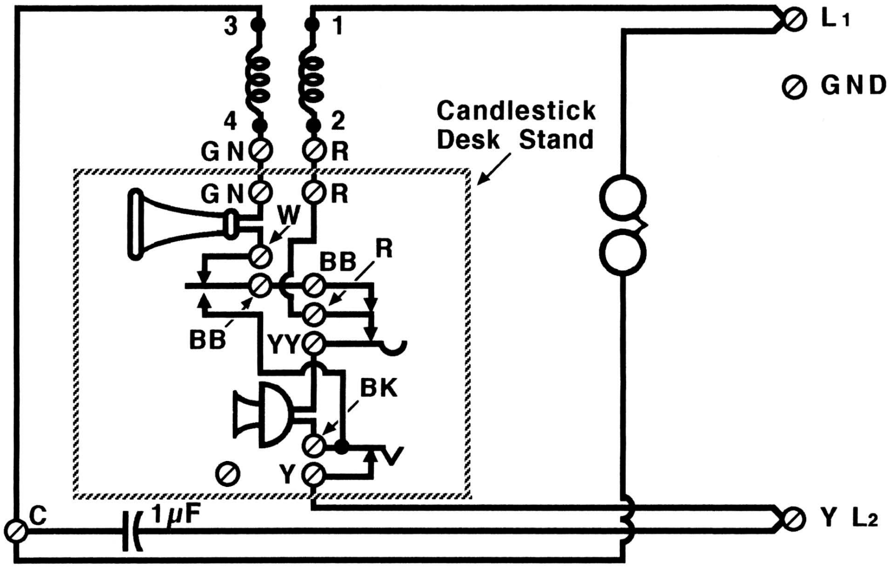

Fig. 16-10. Wiring of Western Electric candlestick desk stand with dial and booster subset, showing switch contacts of the dial.

During dial rotation, however, several changes occur. First, contacts W and BB are opened, preventing any current from flowing through the receiver. This keeps dial pulses (loud clicks) from being heard in the receiver. Second, contacts BB and BK are closed, shorting out the transmitter. This reduces resistance in the line circuit, giving larger current pulses at the central office. These two shunt switches remain in their respective positions until dial rotation stops. Finally, the impulse switch contacts BK and Y bump open a number of times during dial rotation -- the number of switch openings corresponding to the number being dialed -- thus creating the dial pulses.

Because the impulse switch opens and closes a relatively high-voltage circuit (generally 48 volts dc), dialing creates radio interference. The very rapid increase in current that occurs when the switch makes contact is in some ways equivalent to creating a cluster of high-frequency (radio frequency) current pulses. By shorting out these high-frequency components, radio interference can be eliminated. In the early Western Electric dial telephones, this short-circuiting was accomplished with a No. 61 filter, whose equivalent circuit is shown in Fig. 16-11. This radio interference filter is, in fact, just a rolled foil-and-paper condenser in a can, but one of the foil strips has an electrode at each end connected to the red and yellow leads. Because this foil strip is rolled many times, it has an inductance like a coil; the strip also has a resistance. In the filter, radio-frequency components find a low-impedance pathway through the condenser (approximately 0.5 microfarad) that bypasses the impulse switch whether it is open or closed. Thus, the radio-frequency currents will be short-circuited around the impulse switch, as desired.

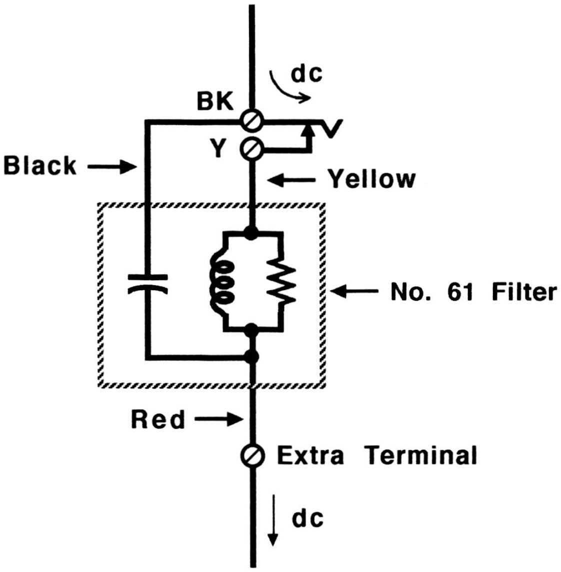

Fig. 16-11. Circuit of Western Electric radio-interference filter to reduce dialing noise in nearby radios.

To install the filter (refer to Figs. 16-10 and 16-11), the yellow wire from the subset was removed from dial terminal Y and connected to an extra terminal provided on the mounting bracket of the filter. The red wire from the filter was also connected to that extra terminal. Then, the yellow and black wires from the filter were connected to the Y and BK dial terminals as shown in Fig. 16-11 to complete the installation.

Such a filter is found on some, but not all, dial telephones and can be removed without affecting the performance of the phone, although the condenser in the filter was also found to reduce arcing (and burning) of the impulse switch contacts. In fact, telephone dial noise is much less of a problem with today's highly selective radios than it was with the broad-band receivers of the 1930s.

Handset Desk Stand

In order to use a handset cord with only three conductors, it was seen in the previous chapter that a 4-contact hook switch was required instead of the 3-contact switch used earlier. Similarly, the constraint of a 3-conductor handset cord requires a 4-contact shunt switch (two SPST switches) rather than the 3-contact shunt switch (SPDT switch) used on the dial for the candlestick desk stands. Hence, a different dial (No. 2H or 4H for handsets) with an extra contact is required in these applications (see Chapter 7).

The wiring of a handset desk stand (Western Electric A, B, or D-type) with a booster subset is shown in Fig. 16-12, and the resulting complete set is referred to as a No. 102 telephone. The dial in this desk stand requires two short jumper wires, as shown in the figure. The wiring of the subset is of course identical to that in Figs. 16-8 and 16-10, and the circuit for the desk stand is equivalent to that of the candlestick desk stand in Fig. 16-10. As with the dial candlestick, shunt switch contacts W and BB in the handset desk stand open to prevent dial clicks in the receiver, and contacts R and BK close to short out the transmitter. The impulse switch contacts BK and Y again produce the dial pulses. The circuit in Fig. 16-12 is also similar to that for the Western Electric C-type space saver with a booster subset, except that several extra terminals are used in the space saver to accommodate its remotely mounted dial. This complete set is referred to as a No. 101 telephone.

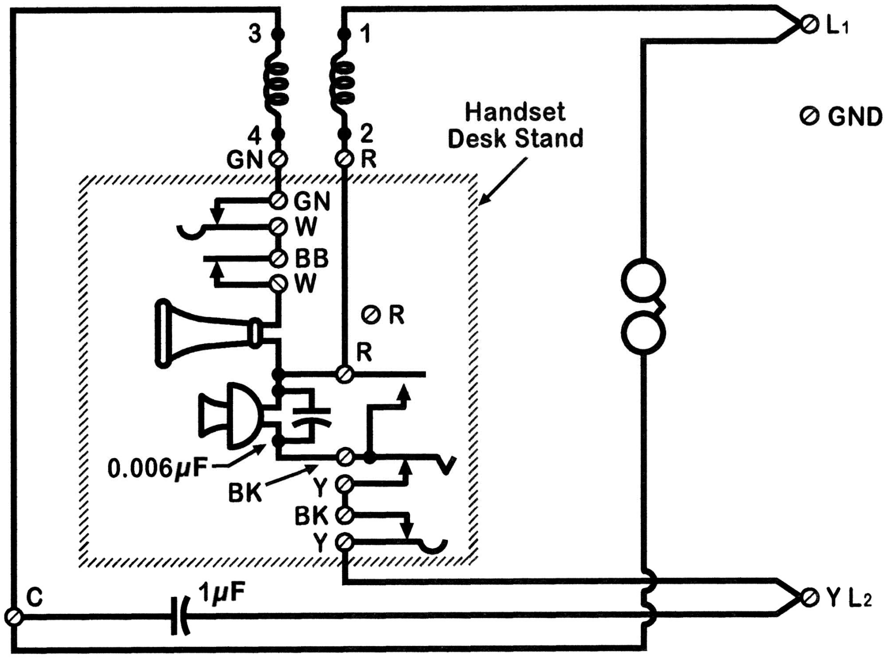

Fig. 16-12. Wiring of Western Electric handset desk stand and booster subset, showing extra hook switch and dial switch contacts required for a 3-wire handset.

The non-dial version of this telephone is connected as follows. The white lead of the handset is connected to W on the hook switch. The black lead of the handset is connected to BK on the hook switch. The red lead of the handset is connected to the tie-point R in the desk stand, as is the red lead from the subset (this tie-point is not used in the dial version). Color-coding is thus maintained. Simplification of this conversion between dial and non-dial versions will appear in the 300-type telephones.

It was found that the large condenser discharge, which results from hook switch operation and causes loud receiver clicks, also produces a current pulse through the transmitter that results in electrical packing or “cohering” of the carbon granules (Jones and Inglis 1932, 258). The granules would stick together and this would reduce the efficiency of the transmitter. By connecting a relatively small 0.05-microfarad condenser across the transmitter (see Fig. 16-12), the current pulse could be largely shunted around the transmitter. This condenser has an impedance at 1,000 cycles per second that is more than ten times that of the transmitter’s resistance such that very little ac current bypasses the transmitter in the voice frequency range. Because of this cohering problem, a 0.05-microfarad condenser was built into the transmitter holder in Western Electric’s E1 handset and was available as an option in the F1 handset.

As a result of somewhat different electrical properties of the later anti-sidetone circuits (see next chapter), the condenser discharge associated with hook switch operation was substantially reduced, thus significantly decreasing receiver clicks and eliminating the cohering of carbon granules in handsets used with those circuits. Further, on the candlestick desk stands and compact wall phones that preceded the handset desk stands, the mechanical impact of using the hook switch would shake the carbon granules and keep them loose. Hence the 0.05-microfarad transmitter-bypass condenser was only needed in handsets that were used with the booster circuit. This condenser will not be shown in diagrams for other circuits although it will be present, with no consequences, in E1 handsets and may be present in F1 handsets.

Kellogg Circuit with Different Switches and Dials

The Kellogg dial (see Chapter 7) is different from the Western Electric dial, thus requiring a slightly different hookup. The wiring of a Kellogg desk stand with this dial is shown in Fig. 16-13.

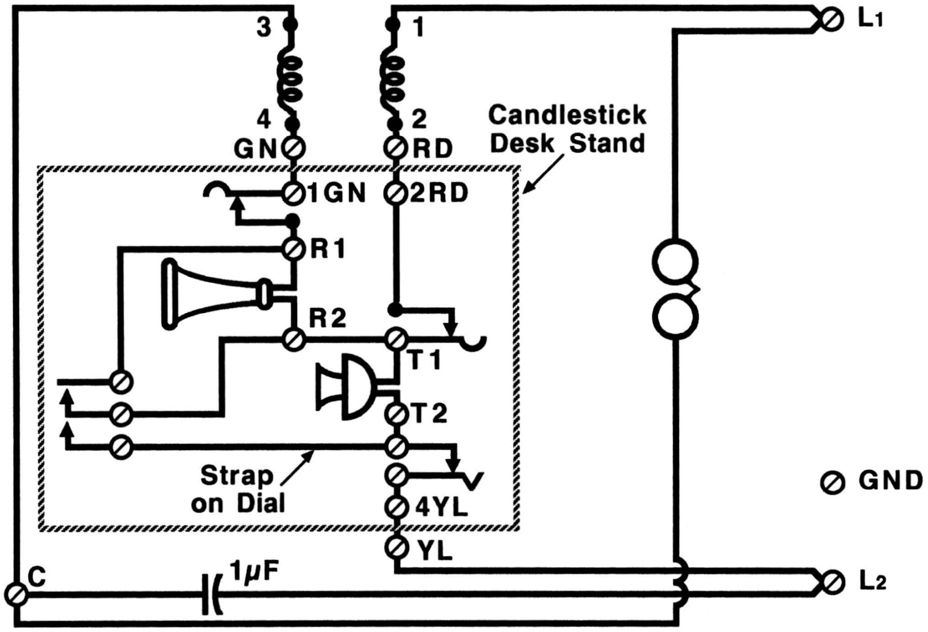

Fig. 16-13. Wiring of Kellogg candlestick desk stand and booster subset, showing different dial switch and hook switch arrangements.

Because Kellogg used a 4-contact hook switch in its candlestick and handset desk stands, the circuit shown in Fig. 16-13 applies to both (e.g., the No. 301 candlestick desk stand and the No. 730 handset desk stand). Like the Western Electric circuit, one shunt switch on the dial shorts out the transmitter during dial rotation. However, the other shunt switch shorts out the receiver, rather than opening that branch of the circuit, to avoid dial clicks. The matching booster-circuit subset for these desk stands is the Kellogg No. 602. Western Electric, Kellogg, and Stromberg-Carlson subsets with the booster circuit are almost identical, have similar terminal markings, and all are interchangeable.

Kellogg desk-stand wiring was a little less standardized than others. For example, Kellogg often used dials made by Automatic Electric Co., and the contact arrangement on those dials was different still. Nevertheless, the shunt switches were connected so that they shorted out both the transmitter and receiver during dial rotation like the Kellogg dial. Yet another variation in wiring appears in the Kellogg F817 compact wall phone, which had its hook switch sections located at the No. 1 and No. 3 ends of the coil, rather than at the No. 2 and No. 4 ends, as shown in Fig. 16-13. These variations are all electrically insignificant.

Automatic Electric Circuit with Different Switches and Dial

The Automatic Electric dial (see Chapter 7) is very similar to the Kellogg dial, and the switch arrangements in Automatic Electric's desk stands are also similar to Kellogg's. The complete circuit for the Automatic Electric Type 21 candlestick desk stand with the booster circuit is shown in Fig. 16-14. This circuit would also apply to Automatic Electric's Type 1A handset desk stand. It should be noted that the Automatic Electric desk stands have terminal strips with terminals numbered from 1 to 8, and the components within the desk stand must be hooked up to the terminal strips to match the diagram. This internal hookup is different when the desk stands are used with the later anti-sidetone circuits (Chapter 17).

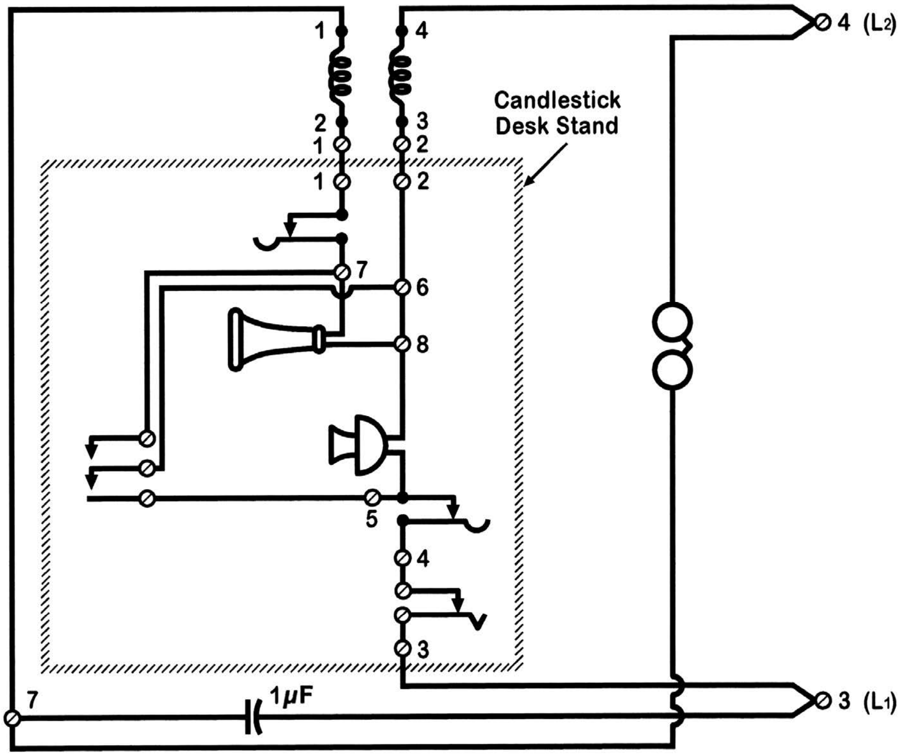

Fig. 16-14. Wiring of Automatic Electric candlestick desk stand and booster subset.

Other Early Common-Battery Circuits

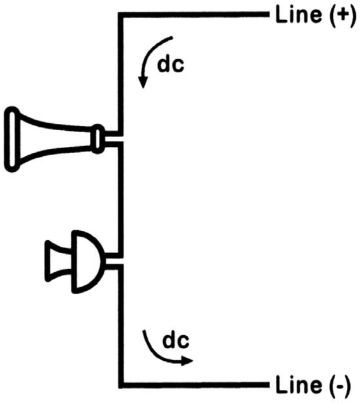

Fig. 16-15. Simple series circuit for common-battery systems.

The simplest common-battery circuit consists of a transmitter and receiver in series as shown in Fig. 16-15. It is, of course, possible to construct such a circuit out of any transmitter and receiver, with the receiver polarity selected to increase the pull of the polarizing magnet as done when local-battery sets were connected to common-battery lines (see the end of Chapter 15). Nevertheless, the performance of the receiver would be degraded and the diaphragm might even stick to the pole pieces (freeze) in extreme cases. These receiver problems were alleviated in a special dc receiver made by Automatic Electric that could be used on their Type 21 candlestick. The receiver had no permanent magnet, and the bakelite shell was weighted to make it feel like a standard receiver. The polarizing magnetic field was generated by dc flowing through the receiver's coil windings. The receiver had a relatively high ac impedance (Table 3-1) and its circuit was poorly matched to the low resistance transmitter; with no voltage step-up or boost, this circuit put a low-voltage voice signal on the line. Further, like all circuits in which dc is present in the receiver, hook switch operation created objectionably loud clicks.

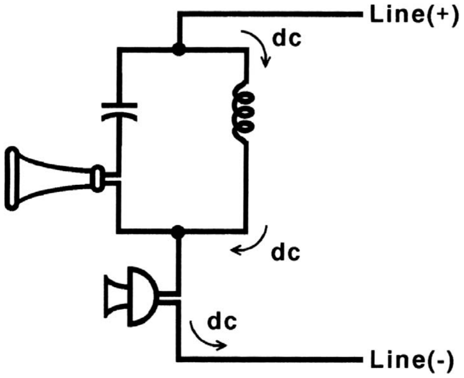

Fig. 16-16. Kellogg's retardation-coil circuit for common-battery systems.

Kellogg used a circuit patented by William Dean that kept dc out of the receiver, and this circuit is shown in Fig. 16-16.[8] This retardation-coil circuit was used, for example, in the Kellogg Grabaphone (see Chapter 11). In that application, the condenser has a capacitance of 0.5 microfarads and the No. 16A retardation coil has an impedance of about 525 ohms at 1,000 cycles per second. This circuit sets up parallel current paths in the vicinity of the receiver, incorporating the condenser in one path and the coil in the other. The condenser blocks direct current from going through the receiver, yet it lets the ac voice current pass through. The coil in the other path has roughly twice the ac impedance of the condenser and receiver, thus retarding the ac current flow through the coil and forcing it into the receiver path.

With no voltage step-up or boost, this circuit puts a low-voltage voice signal on the line. The impedances of the transmitter and its load are not matched either in this circuit, resulting in poor power delivery. Further, this particular retardation coil has a relatively low impedance (only about two-and-a-half times that of the receiver path), permitting about a third of the voice current to flow through the coil and be wasted.[9]

By connecting the ringer between Line (-) and the point where the receiver is connected to the condenser, the condenser shown in Fig. 16-16 also blocks direct current from flowing through the ringer. It is typical of these early common-battery circuits that hookups were found to get double duty from the then-bulky condenser.

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[8] William W. Dean, "Subscribers Telephone-Circuit," Patent No. 747,331, dated December 15, 1903; application filed December 23, 1902.

[9] The more effective retardation coil in Western Electric's No. 307 local-battery telephone has an impedance of approximately 2,500 ohms at 1,000 cycles per second. See Chapter 18.

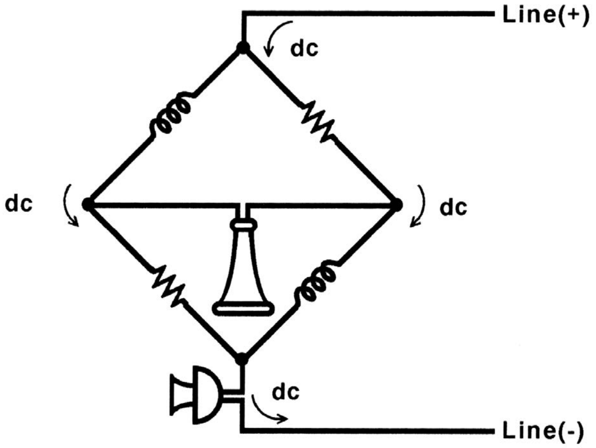

Fig. 16-17. Dean's bridge circuit for common-battery systems.

Dean developed another circuit incorporating retardation coils after he left Kellogg and started his own company. He utilized the Wheatstone bridge principle (see the Appendix) in this circuit, widely known as the Dean bridge circuit, shown in Fig. 16-17. It used two retardation coils and two resistors in opposing legs of a Wheatstone bridge. The dc resistances of the coils and resistors were low and were all of exactly the same value. Therefore, dc current through the circuit produced equal dc voltages across all legs of the bridge such that the dc voltage drop across the receiver was zero. The bridge was therefore balanced with regard to direct current and no direct current would flow through the receiver.

The ac voice signal, however, would see high impedances in the two coils, and the ac current would take the zig-zag path of least resistance through the resistors and the receiver. Dean's bridge circuit, like the retardation circuit described previously, did not require a condenser; however, a condenser was still required for the ringer.

Stromberg-Carlson used the simple local-receiver circuit shown in Fig. 16-2 in early phones like its No. 3 tapered-shaft desk stand (not shown, but similar to the Western Electric desk stand shown in Fig. 8-8 of Chapter 8). The coil, which is mounted in the base of that desk stand, is electrically identical to the Stromberg-Carlson No. 15A coil used in early local-battery circuits (Table 15-1 of Chapter 15). This is exactly as should be expected, because the amount of step-up required to match the low transmitter impedance to the higher receiver impedance is the same as the step-down required to go the other way. The symmetry of the local-battery and local-receiver circuits was rather advantageous, and this desk stand could be connected to produce either circuit without changing the coil. The advantage of not requiring a condenser in the talking circuit was lost, however, as a condenser was needed in series with the ringer (mounted in a separate bell box for this desk stand).

One final circuit that will be mentioned is the Stromberg-Carlson circuit used in Kansas City. This circuit, shown in Fig. 16-18, has some of the characteristics of the Bell booster circuit because part of the transmitter current goes directly through the receiver circuit, and induced voltages across the primary tend to increase line voltage when transmitting. However, the Kansas City circuit did not perform as well as the booster circuit.

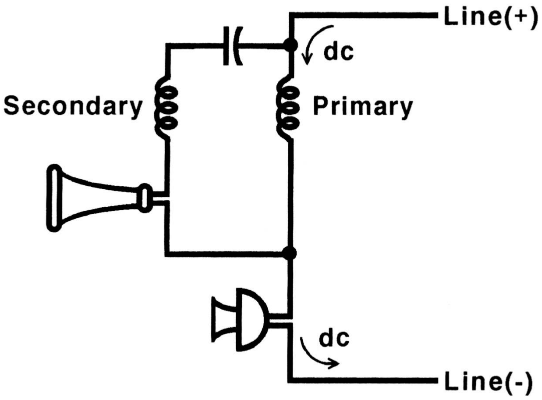

Fig. 16-18. Stromberg-Carlson's Kansas City circuit for common-battery systems.

Miller reports results of tests made by the Stromberg-Carlson laboratories to compare the performance of various circuits, and these results are given in Table 16-2 (Miller 1933, 128). In all cases, the distant telephone in the test had the standard Bell booster circuit. While Miller points out this fact, he does not point out that the further mismatch of impedances (for the non-booster circuits) between the phone being tested and the distant telephone would have biased those results. A better test would compare the performance of matched pairs of telephones, as done in the author's measurements. Nevertheless, Table 16-2 shows that none of the other circuits performs as well as the booster circuit, and Automatic Electric, Kellogg, and Stromberg-Carlson adopted the Bell booster circuit after its patent expired in 1918.

Table 16-2. Comparison of the performance of early common-battery circuits.

Circuit	**Transmitting**	**Receiving**
Bell Booster (taken as standard)[a]	Standard	Standard
S.C. Local Secondary	-3.0 decibels	-1.0 decibels
S.C. Kansas City	-2.5 decibels	-1.5 decibels
S.C. Booster[a]	Same as Std.	Same as Std.
Kellogg Retardation	-4.3 decibels	Same as Std.
Kellogg Booster[a]	Same as Std.	Same as Std.

[a] All three booster circuits had the newer coils with turns ratios around 0.6 (see Table 16-1).

Chapter 17
Common-Battery, Anti-Sidetone Circuits

Sounds in a receiver that are produced by the transmitter of the same telephone are called a sidetone. Clearly, a sidetone is not particularly useful as the purpose of a telephone is to produce sounds in a distant receiver.

Around the turn of the century, George Campbell, working for the Bell System, showed that it was possible to construct anti-sidetone circuits in which none of the power generated by the transmitter would be dissipated in the receiver of the transmitting phone. A very brief description of Campbell's work and of other basic telephone circuits is given in a little booklet by Eppes (1981). Campbell's own papers are highly mathematical and beyond the scope of this book (Campbell and Foster 1920).[1]

The sidetone is, in fact, quite harmful to telephone communications, but that was not fully recognized at first. One drawback was recognized early, however. The sidetone, which was quite large in the booster circuit, was known to produce feedback oscillations when the receiver was held too close to the transmitter. This howling problem, which delayed the widespread introduction of handsets by the Bell System, was eventually solved by the use of solid bakelite in the handset, although the anti-sidetone circuit then under development was intended to solve that problem.

Interestingly, Eppes reports that it was not until 1936, several years after this circuit was introduced, that the full value of the anti-sidetone circuit was realized (Eppes 1981, 5; see also Foley 1939). Two major advantages had not been anticipated. First, it was found that people would speak more loudly into an anti-sidetone set because they did not hear their own voice so loudly; this produced a stronger transmitter signal. Second, and perhaps more importantly, it was found that background noise around the listener was not picked up, thus making listening to a weak signal much more effective.

Around 1930, Western Electric introduced a common-battery, anti-sidetone circuit, which is described in the next section. Several years later, after recognizing the full value of anti-sidetone circuits, Western Electric also introduced a local-battery, anti-sidetone circuit, and that circuit is described in the next chapter. Common-battery, anti-sidetone circuits introduced by Kellogg, Stromberg-Carlson, and Automatic Electric, are described later in this chapter.

Principles of the Western Electric Anti-Sidetone Circuit

The Western Electric common-battery, anti-sidetone circuit is shown in Fig. 17-1. While suppressing the sidetone, this circuit is still a type of booster circuit. To form the new circuit, a third, or tertiary, coil winding was added to the standard booster circuit and connected in parallel with the receiver. This tertiary winding provides an alternate path so that the secondary current, which generates the booster action when transmitting, can bypass the receiver, thereby avoiding a large sidetone. This tertiary winding is in fact wound of higher resistance wire (German silver), and should be thought of as a resistor in series with a coil winding, as shown in Fig. 17-1 -- although it is sometimes shown as a single inductive winding in Western Electric diagrams. The purpose of the so-called balancing resistor in this winding is described in the following paragraph.

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[1] The same paper appears in Campbell (1937, 119-168). In an introduction to that volume, Colpitts describes other considerable accomplishments of Campbell, including his work on line loading coils.

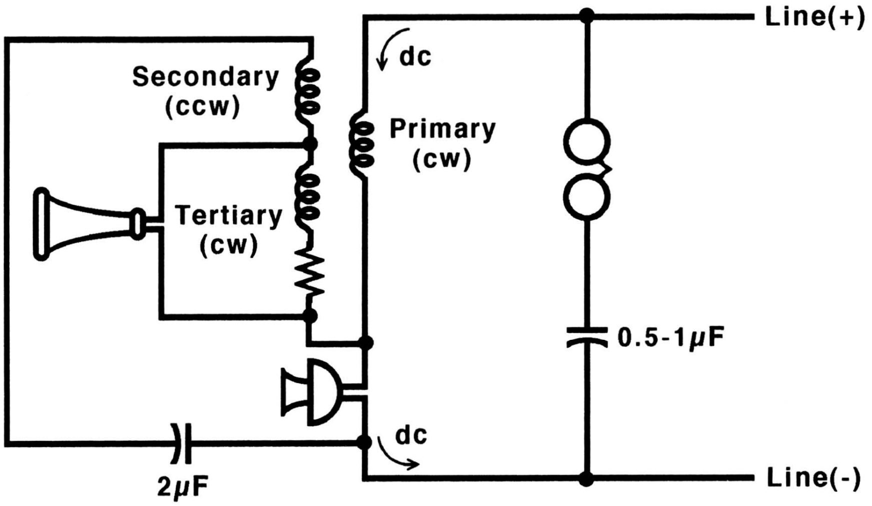

Fig. 17-1. Western Electric's anti-sidetone circuit for common-battery systems.

A second change was also made to the standard booster circuit, and this was the addition of a separate condenser in the ringer circuit. With this new arrangement, direct current is confined to the coil primary winding and the transmitter, and the insignificant dc path through the receiver of the standard booster circuit has been completely eliminated. More importantly, the condenser in the receiver loop was no longer subjected to high voltages, which are present in the ringer circuit, so a lightly insulated condenser of smaller dimensions could be used. The capacitance was then increased to 2 microfarads (only about 80 ohms at 1,000 cycles per second) without becoming too bulky.[2]

The circuit in Fig. 17-1 is one of 174 circuits studied mathematically by Campbell (Eppes 1981, 21). Although all of these circuits were efficient in transmitting and receiving, this circuit, chosen by the Bell System, has several advantages over others: (1) it uses a single condenser in the talking circuit, (2) it uses the minimum number of conductors in the cords, (3) it requires the minimum number of hook switch contacts, and (4) it has its balancing resistor in series with a coil winding. All windings of this coil are permanently connected in series, resulting in the smallest possible number of terminals on the coil. Finally, it should be noted that the secondary winding has reversed polarity relative to the primary and tertiary winding. The reason for this is covered further on.[3]

Characteristics of the Western Electric coils used with this circuit are shown in Table 17-1. The cylindrical No. 146 coil was used in very early versions of the No. 634 and 684 subsets, but was later replaced by the more common transformer-shaped (closed flux) No. 101A. A No. 101B variation of this latter coil was also used in some party line phones. The resistances and turns ratio of the primary and secondary windings of the No. 146 coil are identical to those of the Western Electric No. 46 coil for the booster circuit. Thus, it is seen that this early anti-sidetone coil was a No. 46 booster coil with an additional section wound on top.

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[2] A new receiver of lower impedance (see Chapter 3) was used with the anti-sidetone circuit so that the condenser's lower impedance still nearly cancelled out the receiver's inductive impedance as in the previous circuit.

[3] Terminology for the winding direction is confusing. Since the three coil sections are permanently connected together in a string, the leads of the tertiary are interchanged during manufacturing and the tertiary is often said to be wound counterclockwise (relatively to the primary). However, when the secondary and tertiary are viewed as transformer windings, as in Fig. 17-1, both are in effect turned upside down. Functionally, therefore, it is the secondary that is wound in a counterclockwise direction.

Table 17-1. Characteristics of induction coils used in Western Electric's common-battery anti-sidetone circuit

Characteristic	**Primary**	**Secondary**	**Tertiary**
	Western Electric No. 146		
Terminal Markings[a]	L1-R	GN-C	R-GN
Resistance, ohms	14	9	56
Turns Ratio, to primary	1.0	0.62	0.38
	Western Electric No. 101A[b]		
Terminal Markings[a]	L1-R	GN-C	R-GN
Resistance, ohms	22	19	75
Turns Ratio, to primary[c]	1.0	0.70	0.38

[a] The terminals marked YL2 on the No. 146 and 101A coils and the terminal marked GND on the No. 146 coil are not connected to the coil windings and are used merely as tie points.

[b] The 101B variation of this coil has exactly the same characteristics except terminal L1 is renamed RR and a center tap in the primary is connected to terminal M, which replaces terminal YL2 on the coil.

[c] The actual numbers of turns reported in Eppes (1981, 22) are 796 (primary), 566 (secondary), and 315 (tertiary).

For the discussions that follow, two electrically identical Western Electric telephones with this anti-sidetone circuit were connected to the common-battery supply shown in Fig. 16-5 of Chapter 16. Each telephone had an F1 transmitter, an HA1 receiver, a 2-microfarad condenser, and a No. 101A coil. Properties of the transmitter and receiver were described earlier. Direct current for the measurements was about 30 milliamperes as in earlier cases.

Transmitting (ac)

Figure 17-2 shows this anti-sidetone circuit with typical ac voltages measured while transmitting (with the ringer omitted from the diagram for simplicity). As in the standard booster circuit, the transmitter produces a current in the secondary loop, as well as in the primary circuit. Current in the secondary loop flows through the balancing resistor, the tertiary winding and through the secondary winding, and these two windings together induce a voltage across the primary winding. This induced voltage (about 75 millivolts) adds to the transmitter voltage (also about 75 millivolts), boosting the output to a higher value (125 millivolts) just as in the standard booster circuit.

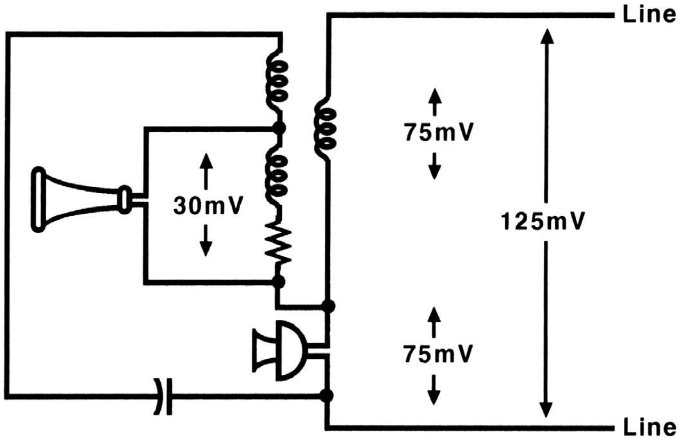

Fig. 17-2. Typical ac voltages in the Western Electric anti-sidetone circuit when transmitting.

The anti-sidetone feature of the circuit works as follows (Gibbon 1938). Current flowing through the balancing resistor produces a voltage across it (Ohm's law). Currents in the primary and secondary windings induce a voltage across the tertiary winding. The coil has been designed such that the induced voltage across the tertiary winding is approximately equal to, but of opposite sign from, the voltage across the balancing resistor.[4] Hence, the sum of those two voltages is nearly zero. The receiver, therefore, sees a near-zero voltage and very little current flows through it (small sidetone); most of the current flows through the tertiary winding and balancing resistor, bypassing the receiver as desired.

It is theoretically possible to find a balancing impedance that would have exactly the same voltage magnitude as the tertiary winding, thereby resulting in no sidetone at all. That cannot be done with a simple resistor, however. Because the desired impedance of the ideal balancing component will depend on the line impedance, which contains some reactive contributions (inductance and capacitance), a more complex component would be required to achieve the ideal value. Such a component is used in the next circuit, described in Chapter 19. In the present circuit, however, a simple resistance is employed and the sidetone voltage is just 30 millivolts, less than a quarter of that in the old booster circuit.

Receiving (ac)

Figure 17-3 shows this anti-sidetone circuit when it is receiving. The voltage source is now the line voltage (125 millivolts), and it is dropped across the primary winding (about 95 millivolts) and the transmitter (30 millivolts), still very similar to the standard booster circuit.

Again, currents in the primary and secondary windings will induce a voltage across the tertiary winding. And current flowing through the receiver will produce a voltage across it. By appropriate coil design, the voltage across the tertiary winding can be made equal to the voltage across the receiver; hence, the voltage across the balancing resistor will be zero and no current will flow through the resistor (or the tertiary winding). Therefore, when receiving, the anti-sidetone circuit behaves as if the tertiary winding and balancing resistor were not present -- just like the standard booster circuit.

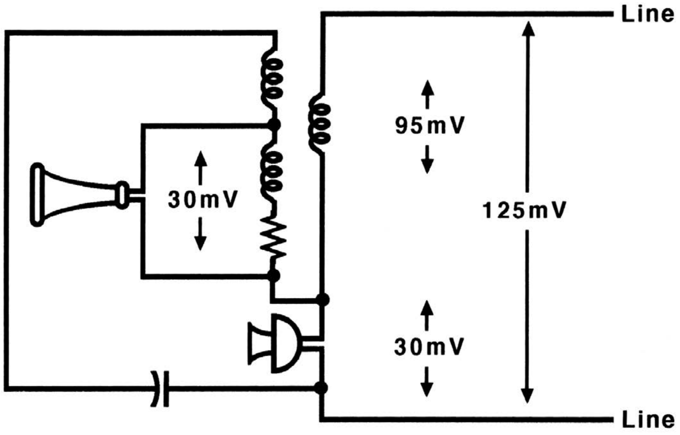

Fig. 17-3. Typical ac voltages in the Western Electric anti-sidetone circuit when receiving.

Several observations are of interest. First, in practice, the coil windings would be designed to produce the receiving properties just described. This is called neutralizing balance. Because the voltage across the balancing resistor is zero when receiving, neutralizing balance can be achieved without regard for the size of the balancing resistor. Therefore, the designer is free to choose any value for the balancing resistor that is needed to achieve the properties described above when transmitting (i.e., low sidetone). That is called sidetone balance. Hence, neutralizing balance and sidetone balance can be achieved simultaneously.

A second observation is that the receiver voltage when receiving (30 millivolts) is lower than the receiver voltage of the standard booster circuit when receiving (45 millivolts, as seen in Fig. 16-7 of Chapter 16). However, the booster circuit measurements were made with a No. 144 receiver, which was typical for that circuit but has a higher impedance (240 ohms) than the HA1 receiver (120 ohms) used with the anti-sidetone circuit. When these differences are taken into account, it is found that the receiving efficiency (power delivered) of the two circuits is approximately the same, as it should be for neutralizing balance in the anti-sidetone circuit.

In summary, the Western Electric anti-sidetone circuit has done away with the large sidetone of the standard booster circuit. It still has a sidetone, however, and its sidetone is about the same magnitude as its

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[4] This sign reversal requires that the tertiary winding be of opposite polarity than the counterclockwise secondary winding.

receiver voltage when receiving. Thus, this anti-sidetone circuit has only achieved a neutral sidetone, much like that of the standard local-battery circuit. Further, the anti-sidetone circuit, like the booster circuit, still produces little more than half the line voltage of the local-battery circuit.

Examples of the Western Electric Anti-Sidetone Circuit

The first appearance of the Western Electric anti-sidetone circuit was in the handset desk stands (A, B, and D-type) and the wall-mounted space saver (C-type) with the anti-sidetone subsets (Nos. 634 and 684), so the wiring for these sets is discussed first. This circuit was also used with the 100-series anti-sidetone candlestick modifications, the No. 653 compact wall phone, and of course the 300-series telephones.

Handset Desk Stands

The wiring diagram for a Western Electric handset desk stand with a dial and an anti-sidetone subset is shown in Fig. 17-4, and this complete set is referred to as a No. 202 telephone. Similarity to the basic circuit in Fig. 17-1 should be apparent. The desk stand's internal hookup is the same as when it is used with a booster subset (see Fig. 16-12 of the previous chapter), and the functioning of the dial and the conversion to a non-dial hookup are exactly like that described in Chapter 16. The only difference in the desk stand's connection is that a fourth lead (black) in the cord from the subset is connected to terminal BK.

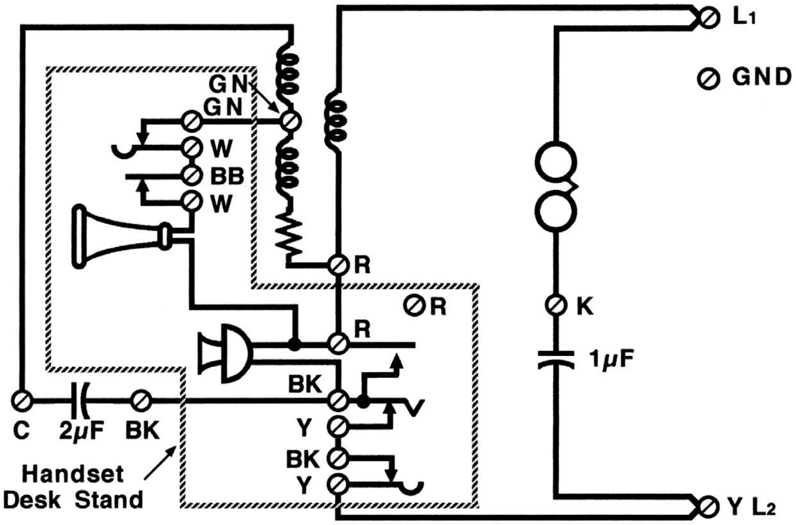

Fig. 17-4. Wiring of a Western Electric handset desk stand and anti-sidetone subset, showing the fourth lead connected to the desk stand.

The location of the hook switch contacts BK and Y in this circuit is important. Because all sections of the coil are permanently connected (unlike the coil in the booster circuit), the location of this switch at Y rather than at R not only stops current from going through the transmitter, but it also disconnects the 2-microfarad condenser from the dc line voltage when the phone is on-hook. Disconnecting this dc voltage avoids charging up that condenser and prevents a subsequent large discharge in the receiver circuit. Thus, an extra benefit has been derived from the 4-contact hook switch, which was required for use with a 3-wire handset.

For the dial version, connection of the fourth lead of the subset cord is made directly to BK on the dial, thus keeping the impulse switch and related dial-pulse noise out of the circuit loop containing the 2-microfarad condenser. For the non-dial version, this black lead is connected to BK on the hook switch.

These older sets used ringers with lower impedances than the later B-type ringers, so the larger 1-microfarad condenser was used in the ringer circuit. With only trivial modifications to accommodate inaccessible dial terminals, this circuit also describes the C-type and G-type wall-mounted space savers with anti-sidetone subsets to become No. 201 and 211 telephones, respectively. The No. 61 filter, which is used to reduce radio interference caused by dialing, was also used optionally on desk stands, space savers, and 300-type telephones with the anti-sidetone circuit. Filter operation and hookup for all of these anti-sidetone applications is the same as when used with the standard booster circuit, as discussed in the previous chapter.

Modified Candlestick Desk Stands

Candlestick desk stands without modification could have been used with the anti-sidetone circuit were it not for one problem. The 2-microfarad condenser would see the dc line voltage and charge up when the phone was on-hook. Thus, one hook switch section had to be located between the condenser and the line terminal, and this required two separate sets of contacts (4 leads), rather than the 3-contact hook switch that was standard. Consequently, candlestick desk stands were modified to add the extra hook switch contact.

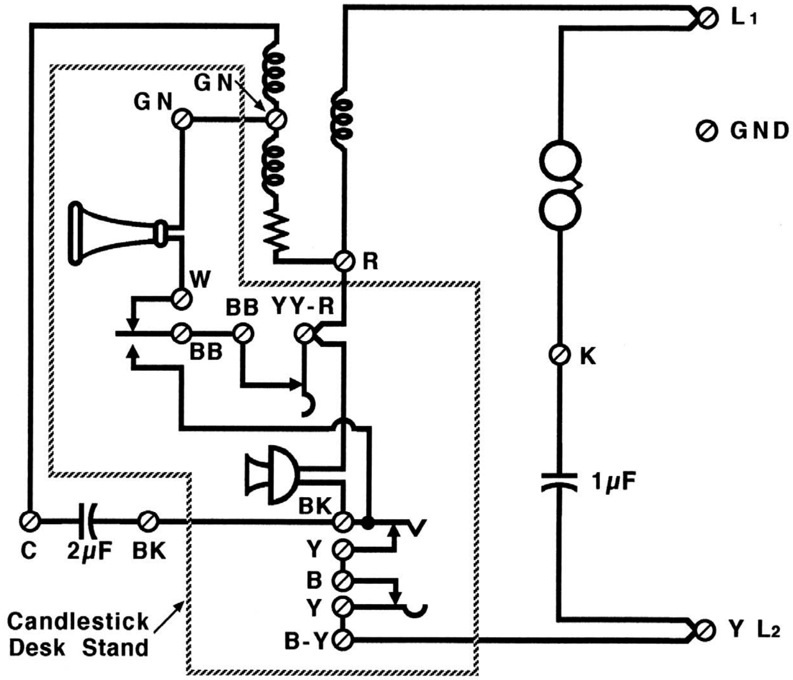

Fig. 17-5. Wiring of a modified (100-series) Western Electric candlestick desk stand and anti-sidetone subset, showing the separate hook switch sections.

Figure 17-5 shows the wiring for a No. 150AL or 151AL modified candlestick with a dial.[5] The original No. 2A dial could still be used because all four leads are available from the transmitter and receiver (unlike the 3-lead handsets). Wiring for the non-dial No. 120AL and 140AL modified candlesticks is achieved by connecting the white receiver lead to BB on one hook switch section, and by connecting together the black transmitter lead and the black lead from the subset to terminal B of the other hook switch section. As usual, hook switch contacts in the receiver circuit make contact last for quiet operation.[6]

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[5] Terminal markings on the modified candlesticks are hand stamped and may vary.

[6] Notice that an un-modified candlestick with its 3-conductor cord will work with an anti-sidetone subset. By simply omitting the connection at BK, the 2-microfarad condenser and the secondary winding of the coil are effectively eliminated from the circuit. What is left is a local-receiver circuit like that in Fig. 16-2.

300-Type Telephones

Figure 17-6 shows the wiring for the standard 300-type telephone. This hookup is, of course, quite similar to that of the handset desk stands, except that fewer marked terminals and connecting cords are required because the wiring is all contained in a single housing. There are, however, two minor differences of significance. One is the connection of the dial shunt switch for the transmitter. In the 300-type telephone, this switch also shorts out the primary coil winding, thus further reducing the telephone's dc resistance for dialing. This was not practical in the desk stands because the transmitter and the coil were in separate housings. The other difference is the use of a 0.5-microfarad condenser in the ringer circuit to match up with the higher impedance of the B-type ringer (see Chapter 6).

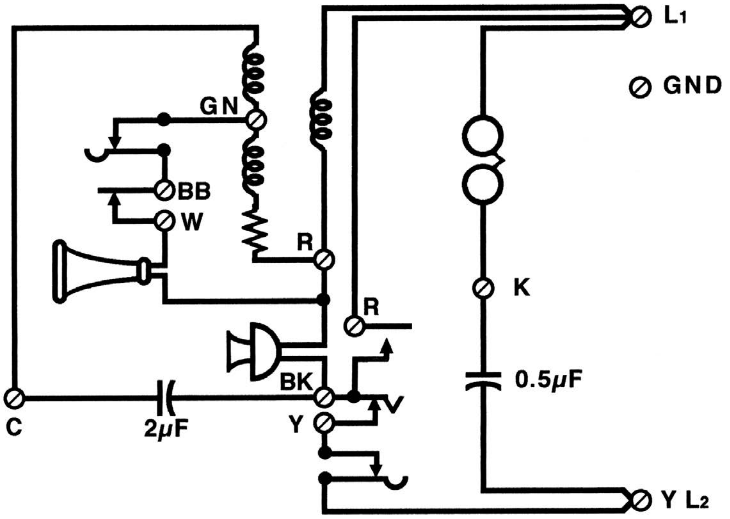


Fig. 17-6. Wiring of a typical Western Electric 300-type telephone.

Conversion from the dial version of this phone to the non-dial version was simplified by a terminal strip mounted on the back of the dial blank. The three switches on the dial were, in effect, replaced by three terminals marked W BB, Y BK, and SR (the slate/red lead went to R on the dial in a 300-type telephone). When the five leads for the dial were connected to the similarly marked terminals on the dial blank, the circuit was appropriately altered.

Wiring of the Western Electric No. 653 subset-based wall phone is functionally identical to that of the 300-type telephone, with the dial shunt switch shorting out the transmitter and primary coil winding together. However, the switch sections between the receiver and terminal GN are moved to the other side of the receiver and connected to terminal R. This relocation is done merely as a matter of convenience and has no effect on circuit operation.

300-Type Party Line Circuits

As with previous Western Electric circuits, selective ringing could be achieved by connecting the ringer between one side of the line and ground and by using appropriate relays or gas discharge tubes. Although these arrangements would selectively signal the appropriate subscriber of an incoming call on a party line, they could not identify the party who was initiating an outgoing call. Such identification was important for toll calls. One method devised to provide caller identification resulted in several permanent changes in later telephone circuits. The origin of those changes is described here.

Figure 17-7 shows the wiring of a Western Electric telephone that can identify itself to the central office. This circuit is found in the 304 and 5304 desk sets and in the 354 wall phone. These phones were equipped with the center-tapped 101B induction coil and the split-winding B2A ringer, both of which were described earlier. These phones also had a 3-section hook switch, and the extra contacts are shown near the top of the figure just above terminal RR. A non-dial phone has been diagrammed here to reduce clutter in the figure, but this circuit was usually used in dial telephones. The usual connection of the tip side of the line to L1 and the ring side of the line to L2 is reversed in this Western Electric circuit, but that reversal is unimportant for this discussion.

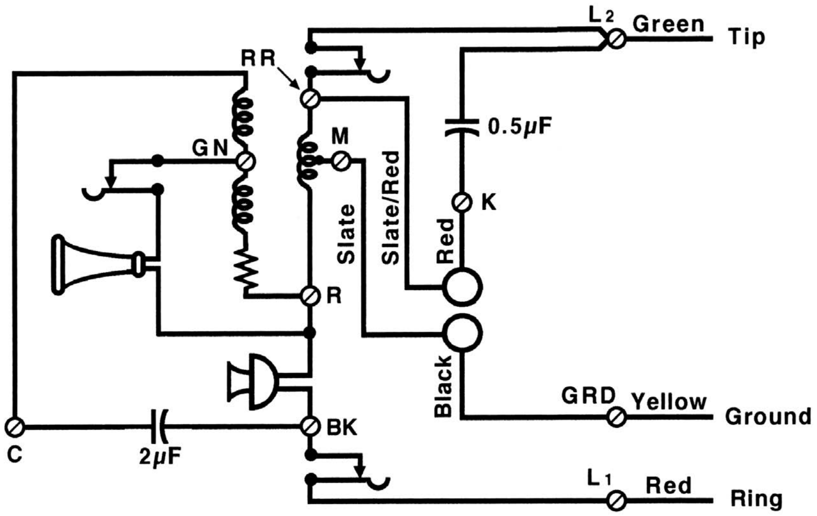


Fig. 17-7. Wiring of a Western Electric 300-type party-line telephone with provisions for caller identification.

First, consider the response of this phone to an incoming ring signal between the tip side of the line and ground. The phone is on-hook so the hook switch contacts are open. The segment of the primary coil winding between RR and M (about 11 ohms dc) has such a low impedance that the slate and slate/red leads are effectively connected together and the ringer responds normally, just like a 2-lead B1A ringer. Notice that the extra hook switch section is required to avoid an unwanted path to ground for both the tip and ring sides of the line.

Next, consider a brief period right after dialing has been completed for an outgoing call. The phone is off-hook, so switch contacts are closed as shown. During this period of about a second, battery at the central office is removed from the line and a dc voltage in a separate circuit is applied between the tip side of the line and ground. Direct current then flows from L2 via RR through half of the primary winding to M, through the 1,000-ohm coil section of the ringer (slate and black leads), and then to ground. The magnitude of this current, which is used to operate register relays at the central office, is determined by the resistance of the ringer winding (1,000 ohms in this case).

By interchanging leads, the 3,500-ohm ringer winding can be placed in this dc circuit. And for a standard 302 telephone with its ringer (and condenser) between the tip side of the line and ground, there is no dc path to ground at all (infinite resistance). Even in the presence of a high line resistance (for example, 1,000 to 2,000 ohms), the central-office equipment can distinguish between 1,000 ohms, 3,500 ohms, and an infinite resistance, thereby providing the desired caller identification.

Next, consider the ringer connections to the coil, which are arranged to reduce noise pickup from ground during voice communications. The slate lead of the grounded ringer coil section is connected to M, the center tap of the primary winding. Just as with the Hayes central-office circuit, the coil sections between this point and either side of the line provide isolation and reduce noise pickup compared with grounding either side of the line.

Finally, notice that the two coil sections of the ringer could act as a transformer. If the slate/red lead had been connected to M, an unwanted voltage picked up by the slate/red-to-red coil would be imposed on the primary winding between M and RR. By connecting slate/red to RR, this section of the ringer winding is effectively shorted out (through the hook switch and the 0.5-microfarad condenser), preventing the ringer coils from acting as a transformer.

In all future circuits (see Chapter 19), induction coils have either a center tap or a split winding and ringers have unequal split windings for caller identification. However, in the common bridging application of most modern telephones, these features are superfluous and do not affect the operation in any way.

Principles of Kellogg's Anti-Sidetone Triad Circuit

Kellogg took a different approach to get sidetone suppression and used a circuit based on the Wheatstone bridge described in the Appendix. This circuit, which Kellogg called the Triad, is shown in Fig. 17-8 in a manner that is directly comparable to Fig. A-10 in the Appendix. A more conventional diagram of this circuit, with the condensers added, is shown in Fig. 17-9.

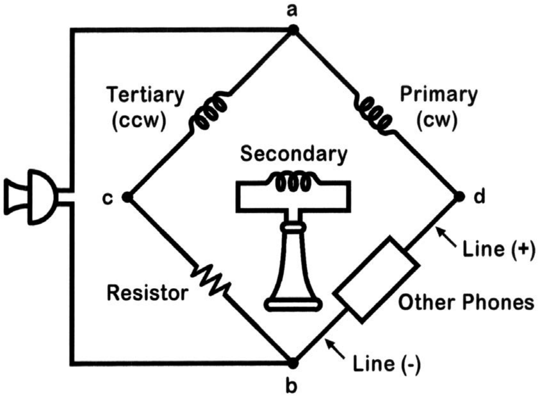


Fig. 17-8. Kellogg's bridge-type, anti-sidetone Triad circuit for common-battery systems.

The 1.5-microfarad condenser shown in Fig. 17-9 is used to block direct current from flowing around the transmitter and being wasted. However, a 1-microfarad condenser is also seen in the receiver current loop. Unlike most typical uses of a condenser, this condenser was not put in the circuit to block direct current (there is none in this loop), but rather to lower the overall impedance of the receiver loop by partly cancelling out the receiver's inductive impedance. The condenser was used in this manner in the Kellogg No. 900 and 925 telephones and in the No. 610 subset. However, in the later Kellogg 1000 red-bar telephone, the condenser was removed from the receiver loop and coil parameters were adjusted accordingly.

Characteristics of the coils used in these circuits are given in Table 17-2. The No. 103-A coil is an old-style cylindrical coil with wooden end blocks; it is found in the F610 metal subset. The 106-A coil is a large transformer-shaped closed-flux coil found in the 900-series telephones. And the No. 113-A is an encapsulated plug-in coil used in the Kellogg 1000 telephone. In the No. 103-A and 106-A coils, the six wire leads from the three coil sections are identified as 1 through 6. They are actually marked that way on the wooden blocks of the No. 103-A coil. Only five terminals are provided on the terminal blocks, however, and leads 5 and 3 are both permanently connected to one terminal with the unusual double marking 53. Connecting 5 to 3, rather than connecting 6 to 3, gives the polarity reversal that is needed in this circuit. The polarity of the secondary is shown in Fig. 17-9 although it is unimportant because the secondary is effectively isolated from the other coil sections. There is, however, one harmless point of contact — at coil terminal 53 — as will be seen in later figures.

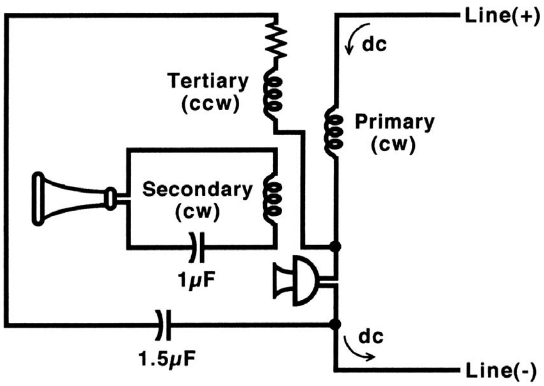


Fig. 17-9. Kellogg's Triad circuit drawn differently, with condensers added (same basic circuit as Fig. 17-8).

Table 17-2. Characteristics of induction coils used in Kellogg's Common-battery anti-sidetone circuits

Characteristic	**Primary**	**Secondary**	**Tertiary**
	Kellogg No. 103-A		
Terminal Markings	1-2	53-4	53-6
Resistance, ohms	38	17	115
Turns Ratio, to primary	1.0	0.37	0.40
	Kellogg No. 106-A[a]		
Terminal Markings	1-2	53-4	53-6
Resistance, ohms	13	14	138
Turns Ratio, to primary	1.0	0.50	0.50
	Kellogg No. 113-A		
Terminal Markings	1-7[b]	2-5	3-4
Resistance, ohms	15	16	273
Turns Ratio, to primary	1.0	0.89	0.57

[a] Later versions of the No. 106-A coil have an extra terminal marked 7. Terminal 7 is connected to terminal 6 through a 62-ohm resistor.

[b] Terminal 1 on the No. 113-A coil is internally connected to terminal 3 through a 100-ohm resistor.

For the discussion that follows, two identical No. 925 Masterphones were connected to the common-battery supply shown in Fig. 16-5 of Chapter 16. Each phone had Eaton's non-positional transmitter, a No. 89A receiver, condensers as shown in Fig. 17-9, and a No. 106A coil connected at terminal 6 (the extra 62-ohm resistor between terminals 6 and 7 was not used).

Transmitting (ac)

This circuit behaves in a manner that is similar to a Wheatstone bridge when it is transmitting. Transmitter current flows from a to b in Fig. 17-8 through the primary winding and through the tertiary winding. Because these two windings have opposite polarity, they produce magnetic fields that tend cancel out, thus inducing a small or zero voltage in the secondary winding, depending on the turns ratios of the windings. This produces the reduced sidetone in the receiver.

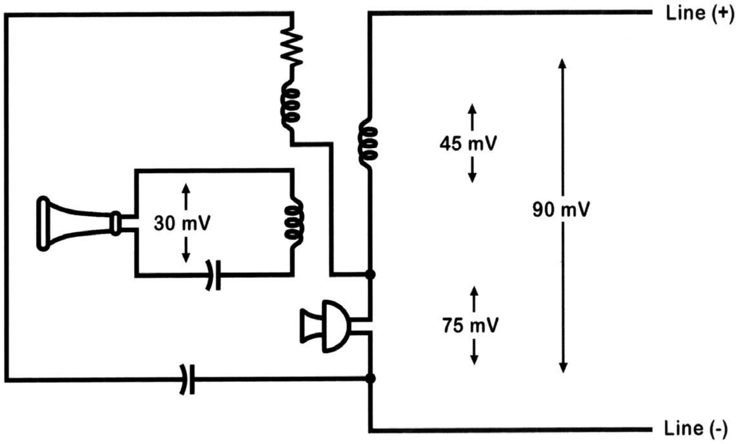


Fig. 17-10. Typical voltages in Kellogg's Triad circuit when transmitting.

Figure 17-10 shows typical measured voltages for this circuit when it is transmitting. The bridge is not fully balanced, and a 30-millivolt sidetone is produced. This is a desirably small value, which happens to be the same as the sidetone in Western Electric's booster-type anti-sidetone circuit. In fact, the Triad circuit can also be thought of as a type of booster circuit, with the tertiary winding inducing a positive voltage in the primary winding. The "boost" in the Triad is rather small, however, resulting in a line voltage of only 90 millivolts compared with 125 millivolts for the Western Electric circuit.

Receiving (ac)

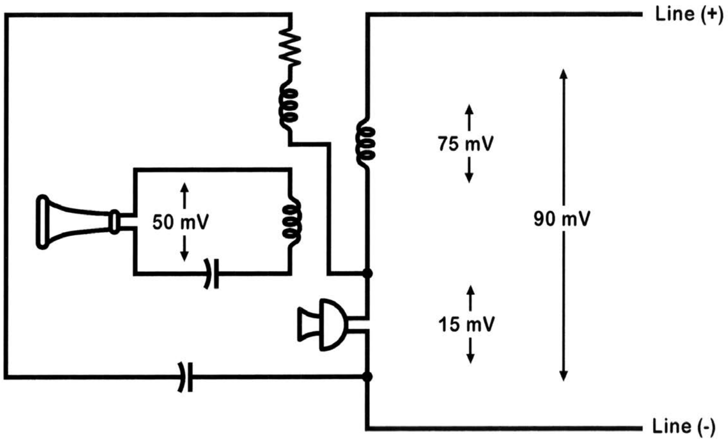


Fig. 17-11. Typical voltages in Kellogg's Triad circuit when receiving.

When receiving, this circuit no longer has the characteristics of a Wheatstone bridge. Figure 17-11 shows typical measured voltages for this circuit when it is receiving. The voltage source is now the line voltage (90 millivolts), which is dropped across the primary winding (75 millivolts) and the transmitter (15 millivolts). The relatively low loss across the transmitter results in a rather high induced voltage across the secondary winding and hence the receiver (50 millivolts).

The overall performance of the Triad circuit is thus similar to the Western Electric anti-sidetone circuit, although the result is produced with a lower voltage on the line and a greater sensitivity when receiving. The lower line voltage results in a lower signal-to-noise ratio, and phones with the Triad circuit are thus susceptible to a little more line noise.

Examples of Kellogg's Anti-Sidetone Triad Circuit

Early Applications of the Triad Circuit

Figure 17-12 shows the wiring for the No. 900 non-dial telephone. A similar wiring arrangement is used for desk stands with the No. 610 subset, although switching and terminal markings are different. Major features of the hookup in the No. 900 telephone are described in the following paragraphs.

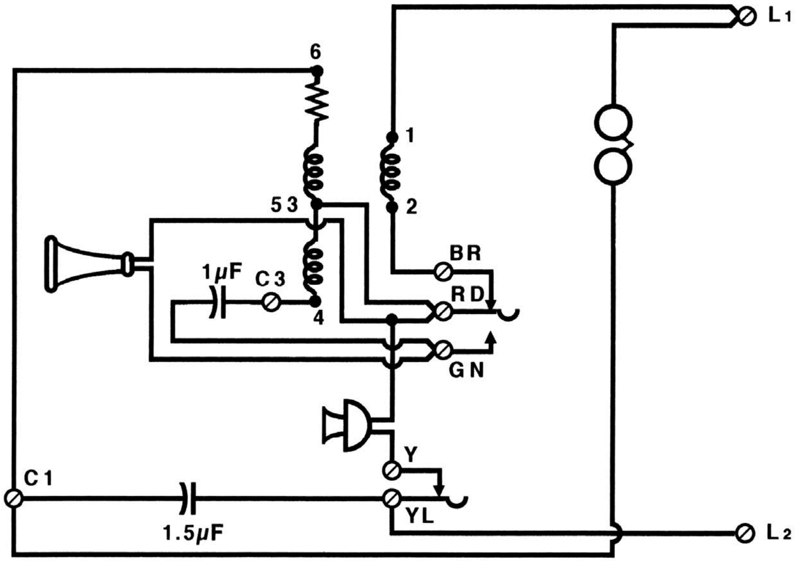


Fig. 17-12. Wiring of the Triad circuit in the Kellogg No. 900 telephone, with the old double-duty arrangement for the ringer condenser.

There is a single inconsequential point of contact between the receiver loop and the rest of the circuit. This point is at RD on the hook switch, terminal 53 on the coil, and the common receiver-transmitter lead (red) from the handset. All of these are connected together as a point of convenience, which creates no new current loops and has no effect on operation of the circuit.

Terminal GN on the hook switch shorts out the receiver when the phone is on-hook. When the handset is lifted, this switch section opens after both other contacts have closed (if well adjusted) keeping pulses from the discharging condensers out of the receiver.

The old double-duty arrangement for the 1.5-microfarad condenser is used, foregoing the advantage of a separate condenser in the ringer circuit. Although the extra hook switch section keeps discharge pulses out of the receiver, those pulses are still put onto the line.

Triad Circuit with Three Condensers

Three condensers were used in the No. 925 telephone, finally providing a separate condenser for the ringer. Wiring for this phone is shown in Fig. 17-13. As in the Western Electric circuit, the condenser in the booster loop (1.5 microfarad in this case) is switched at Y and YL to keep the dc line voltage off the condenser when the phone is on-hook.

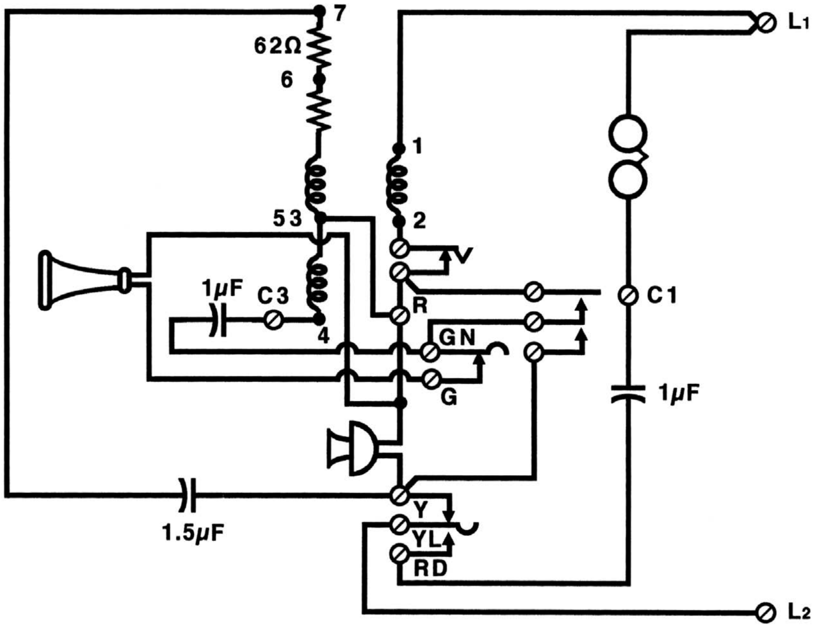


Fig. 17-13. Wiring of the Triad circuit in the Kellogg No. 925 telephone, with three condensers.

A multi-contact hook switch is again used, but in a different way from the previous case. In the No. 925, the extra contact RD is used to disconnect the ringer circuit when the handset is lifted (opens first if well adjusted). This keeps condenser discharge pulses from the ringer circuit out of the talking circuit, even though a separate switch does not close the receiver circuit until discharge pulses have died out.

Although the basic talking circuit is the same as in the previous case, an extra resistance (62 ohms) has been added to the end of the tertiary coil winding. The normal hookup would have the 1.5-microfarad condenser lead going to terminal 6, but for extra sidetone reduction on short lines, it is connected to terminal 7 as shown. The extra resistance merely reduces the amount of transmitter current going through the booster loop, thereby reducing the booster action and hence its sidetone.

The Triad Circuit's Final Configuration

The final rendition of the common-battery Triad circuit was in the No. 1000 red-bar telephone. The wiring for a non-dial version of this phone is shown in Fig. 17-14. The dial version uses a typical Kellogg arrangement of shunt switches that short out both transmitter and receiver, and with the impulse switch between L2 and terminal 7. The non-dial version is depicted here with some of the many terminal markings omitted to avoid clutter in the diagram. The non-dial telephone itself requires a jumper wire between terminals 2 and 4 of the dial cord socket (not shown).

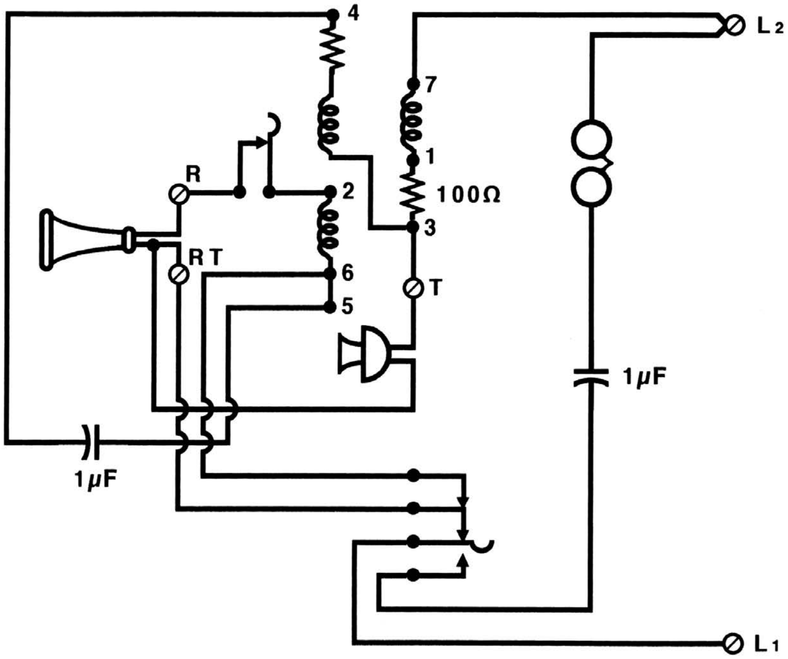


Fig. 17-14. Wiring of the Triad circuit in the Kellogg No. 1000 telephone, with no condenser in the receiver loop.

The main difference between Fig. 17-14 and previous diagrams for the Triad circuit is the absence of the condenser in the receiver loop. Therefore, this telephone requires only two condensers, while retaining one of them for exclusive use in the ringer circuit. Although the receiver-loop condenser is gone, the increased turns ratio of the secondary winding compensates for a higher impedance with a higher voltage, and the operating principle in general terms is unchanged.

An extra resistor (100 ohms) is also provided in this telephone for sidetone adjustment. By suitably positioning a metal link on the terminal block, this resistor can be put in two different locations or omitted altogether. In one position, as shown in Fig. 17-14, the resistor merely adds resistance to the line, thus attenuating signal strength. This connection is used for short lines where signal levels are too high. Two other options are available for longer lines. One puts the 100-ohm resistor in series with the tertiary coil winding, in effect providing the same option available with terminal 7 in Fig. 17-13. The other option shorts out the 100-ohm resistor, effectively removing it from the circuit. According to the drawing tucked away inside each telephone, adjustments were made in the field for "whichever position gives desired sidetone reduction."

Contact movements in the hook switch are again sequenced to remove the ringer first when the handset is lifted, and to connect the receiver last in order to minimize receiver clicks. Finally, provisions were made by positioning other links to obtain 0.5 microfarads (instead of 1 microfarad) in the ringer circuit for use with harmonic ringers in the higher frequency range.

Stromberg-Carlson's Anti-Sidetone Circuits

Stromberg-Carlson used two different anti-sidetone circuits. The major coils used by Stromberg-Carlson are described in Table 17-3. The No. 45A coil was used only with the early Stromberg-Carlson anti-sidetone circuit in the No. 1212 telephone. This coil, with its turns ratios greater than one, is not like any of the other anti-sidetone coils, and its tertiary winding has no added resistance for balancing. However, the Stromberg-Carlson No. 46A coil is almost identical to the Western Electric No. 101A, although their external appearance is quite different. Further, because turns ratios are the most important characteristics of a coil, the coil in the Stromberg-Carlson No. 1543 telephone is also essentially the same. Thus all of the Stromberg-Carlson telephones produced later in this period use a coil like Western Electric's, and the similarity does not end there.

Table 17-3. Characteristics of induction coils used in Stromberg-Carlson's common-battery anti-sidetone circuits

Characteristic	Primary	Secondary	Tertiary
Stromberg-Carlson No. 45A			
Terminal Markings	1-2	3-4	3-5
Resistance, ohms	10	36	45
Turns Ratio, to primary	1.0	1.95	1.35
Stromberg-Carlson No. 46A[a]			
Terminal Markings	1-2	3-4	5-6
Resistance, ohms	24	24	73
Turns Ratio, to primary	1.0	0.70	0.40
Stromberg-Carlson Coil in No. 1543 Telephone[b]			
Terminal Markings	3-10	9-13	7-11
Resistance, ohms	16	10	56
Turns Ratio, to primary	1.0	0.70	0.40

[a] The coil in early No. 1243 telephones is in a network package, but it is the same as the No. 46A coil except for terminal markings. In later sets, the coil in the No. 1243 phone is the same as that in the No. 1543 telephone.

[b] This coil is also in a network package. See Fig. 17-18 for additional information on this coil.

Early Stromberg-Carlson Anti-Sidetone Circuit

The first Stromberg-Carlson anti-sidetone circuit is shown in Fig. 17-15. While it is also a type of booster circuit, its operation is quite different from the Western Electric or Kellogg circuits.

First, when transmitting, imagine a portion of the transmitter voice current (ac) going through the condenser and then splitting. Part of that current goes up through the counterclockwise secondary winding and part of it goes down through the clockwise tertiary winding. Considering both the direction of current flow and the direction of winding, both of these windings have the same sense as the secondary loop in the standard booster circuit. Therefore, the secondary and tertiary windings both induce voltages in the primary winding that add to the transmitter voltage and put a boosted voltage on the line.

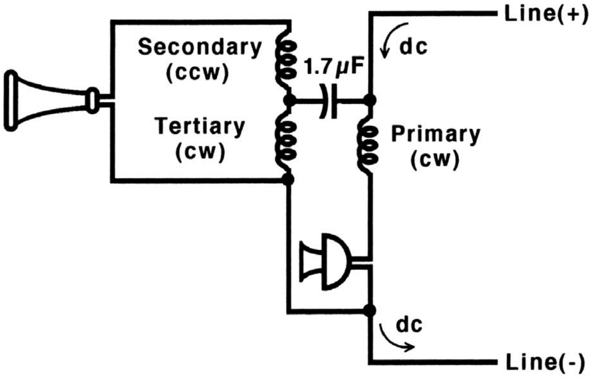


Fig. 17-15. Stromberg-Carlson's early anti-sidetone circuit for common-battery systems.

Next, consider the fact that the primary winding will induce voltages in the secondary and tertiary windings, and that these voltages will be out of phase because the secondary and tertiary are wound in opposite directions. These two voltages will, therefore, subtract (rather than add) -- tending to give a small net voltage across both coils and the receiver, resulting in a low sidetone.

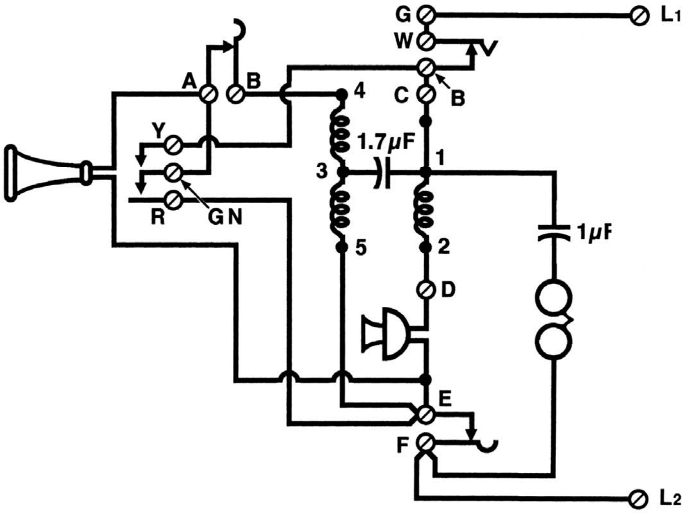


Fig. 17-16. Wiring of the Stromberg-Carlson No. 1212 telephone, with the early anti-sidetone circuit.

The anti-sidetone circuit in Fig. 17-15 was only used in early Stromberg-Carlson sets, such as the No. 1212. The wiring for that telephone is shown in Fig. 17-16. With one exception, switching in this arrangement is rather typical. Hook switch sections disconnect both the transmitter and receiver circuits, and they keep line voltage off the 1.7-microfarad condenser. And dial shunt switches short out the transmitter and receiver during dial rotation. However, to utilize a 3-lead dual condenser, the ring signal must go through the dial impulse switch. Stromberg-Carlson retained this arrangement in later circuits.

Stromberg-Carlson's Western Electric-Type Circuits

Figure 17-17 shows the later Stromberg-Carlson anti-sidetone circuit that was used widely in many models from the No. 1222 to the No. 1543 telephones, as well as the No. 1230 subset. The singular important thing to notice about Fig. 17-17 is that it is the Western Electric circuit with an insignificant rearrangement of several components. The tertiary winding and receiver (together as a unit), the secondary winding, and the condenser have merely had their positions interchanged in a part of the circuit where they are connected in series. Such a rearrangement of the order of components in series has no effect on operation. This circuit was tested with the same methods described earlier. Considering the similarities in coil characteristics and circuit design, the measured performance characteristics (sidetone, line voltage, receiving sensitivity, etc.) were, of course, all found to be the same as for the Western Electric anti-sidetone circuit.

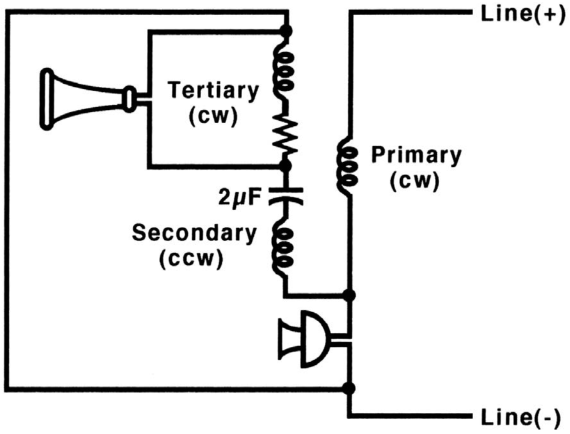


Fig. 17-17. Stromberg-Carlson's Western Electric-type anti-sidetone circuit for common-battery systems.

Several of the applications of this circuit by Stromberg-Carlson incorporated an imaginative and unique feature, and Fig. 17-18 shows the wiring for the No. 1543 telephone, which has this feature. All numbered terminals shown in the figure are on a molded bakelite network that contains the coil windings, resistors, and the 2-microfarad condenser for the talking circuit. Several external straps are required between terminals (e.g., between terminals 10 and 13). Overall, this diagram is readily comparable to the basic circuit in Fig. 17-17, and a typical arrangement of dial and hook switch contacts is used. The non-dial telephone is formed by simply removing the dial and connecting a strap between terminals 1 and 3.

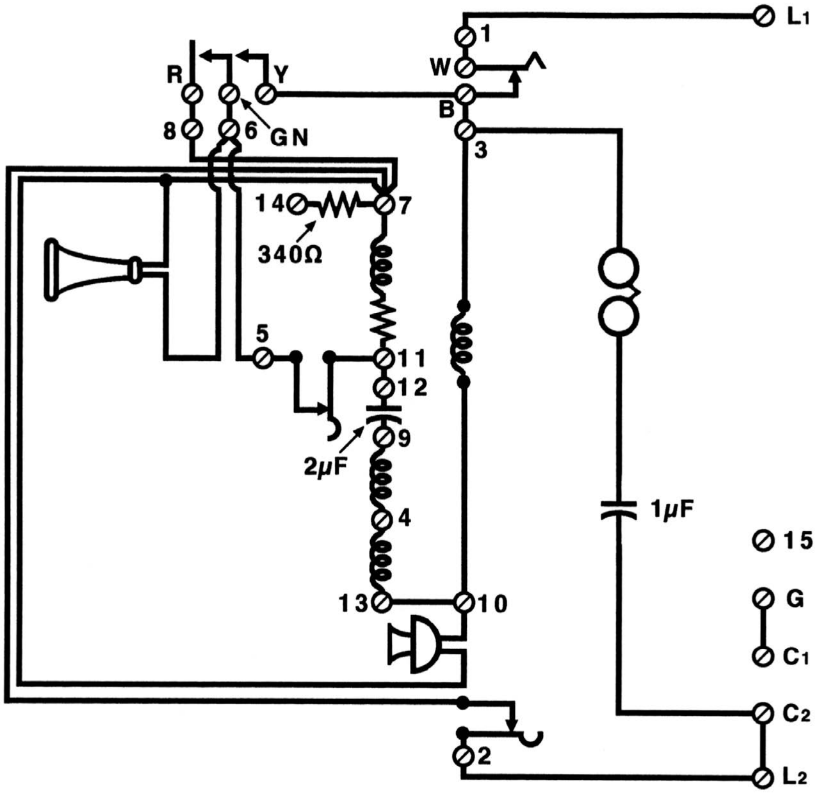


Fig. 17-18. Wiring of the Stromberg-Carlson No. 1543 telephone, with provisions for an alternate local-battery hookup.

The innovative feature of this network is that it can be connected as either a common-battery, anti-sidetone circuit (as shown) or as a local-battery, anti-sidetone circuit without changing any components. The 340-ohm resistor at terminal 14 and the center tap in the secondary winding at terminal 4 are used for that local-battery circuit and play no role in the common-battery circuit. The local-battery circuit is described fully in the next chapter.

Stromberg-Carlson used several different networks in the 1240-series and 1540-series telephones. Later versions of the No. 1243, for example, had internal wiring almost identical to that shown in Fig. 17-18, which will be shown connected for local-battery service in an example in the next chapter. Earlier versions of the No. 1243 had different internal wiring with no provisions for local-battery hookup, although the basic circuit was still the same as Fig. 17-17. Late model No. 1543s, on the other hand, had an internal circuit equivalent to the No. 425B network described in Chapter 19. These Stromberg-Carlson telephones do not exhibit the persistent periods of product standardization found in the Western Electric line.

Automatic Electric's Anti-Sidetone Circuits

Automatic Electric used three different anti-sidetone circuits in their telephones of the 1930s and 1940s. One was original and rather ingenious, utilizing a two-winding coil in the receiver to serve as both the induction coil and the receiver coil for driving the diaphragm. Another was like Kellogg's Triad circuit. And the final version was like Western Electric's anti-sidetone circuit.

Automatic Electric Circuit with Induction-Coil Receiver

Table 17-4. Characteristics of coils used in Automatic Electric's induction-coil receiver

Characteristic	Primary	Secondary
Automatic Electric No. D281582		
Terminal Markings	1-2	2-3
Resistance, ohms	50	45
Turns Ratio, to primary	1.0	0.40
Automatic Electric No. D282251		
Terminal Markings	1-2	2-3
Resistance, ohms	50	245[a]
Turns Ratio, to primary	1.0	0.40

[a] Includes a 200-ohm non-inductively wound resistance.

Automatic Electric developed a circuit that incorporates the induction coil within a special receiver (Burden/AE 1948, 78). The characteristics of this coil, which has only two windings, are given in Table 17-4. The circuit uses a resistance in series with the secondary coil winding, and the resistance was wound non-inductively into the secondary winding in a later version of the induction coil receiver. The circuit is shown in Fig. 17-19 and was based on the booster circuit. The similarity to the booster circuit can be seen by comparing this figure with Fig. 16-3. The primary and secondary coils are wound around a single pole piece in the receiver, and the magnetic field that is produced by the ac voice signal not only couples the two windings like a transformer, but also vibrates the receiver diaphragm. Note that the resistor, which has a value around 200 ohms, is even similar to the impedance of typical receivers of that period (see Table 3-1). Direct current through the primary winding provides the magnetic polarization that is needed for a receiver.

The anti-sidetone character of this circuit can be seen as follows. When the transmiter is producing the ac signal, ac current will flow (for example) up through the primary winding and up through the secondary winding as viewed in Fig. 17-19. Because the primary and secondary are wound in different directions, the two windings produce magnetic fields in opposite directions and they tend to cancel each other out. This reduces the net ac magnetic field that excites the diaphragm, thus reducing side tone. When receiving and the line is producing the ac voltage, the current will flow down through the primary winding and up through the secondary winding. In this case, the two ac magnetic fields add together to enhance the pull on the diaphragm.

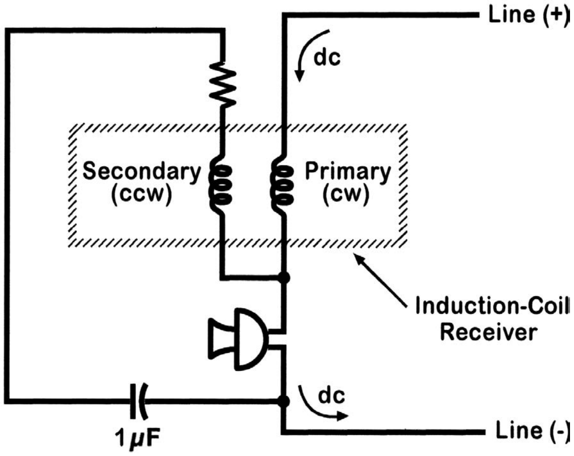


Fig. 17-19. Automatic Electric's anti-sidetone circuit with an induction-coil receiver for common-battery systems.

The induction-coil receiver was sometimes supplied in the handset of an Automatic Electric Type 1A desk stand. The wiring diagram for a desk stand thus equipped and used in combination with a subset is shown in Fig. 17-20 (hatch marks show the demarcation between the desk stand, the subset, and the receiver). Although no coil was required in the subset (there is plenty of room for one), the advantage of reduced size was lost and this arrangement was seldom used.

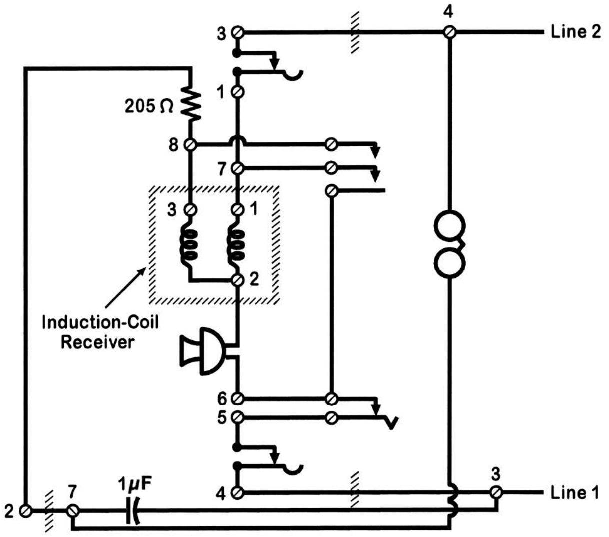


Fig. 17-20. Wiring of an Automatic Electric Type 1A desk stand and subset with an induction-coil receiver, a separate resistor, and a condenser in the voice circuit.

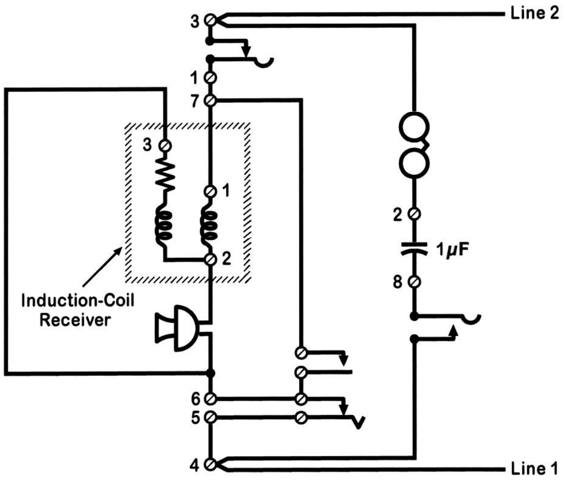


Fig. 17-21. Wiring of an Automatic Electric Type 32A step-base telephone with an induction-coil receiver that has extra resistance built into the coil.

A more common application of this circuit appeared with a couple of modifications. The resistance in the receiver circuit was wound non-inductively right into the coil, thus eliminating the need for a separate resistor. Since dc is already present in the receiver circuit of this phone, the condenser, which is used primarily to block dc from flowing in a circuit, was simply omitted from the receiver circuit. The resulting circuit was typically used in the step-base Type 32A Monophone, which is shown in Fig. 11-13. The wiring diagram for this phone is shown in Fig. 17-21. A buzzer (or a small ringer with its own condenser) was usually mounted in the base of this enlarged desk stand. This arrangement produced a complete telephone that does not require a subset -- and the handset requires a cord with only two conductors.

For a given ac transmitter voltage, the output of this circuit is significantly less than that of the booster circuit or the Western Electric anti-sidetone circuit. Further, this circuit shares a major problem with all circuits that permit dc in the receiver; namely, hook switch operation is very noisy. Because of these limitations, this phone was usually used on private exchanges that had low transmission losses.

Automatic Electric's Triad-Type Circuit

Automatic Electric's first widely used anti-sidetone circuit is the same as that used in Kellogg's No. 1000 telephone, without the 100-ohm resistor for sidetone adjustment (see Fig. 17-14). Of course there are differences in the placement of switches, but the basic circuit is the same. Characteristics of the coils used in this circuit are given in Table 17-5. The first entry in the table is for early open-core coils (D281528A and 281901A) used with this circuit in large metal subsets. The second entry in the table is for later open-core coils

Table 17-5. Characteristics of induction coils used in Automatic Electric's Triad-type circuit

Characteristic	**Primary**	**Secondary**	**Tertiary**
Automatic Electric No. D281528A and D281901A			
Terminal Markings	3-4	1-2	5-6
Resistance, ohms	18	21	205
Turns Ratio, to primary	1.0	0.59	0.42
Automatic Electric No. D282155A and D282516A			
Terminal Markings	5-8	1-2	3-10
Resistance, ohms	14.5	13	220
Turns Ratio, to primary	1.0	0.59	0.40

(D282155A and D282516A) used in the Type 34 desk phone and the Type 35 wall phone. Similarities can be seen between these coils and the coils used by Kellogg (Table 17-2). The wiring diagram for this circuit as used in the Automatic Electric 1A desk stand with a subset is shown in Fig. 17-22. Notice that the components in the 1A desk stand are connected to the desk stand’s terminal strips (terminals 1-8) differently than in Fig. 17-20. Wiring for Type 34 and 35 telephones is shown in Fig. 17-23.

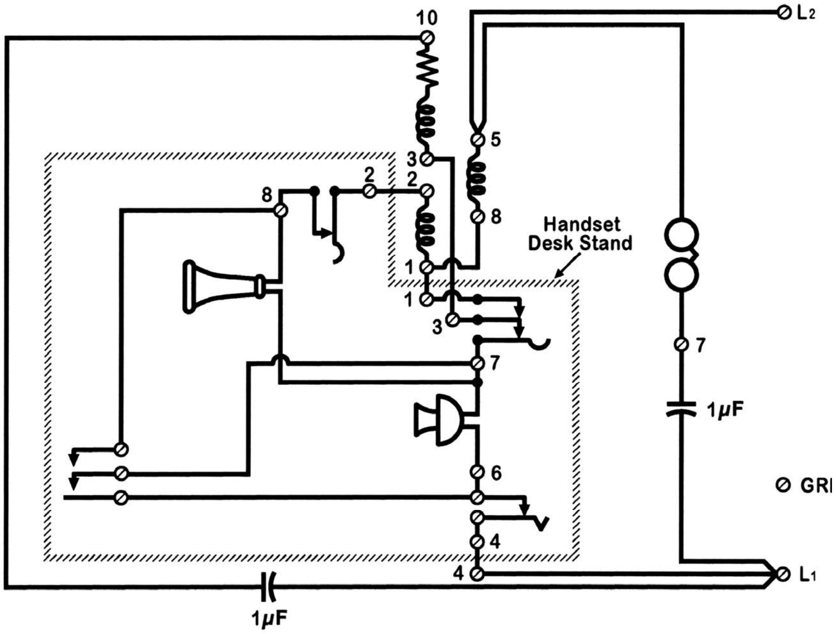


Fig. 17-22. Wiring of an Automatic Electric Type 1A desk stand and subset with the Triad-type circuit.

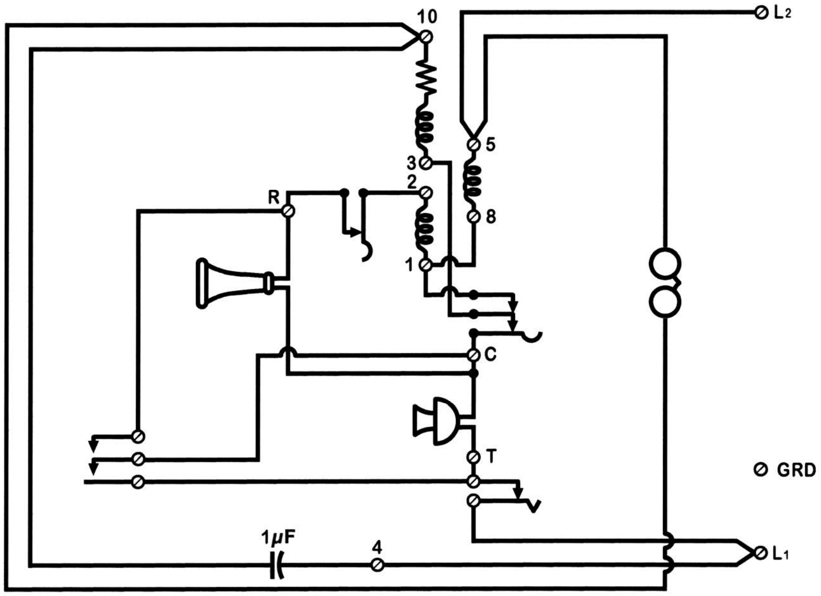


Fig. 17-23. Wiring of Automatic Electric Type 34 and Type 35 telephones with the Triad-type circuit.

Automatic Electric's Western Electric-Type Circuit

Automatic Electric, like Stromberg-Carlson, switched to the Western Electric anti-sidetone circuit around 1940 and used this circuit in their Type 40 desk phone, Type 50 wall phone, and Type 43 subset. Characteristics of the coil used in this circuit are given in Table 17-6. This coil has a semi-closed-core design that incorporates soft iron bars on the ends and along the bottom to partially close the magnetic flux path (Burden/AE 1948, 67). This coil has properties almost identical to Western Electric's No. 101A coil (Table 17-1).

Table 17-6. Characteristics of induction coil used in Automatic Electric's Western Electric-type circuit

Characteristic	**Primary**	**Secondary**	**Tertiary**
		Automatic Electric No. D282996A	
Terminal Markings	1-2	3-4	5-6
Resistance, ohms	28	14	65
Turns Ratio, to primary	1.0	0.69	0.39

Wiring for the Type 40 and 50 telephones is shown in Fig. 17-24. By comparing this figure with Fig. 17-1, it can be seen that this is the Western Electric circuit with only one insignificant rearrangement of a component; the primary winding of the induction coil has been moved from above the transmitter to below it in Fig. 17-24. This has no effect on the operation of the circuit. Dial and hook switch operation are a little different, so there are other minor differences in the hook-up of these phones. Notice that the 1-microfarad ringer condenser and the 100-ohm resistor form a built-in radio-interference filter to reduce dialing noise in nearby radios when the phone is off hook. These components are shorted out when the dial is not being used (impulse contacts closed) and have no effect on the talking circuit.

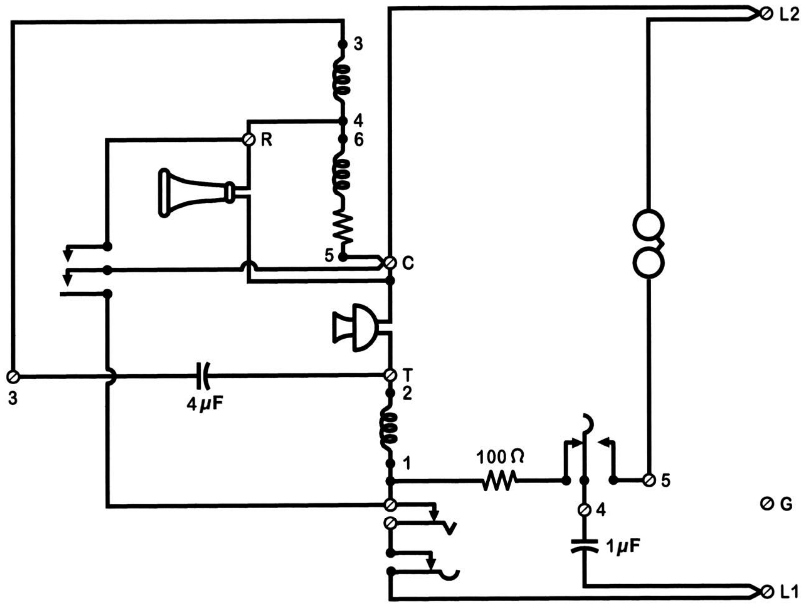


Fig. 17-24. Wiring of Automatic Electric Type 40 and Type 50 telephones with the Western Electric-type circuit.

* * *

Chapter 18
Local-Battery, Anti-Sidetone Circuits

Principles of the Wheatstone Bridge Circuit

The full value of sidetone suppression had become apparent by the late 1930s, so manufacturers introduced anti-sidetone circuits in their local-battery sets, even though sidetone performance of those sets was never particularly bad. The circuit, used widely by Western Electric, Kellogg, Stromberg-Carlson, Automatic Electric, and others, was based on the Wheatstone bridge described in the Appendix. The performance of this classic circuit is almost unsurpassed. The basic local-battery, anti-sidetone circuit is shown in Fig. 18-1, drawn in a manner that is directly comparable to Fig. A-10 in the Appendix. A more conventional diagram of this circuit, with its magneto and ringer added, is shown in Fig. 18-2.

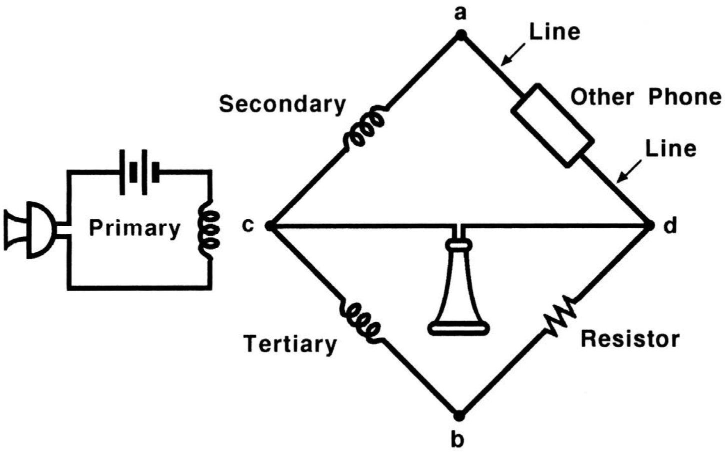


Fig. 18-1. Wheatstone bridge-type local-battery, anti-sidetone circuit.

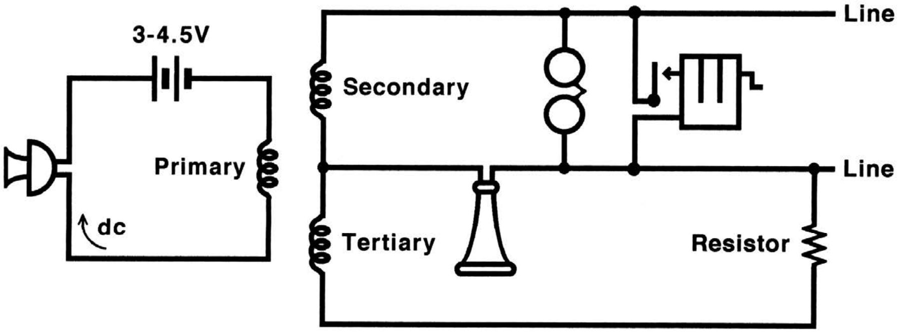
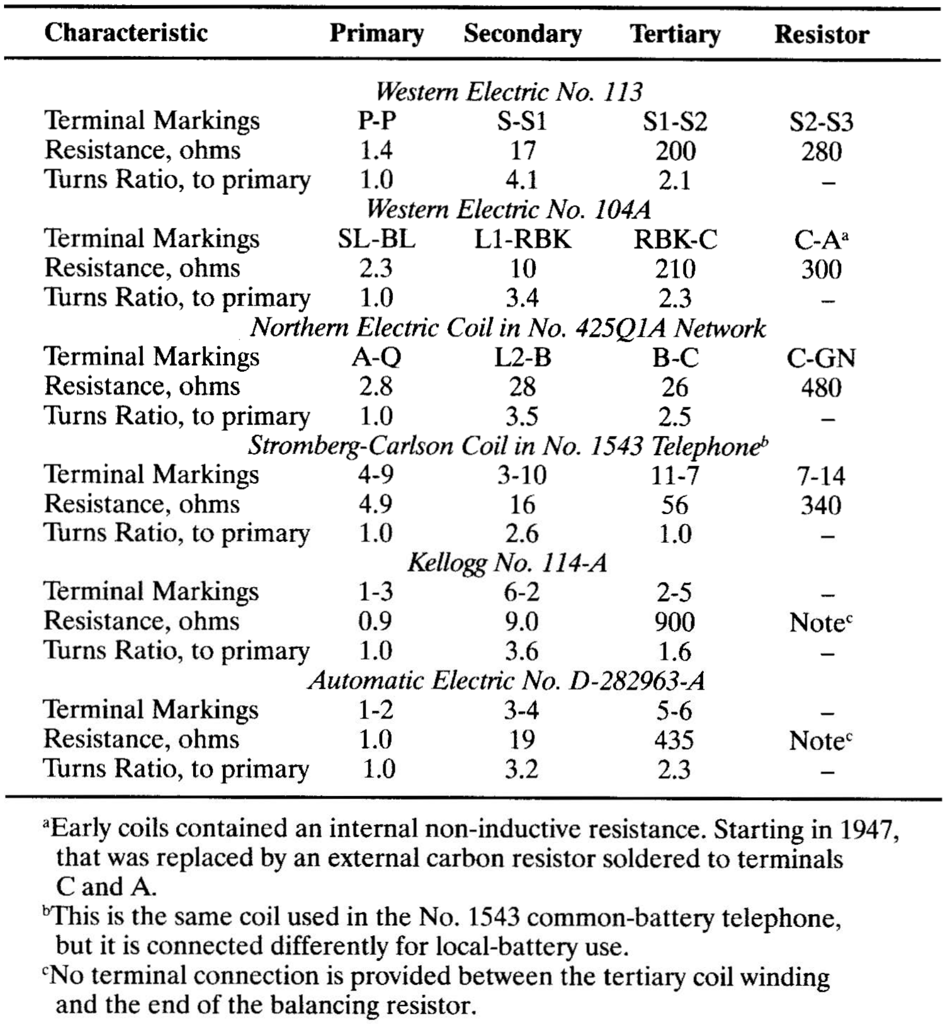


Fig. 18-2. The local-battery, bridge-type, anti-sidetone circuit with ringer and magneto; same basic circuit as Fig. 18-1.

As with the standard local-battery circuit, direct current is confined to the primary coil winding and the transmitter, and the current is supplied by batteries of 3 or 4.5 volts (2 or 3 dry cells). Characteristics of various coils used with this circuit are given in Table 18-1.

Before the operation of this circuit is discussed, several observations can be made about these coils. First, notice that the values for the primary and secondary windings of the Western Electric No. 113 coil are identical to those of the old Western Electric No. 13 coil used with the standard local-battery circuit. The No. 113 coil is thus seen to be a No. 13 coil with an extra winding on top, similar to the relation between the No. 46 (booster) and No. 146 (anti-sidetone) common-battery coils discussed earlier.

Table 18-1. Characteristics of induction coils used in the local-battery, bridge-type, anti-sidetone circuit.



Characteristic	Primary	Secondary	Tertiary	Resistor
		Western Electric No. 113		
Terminal Markings	P-P	S-S1	S1-S2	S2-S3
Resistance, ohms	1.4	17	200	280
Turns Ratio, to primary	1.0	4.1	2.1	–
		Western Electric No. 104A		
Terminal Markings	SL-BL	L1-RBK	RBK-C	C-A[a]
Resistance, ohms	2.3	10	210	300
Turns Ratio, to primary	1.0	3.4	2.3	–
		Northern Electric Coil in No. 425Q1A Network		
Terminal Markings	A-Q	L2-B	B-C	C-GN
Resistance, ohms	2.8	28	26	480
Turns Ratio, to primary	1.0	3.5	2.5	–
		Stromberg-Carlson Coil in No. 1543 Telephone[b]		
Terminal Markings	4-9	3-10	11-7	7-14
Resistance, ohms	4.9	16	56	340
Turns Ratio, to primary	1.0	2.6	1.0	–
		Kellogg No. 114-A		
Terminal Markings	1-3	6-2	2-5	–
Resistance, ohms	0.9	9.0	900	Note[c]
Turns Ratio, to primary	1.0	3.6	1.6	–
		Automatic Electric No. D-282963-A		
Terminal Markings	1-2	3-4	5-6	–
Resistance, ohms	1.0	19	435	Note[c]
Turns Ratio, to primary	1.0	3.2	2.3	–

[a] Early coils contained an internal non-inductive resistance. Starting in 1947, that was replaced by an external carbon resistor soldered to terminals C and A.

[b] This is the same coil used in the No. 1543 common-battery telephone, but it is connected differently for local-battery use.

[c] No terminal connection is provided between the tertiary coil winding and the end of the balancing resistor.

Next, notice that the resistances of the tertiary windings and of the resistors in Table 18-1 vary considerably from coil to coil, but the sum of those two resistances is rather consistent. The resistor in Fig. 18-1 is effectively the sum of the tertiary winding's inherent resistance plus any added resistance. In fact, the exact location of point b in Fig. 18-1 is not well defined in any of the coils, and access to that precise point is not needed for any external electrical connection. Consequently, different coils have a terminal at different locations -- the Kellogg coil has none at all -- along this resistance string without affecting the basic properties of the circuit.

For the discussion that follows, two identical Western Electric telephones with the local-battery, anti-sidetone circuit were connected together. Each phone had a No. F1 transmitter, a No. HA1 receiver, a No. 113 coil, and a 3-volt battery. Properties of the transmitter and receiver were given earlier. Also as before, the direct current in the transmitter circuit was about 30 milliamperes for the measurement of typical voltages.

Transmitting (ac)

This circuit behaves like a Wheatstone bridge when transmitting. Refer again to Fig. 18-1. The transmitter, via the primary winding, establishes an ac voltage across points a and b by inducing voltages in the secondary and tertiary windings. Current then flows from a to d to b producing voltages (Ohm's law) across the resistances in those legs of the bridge. If the secondary voltage equals the line voltage (which includes the voltage across the other telephone) and the tertiary voltage equals the resistor's voltage, then the voltage across the receiver (c to d) is zero; the bridge would be balanced and there would be no sidetone.

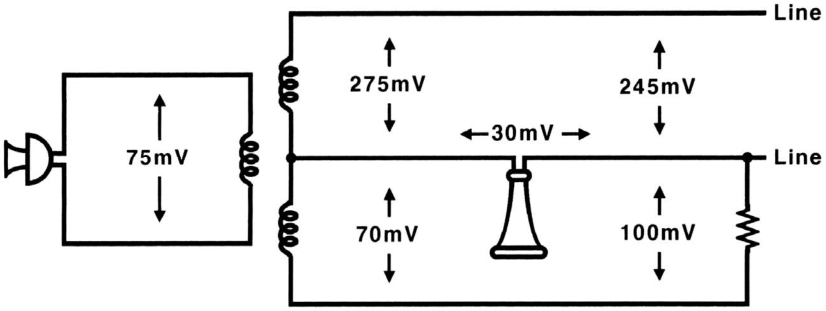


Fig. 18-3. Typical ac voltages in the local-battery, bridge-type, anti-sidetone circuit when transmitting.

Figure 18-3 shows typical measured voltages for this circuit when it is transmitting. The bridge is seen to be nearly, but not quite, balanced, leaving a residual sidetone voltage of 30 millivolts across the receiver. Although this is a small sidetone, note that the two test telephones were connected together directly with no line resistance between them. Had there been a few hundred ohms of line resistance, as would be typical, the voltage drop across the line would have been a little larger, the voltage drop across the balancing resistor a little smaller, and the sidetone would have been even lower.

Provisions are made in most phones with this circuit to adjust the impedance of the balancing resistor to match prevailing line conditions. Nevertheless, even in the somewhat imbalanced condition as tested, the local-battery, anti-sidetone circuit has a low sidetone and puts a large voice signal on the line.

Receiving (ac)

When receiving, this circuit no longer has the characteristics of a Wheatstone bridge. The primary winding, with its dormant transmitter, is no longer a voltage source, but rather just a resistive load across the secondary and tertiary windings. When receiving, the voltage source is the line voltage, typically around 245 millivolts (Fig. 18-4).

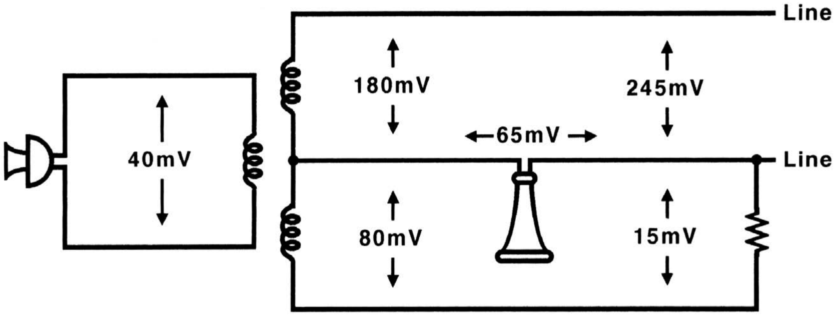


Fig. 18-4. Typical ac voltages in the local-battery, bridge-type, anti-sidetone circuit when receiving.

Ideally, one would like signal current to flow from the line (refer to the upper Line in Fig. 18-4), through the secondary winding, and then back through the receiver, with none of it going around the receiver through the tertiary winding and balancing resistor. This ideal situation would be just like the standard local-battery circuit and would be achieved if the secondary winding induced a voltage in the tertiary winding that was exactly equal to the receiver voltage. Test results in Fig. 18-4 show this to be approximately, although not exactly, the case. The 80-millivolt tertiary voltage is slightly greater than the 65-millivolt receiver voltage, leaving a net 15 millivolts across the balancing resistor, and wasting only a little power.

Similarities in design considerations can be seen for this and the Western Electric common-battery, anti-sidetone circuit. In both cases, coils are designed to achieve neutralizing balance such that signal current does not bypass the receiver when receiving. And a balancing impedance (resistor) is then chosen for sidetone balance; that is, to prevent signal current from going through the receiver of the transmitting phone. Neither circuit achieves its design goal completely, but both approximate it and match the performance of their predecessors while substantially reducing sidetone. And, as before, the local-battery circuit continues to outperform the common-battery circuit by about two to one in terms of line voltage and receiver voltage in the receiving telephone.

Examples of Local-Battery, Bridge-Type, Anti-Sidetone Circuits

Anti-sidetone circuits were applied to most of the types of phones that used the standard local-battery circuit, plus the combined telephones of the 1930s and 1940s, and the post-war 500-type telephones. A variety of these applications will be described to illustrate interesting features added to the basic circuit.

Western Electric Magneto Wall Phone

Figure 18-5 shows the wiring diagram for a Western Electric No. 417 magneto wall phone. This can be readily compared with Fig. 18-2, which shows the basic bridge circuit.

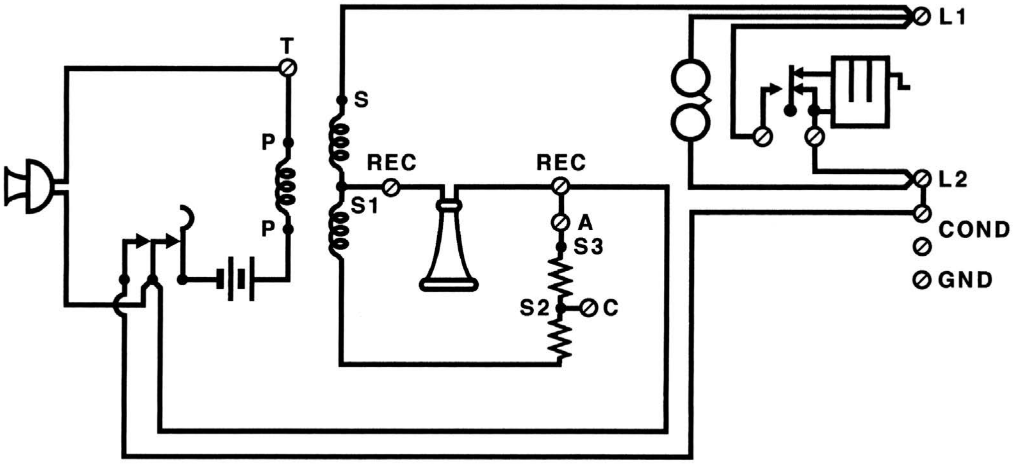


Fig. 18-5. Wiring of Western Electric No. 417 wall phone with local-battery, bridge-type, anti-sidetone circuit, showing provisions for an optional handset and different sidetone-balancing impedances.

As with most phones having the earlier standard circuit, a single inconsequential point of contact is made between the transmitter (primary) current loop and the rest of the circuit to permit the use of a simple 3-contact hook switch. Notice in this case that one transmitter lead is permanently connected to one receiver lead at that point of contact (REC near A). Because of this, a simple conversion could be made to use a handset on this phone. After removing the separate transmitter and receiver, a 3-wire F1 handset could be attached by connecting the black transmitter lead to T, the white receiver lead to REC near S1, and the red common lead to REC near A. It can be seen from Fig. 18-5 that the circuit is unaltered by this conversion. Further, the F1 handset uses exactly the same F1 transmitter and HA1 receiver elements that are supplied separately with this phone, so no change whatsoever is made electrically by using the handset.

From Fig. 18-5, it can also be seen that the balancing resistor is the sum of the tertiary winding's inherent resistance (200 ohms) and the extra resistor (280 ohms) in the No. 113 coil. This 480-ohm balancing resistance was supplied as shown, to be used on low-resistance lines (copper wire or short runs of cable or iron wire) to achieve a good sidetone balance. For high-resistance lines (long runs of iron wire), an extra 280-ohm resistor was provided and inserted between REC and A, after removing the jumper wire, increasing the balancing resistance to 760 ohms. For long lines with a lot of capacitance (long non-loaded cables), a 0.65-microfarad condenser was provided and connected between C and REC near A, and the jumper wire between REC and A was removed; the net balancing impedance in this case was a 200-ohm resistance in series with a 0.65-microfarad capacitance.

Finally, a 1-microfarad condenser was often provided between the COND terminals just as in phones with the older standard circuit. By suitably moving leads to the COND terminals, this condenser could be connected in series with the receiver for sure-ring purposes, or it could be put in series with the ringer when the set was used in connection with common-battery lines.

Western Electric Desk Stands and Ringer Boxes

The local-battery, anti-sidetone bridge circuit was also made available in the wall phone's counterpart, the wooden ringer boxes Nos. 400 and 415, and those boxes could be used with candlestick or handset desk stands. Figure 18-6 shows the wiring diagram for a non-dial candlestick desk stand with an anti-sidetone ringer box. The circuit as shown incorporates the No. 113 induction coil, although the ringer boxes were also produced with the equivalent No. 104A coil (see Table 18-1).

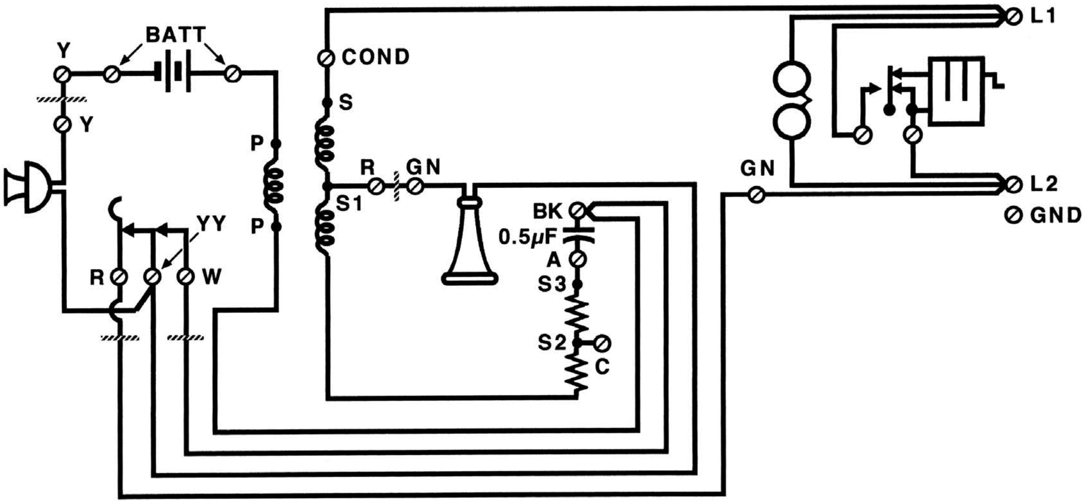


Fig. 18-6. Wiring of Western Electric unmodified candlestick desk stand with local-battery, bridge-type, anti-sidetone ringer box.

Interestingly, the original 3-contact hook switch is useable in this circuit because no switching is required for a condenser as in the common-battery, anti-sidetone circuit. Therefore, original candlestick desk stands could be used as well as the 100-series modified candlesticks, which could obviously be hooked up like a handset desk stand. Nevertheless, the newer receiver with the HA1 receiver element was required because the old No. 144 receiver had approximately twice the impedance of the HA1 or the No. 557 for which this circuit was designed. The older receiver's higher impedance would throw off neutralizing balance of the circuit. In any event, a 4-conductor cord, typical of all anti-sidetone installations, was needed, as seen from Fig. 18-6 (hatch marks in the figure indicate connections between the desk stand and the ringer box).

Although only three sidetone-balancing network options were identified by Western Electric for the No. 417 wall phone, an obvious fourth option was available. The fourth option, as shown in Fig. 18-6, consists of putting the condenser (typically 0.5 microfarads in the ringer boxes) in series with the whole balancing resistor. This option was subsequently used by Western Electric as the as-furnished option, and the jumper wire (used between A and BK for other options) is usually found parked on terminal C.

Western Electric Desk Stands and Subsets

Because of the high performance of the local-battery, anti-sidetone bridge circuit, it was made available in a subset for use at the end of extremely long common-battery lines where performance of the common-battery circuit was marginal. Just as described at the end of Chapter 15, these applications used the mixed operational mode of local-battery talking with common-battery signaling (LBTCBS). The early No. 634Y black metal subset used the No. 113 coil (later the No. 104A coil) and had a circuit identical to that shown in Fig. 18-6, except for (a) terminal markings, (b) a condenser in series with the ringer, and (c) no magneto. This subset could also be used with candlestick and handset desk stands.

Referring again to Fig. 18-6, direct current from local batteries is confined to the primary current loop containing the transmitter. When connected to a common-battery line, however, another direct current from batteries at the central office flows from L1 through the secondary winding, through the receiver, and back to the line at L2. This direct current in the line can be used, as with all common-battery sets, to signal the operator or to operate a dial. However, when direct current flows through the receiver in this manner, its performance can be affected by changing the polarizing magnetic field from its optimum value. Connecting the receiver to obtain the correct polarity to minimize this effect is described at the end of Chapter 15.

To avoid the problem of receiver polarity and the problem of noisy hook switch operation, Western Electric later modified the circuit to shunt direct current around the receiver. This modified circuit is shown in Fig. 18-7, and the modified subset containing either a No. 113 or a No. 104A coil was designated 634YD. In the modified circuit, direct current bypasses the receiver through a retardation coil, and a condenser (2 microfarads) prevents dc from going through the receiver.

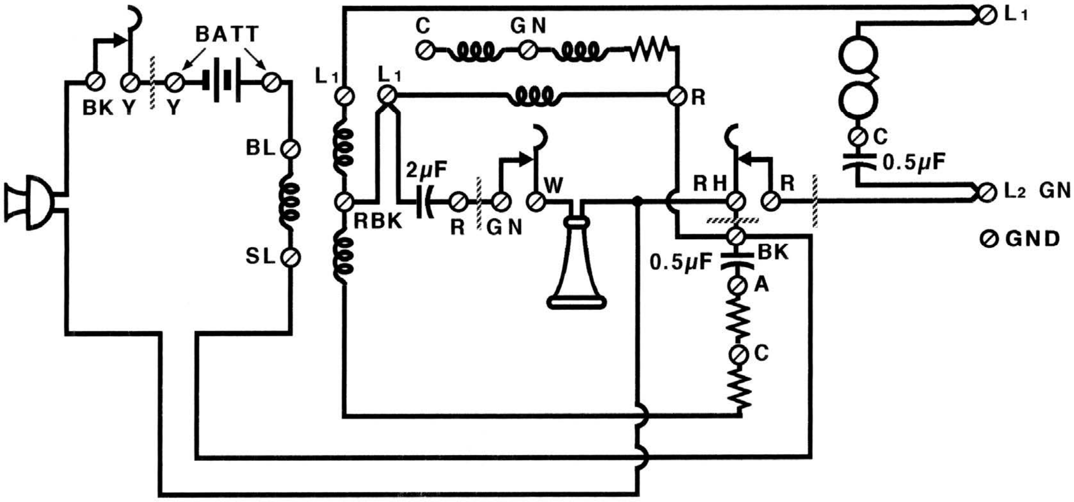


Fig. 18-7. Wiring of Western Electric handset desk stand with local-battery, bridge-type, anti-sidetone subset employing an induction coil for dc receiver bypass for use on common-battery lines.

Western Electric did not use a specially made retardation coil for this purpose in the subsets, but rather utilized one of the windings of an available induction coil. The primary winding of a No. 46 coil (see Chapter 16) was used in connection with the No. 113 induction coil, whereas the primary winding of a No. 101A coil (see Chapter 17) was used in connection with a No. 104A induction coil as shown in Fig. 18-7.[1] The primary windings of these two related coils have the greatest numbers of turns of wire of any Western

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[1] Electrically, either the No. 46 or the No. 101A could have been used with the No. 113 or the No. 104A coils. Mechanically, however, it was easier to use two cylindrical coils mounted piggyback, or two transformer-style coils mounted side by side, rather than to mix them.

Electric coil windings then in service and thus provided the highest available inductive impedance, which was desired for this application.[2] Electrical properties of these coils, when used as retardation coils, are given in Table 18-2 along with corresponding properties of the No. 266A retardation coil that was used in later applications of this circuit.

Table 18-2. Characteristics of coils used by Western Electric as retardation coils in local-battery circuits.

Characteristic	**Coil**
Primary Winding of No. 46 Induction Coil	
Terminal Markings	1-2
Resistance, ohms	14
Inductance, henrys	0.15
Total Impedance, ohms[a]	1,000
Primary Winding of No. 101A Induction Coil	
Terminal Markings	L1-R
Resistance, ohms	22
Inductance, henrys	0.2
Total Impedance, ohms[a]	1,250
No. 266A Retardation Coil	
Terminal Markings	——
Resistance, ohms	90
Inductance, henrys	0.4
Total Impedance, ohms[a]	2,500

[a] Total ac impedance at 1,000 cycles per second.

The dc resistance of the current path through the receiver (30 ohms for the 557) with the 634Y subset or through the retardation coil (see Table 18-2), as shown in Fig. 18-7, is generally less than the resistance through the transmitter (75-275 ohms for the 395 or F1) in a conventional common-battery circuit; therefore, direct current can flow rather freely in this circuit to operate relays at the central office.

Also, the ac impedance through the retardation coil in the circuit shown is much higher than the ac impedance through the receiver and condenser (about 70 ohms); consequently, most of the ac voice signal is forced to go through the receiver as desired.[3]

Figure 18-7, shows the wiring of a non-dial No. 215 handset desk stand with the No. 634YD subset, and hatch marks again indicate connections between the desk set and the subset. This desk stand is a D-type handset mounting with a 3-section (instead of a 2-section) hook switch. Because there are now two dc current loops, one switch is used in each and a third switch (GN and W), which makes contact last, is used to close the receiver circuit after dc switching pulses have died down. This ensures quiet hook switch operation.

In the earlier 634Y subset that did not have a dc bypass around the receiver, it was of course not possible to establish direct current flow in the line before switching in the receiver. Consequently, the 634Y could not utilize the extra hook switch section and would be connected to a standard desk stand or space saver (A, B, C, or D-type mountings with an E1 handset). The wiring shown in Fig. 18-7 is, therefore, not the only hookup possible with desk stands and subsets, but it is the optimum one. Figure 18-7 is, in effect, the prototype for the No. 307 telephone, which is described below.

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[2] The No. 101A coil is the closed-flux version of the No. 146 coil, which was a No. 46 coil with an extra (tertiary) winding, as mentioned in Chapter 17. Hence, the primary windings of the No. 46 and 101A coils are similar.

[3] As noted in Chapter 17, a 2-microfarad condenser almost exactly cancels out the inductive impedance of the receivers being used, leaving a very low net impedance for the condenser and receiver together.

Western Electric 300-Type Telephone

A circuit equivalent to that just described was used in the No. 307 desk telephone. The No. 104A local-battery coil was wound on the same frame as the No. 101A common-battery coil for which the 300-type phone was designed, so the No. 104A fit right into the telephone's base. A larger condenser unit, containing three condensers in one can, also fit within the 300-type housing. Space was not left over for an extra induction coil, however, so the little No. 266A retardation coil was designed to fit snugly in the front of the phone. Figure 18-8 shows the wiring for this No. 307 telephone with a dial for common-battery signaling.

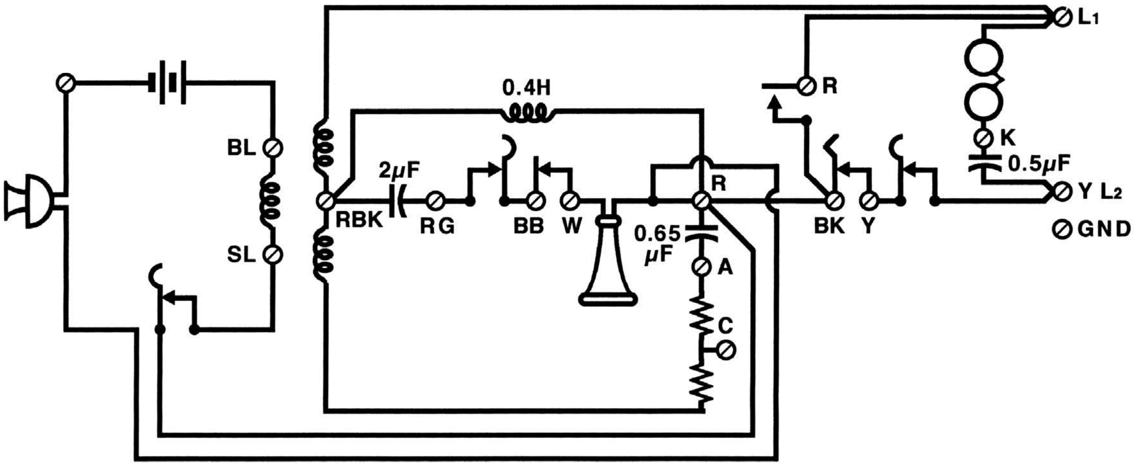

Fig. 18-8. Wiring of Western Electric 300-type telephone with local-battery, bridge-type, anti-sidetone circuit for use on local-battery or common-battery lines.

An insignificantly larger 0.65-microfarad condenser was adopted in the sidetone balancing network of the No. 307 telephone, rather than the 0.5-microfarad condenser previously used. Nevertheless, the same four sidetone balancing options are present here as before, and the circuit is otherwise the same as that in Fig. 18-7.

The No. 307 telephone was also used with a magneto on straight local-battery systems. A dial was not used in those cases; however, the retardation coil and ringer condenser were retained, thus maintaining more equipment uniformity. The separately housed Western Electric No. 299F magneto was added for that service, and the modifications for this application to the wiring shown in Fig. 18-8 would be rather obvious.

Northern Electric 500-Type Telephone

Western Electric's counterpart in Canada used the local-battery, anti-sidetone bridge circuit in several variations in a 500-type telephone. One variation was for straight local-battery service with magneto ringing; another was for local-battery talking with common-battery signaling, either with or without a dial. Yet another variation of this set had a magneto and a dial for magneto ringing on the party line and automatic dialing through the central office to outside areas.

The simplest of these variations -- magneto ringing only -- is shown in Fig. 18-9. Most of the components are enclosed in the 425Q1A network. All terminals in Fig. 18-9 identified by letters are on the network top plate, whereas all numbered terminals are on a separate terminal strip.

Although Fig. 18-9 illustrates the simplest of these variations, it shows the network connections, which are the same in all variations. For variations with common-battery signaling, direct current is shunted around the receiver through the same No. 266A retardation coil as used in the Western Electric No. 307 telephone. Because the sidetone balancing components are permanently connected inside the 425Q1A enclosure, only three sidetone-balancing options are available; these are the same three sidetone-balancing options originally identified for the Western Electric No. 417 magneto wall phone.[4]

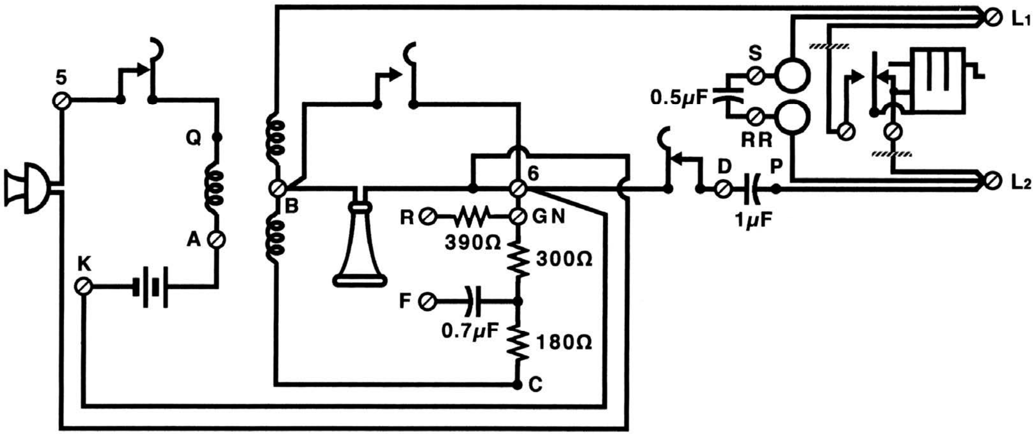

Fig. 18-9. Wiring of Northern Electric 500-type telephone with local-battery, bridge-type, anti-sidetone with a network circuit.

Stromberg-Carlson's Convertible Telephones

Many of Stromberg-Carlson's No. 1243 and 1543 common-battery telephones could be converted to local-battery service by merely interchanging leads on the terminals of their networks. One such example is shown in Fig. 18-10. This wiring arrangement describes a converted No. 1243 with an added sub-base containing a magneto, the whole of which was designated the No. 1248 telephone. In its local-battery configuration, several components in the network were not utilized: the ringer condensers, the 2-microfarad condenser, and a portion of the coil winding between Terminals 4 and 13.

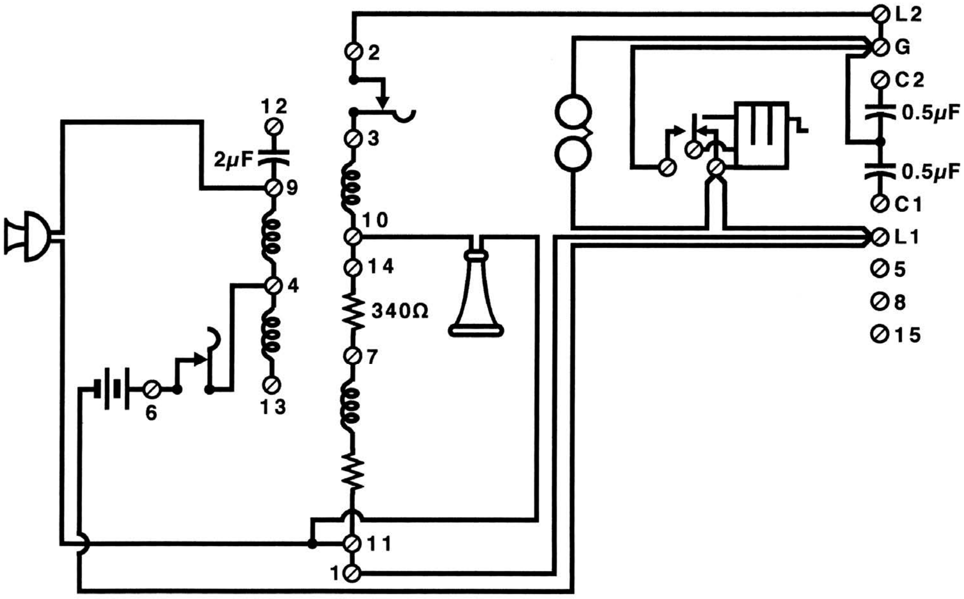

Fig. 18-10. Wiring of Stromberg-Carlson's convertible telephone, hooked up for local-battery service with the bridge-type, anti-sidetone circuit.

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[4] One option uses the jumper between GN and 6 (as shown), the second uses the jumper between R and 6, while the third uses the jumper between F and 6. The condenser cannot be placed between GN and 6, as in the 307 telephone, because one end of the condenser is permanently connected between the 300-ohm and the 180-ohm resistors.

One noticeable, but insignificant, deviation of this circuit from the basic bridge circuit in Fig. 18-2 is the interchanged position of the tertiary coil winding and the 340-ohm balancing resistor. It has already been pointed out that interchanging the order of components in a series portion of a circuit does not affect its overall performance. Further, it has been seen that the demarcation between the tertiary winding and this resistance is not clear in any of these circuit applications, so the interchange made in this Stromberg-Carlson hookup is unimportant.

As a final note on this example, it can be mentioned that the hookup for a converted No. 1543 telephone would be almost identical to Fig. 18-10. The only difference in the networks for these convertible phones is in the connection of the ringer condensers. This can be seen by comparing Fig. 18-10 with the wiring diagram for the No. 1543 common-battery phone shown in Fig. 17-18 of the previous chapter.

Kellogg's Convertible Telephone

Kellogg also made a telephone that could be converted to local-battery service in the field; however, this conversion required the substitution of a different plug-in coil to form the bridge circuit. This local-battery phone, the No. 1000 red-bar telephone with a No. 114 coil, was also available with a sub-base containing a magneto, or it could be equipped with a separate magneto box (No. 1200). Figure 18-11 shows the wiring for this phone outfitted with the magneto box, although the hookup with a sub-base would be nearly identical.

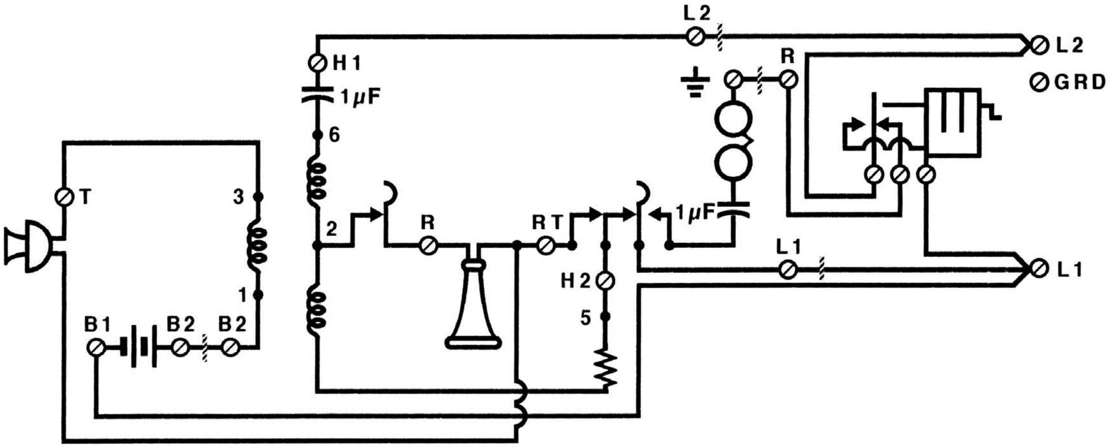

Fig. 18-11. Wiring of Kellogg's convertible telephone, hooked up for local-battery service with the bridge-type, anti-sidetone circuit.

As with the wiring diagram for the corresponding common-battery phone (Fig. 17-14 of the previous chapter), some of the many terminal markings of lesser importance have been omitted in Fig. 18-11 to avoid clutter. One of the important terminals (shown just above the ringer in Fig. 18-11) is marked with the symbol for a ground connection rather than a letter or a number. It should be pointed out that a jumper is required for this circuit between terminals 2 and 4 of the dial-cord plug (not shown), and Link 1 (not shown) has to be in its No. 1 position. Otherwise, the hookup is straight forward and is readily comparable to the basic circuit in Fig. 18-2.

The hatch marks in Fig. 18-11 indicate the connections between the desk set and the magneto box via a 4-conductor cord. The magneto hookup for this phone is seen to be typical of earlier Kellogg arrangements in which the ringer of the cranked phone does not respond (silent ringing). Finally, provisions were made for using this Kellogg 1000 for local-battery talking with common-battery signaling. That hookup would be like Fig. 18-11 with the magneto removed and a retardation coil connected between Terminals H1 and H2.

Automatic Electric Type 60 Wall Phone

Automatic Electric used three different local-battery circuits of this vintage. All of these circuits used the Type 41 handset -- the same handset that was used on Type 40 desk phones and Type 50 wall phones. The first was the Wheatstone bridge circuit that can be found in a Type 60 metal wall phone with both a magneto and a dial (see Fig. 12-18). The wiring diagram for this phone is shown in Fig. 18-12, and it is nearly identical to that of the Western Electric magneto wall phone (Fig. 18-5), except for the addition of the dial.

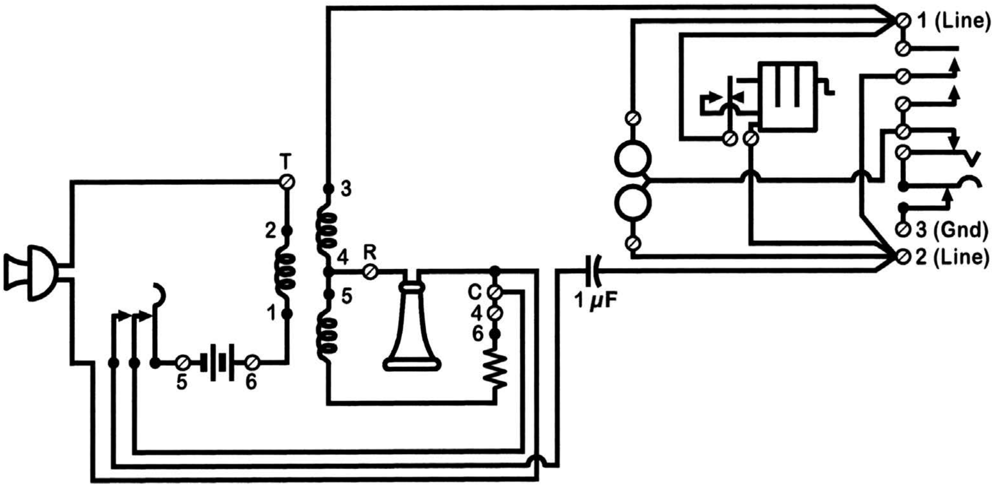

Fig. 18-12. Wiring of Automatic Electric Type 60 wall phone with local-battery, bridge-type, anti-sidetone circuit for use on local-battery or common-battery lines.

No provision was made for dc in or around the receiver, and in fact a 1-microfarad condenser has been added to prevent dc from flowing in that part of the circuit. For dialing purposes, dc from the central office flows from the tip or ring side of the line (tip connection shown in Fig. 18-12) to ground to start the dialing process in this ground-start arrangement. Notice that the center of the two ringer coils is connected to ground to balance the tip and ring sides of the line with respect to ground to reduce noise pickup. When the handset is on hook, the ground connection is broken and the ringer is connected normally between the two line wires.

Western Electric Type 331A Portable Telephone

This specialty phone, which is in the olive colored box, used a straight-forward adaption of the Wheatstone bridge circuit with the No. 104A induction coil. Wiring for this phone is shown in Fig. 18-13 and is similar to the diagrams in Figs. 18-7 and 18-8. Since dc would not be present on the line in this phone's expected applications, no dc bypass was needed for the receiver and a large 2-microfarad condenser was inserted in the line to ensure that no dc reached the receiver. A varistor was connected across the terminals to which the receiver was connected to reduce clicks in the Type 52 headset or F3 (4-conductor) handset.[5] No hook switch is present on this phone, and connections are established when the large plugs on the headset (or handset) cord are inserted into the jacks. To minimize or eliminate ringing sounds that might be overheard when this phone was being used in radio broadcasting, the B-type ringer was mounted without gongs and just made a vibrating noise. A ringer cutoff switch was also provided for completely silent signaling, and ringing could be detected by the flashing neon lamp.

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[5] See discussion of handsets with 4 conductors in the section on early 500-type telephones in Chapter 19.

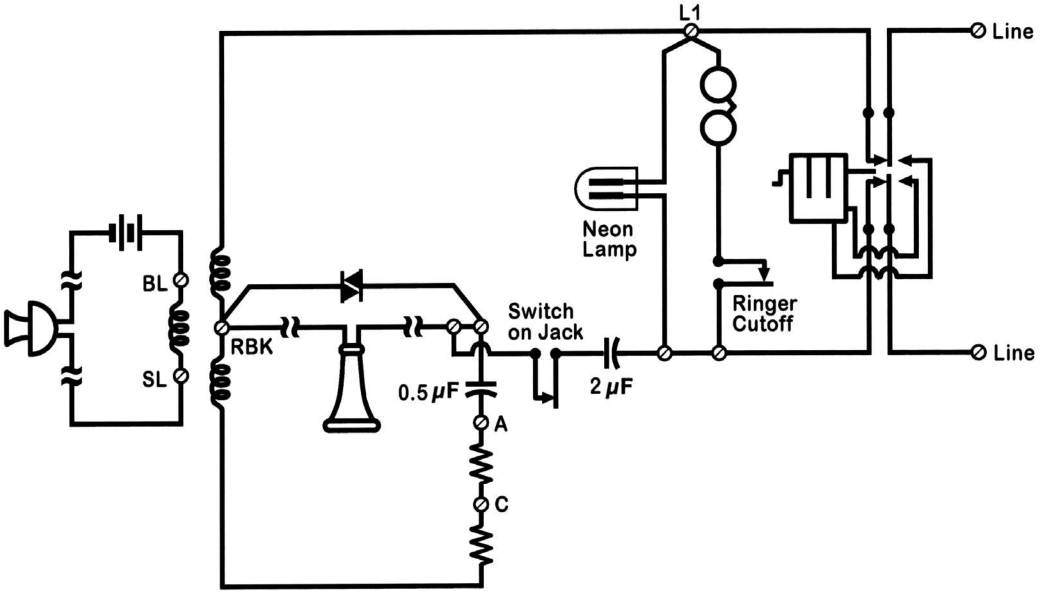

Fig. 18-13. Wiring of Western Electric No. 331A portable telephone with local-battery, bridge-type, anti-sidetone circuit.

Principles of Automatic Electric's Isolation Circuit

Automatic Electric's second circuit of this vintage uses a three-winding coil, whose properties are given in Table 18-3. Coil No. D-283022-A is wound on the same frame as the AE 40 coil and the coil for the Wheatstone bridge circuit covered in the previous section. Coil No. 284317-A, on the other hand, is wound on the same frame as the coil in the AE Type 182 Starlite phone, and this coil is used in later versions of the local-battery wall phone. These two coils are electrically the same except for very minor differences in wire resistance.

Table 18-3. Characteristics of induction coils used in Automatic Electric's local-battery isolation circuit

Characteristic	**Primary**	**Secondary**	**Tertiary**
	Automatic Electric No. D283022-A		
Terminal Markings	1-2	3-4	5-6
Resistance, ohms	2	11	150
Turns Ratio, to primary	1.0	1.9	9.9
	Automatic Electric No. D284317-A[a]		
Terminal Markings	1-2	2-4	5-6
Resistance, ohms	3.3	14	144
Turns Ratio, to primary	1.0	1.9	9.9

[a] More recent transformer-style coil frame with only 5 terminals

The basic principle of this circuit is shown in Fig. 18-14, where it is seen that both the transmitter and the receiver are in local loops that are isolated from the line. This is very similar to the standard local-battery circuit in Fig. 15-1, except that the receiver is also coupled to the line by a transformer arrangement. In this case, both the transmitter winding (primary) and receiver winding (secondary) share the same winding (tertiary) in the line. Direct current is confined to the transmitter loop, and dc is prevented from flowing through the tertiary winding by a condenser. This condenser has a low impedance at voice frequencies and plays no significant role in the circuit other than to isolate the circuit from any dc currents that may be on the line. Impedance matching of the transmitter and its load is accomplished by using more turns in the secondary winding than in the primary winding, and a substantial step-up in line voltage is accomplished with a large number of turns in the tertiary winding.

For the discussion that follows, two electrically identically Automatic Electric telephones were connected together. Each phone had a Type 41 handset and a 3-volt battery. One phone had a D-283022-A coil and one had an equivalent D-284317-A coil.

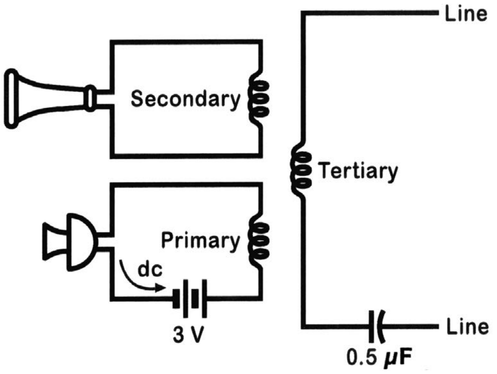

Fig. 18-14. Automatic Electric local-battery isolation circuit.

Transmitting (ac)

Figure 18-15 shows typical measured voltages for this circuit when it is transmitting. For a typical transmitter voltage of 75 millivolts, the large tertiary-to-primary turns ratio puts a whopping 575 millivolts on the line.

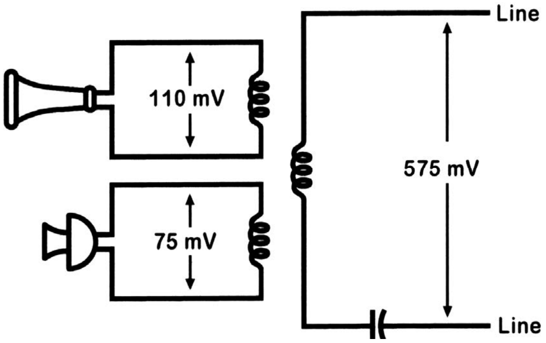

Fig. 18-15. Typical ac voltages in the Automatic Electric local-battery isolation circuit when transmitting.

Receiving (ac)

Figure 18-16 shows typical measured voltages for this circuit when it is receiving. Notice that exactly the same receiver voltage is produced in the receiving phone as in the transmitting phone. Thus, this circuit has a neutral sidetone, just like the standard local-battery circuit; technically, it is not an anti-sidetone circuit -- a type that had become more or less standard in the industry by this time. On the other hand, neutral sidetone of the standard local-battery circuit was never a problem, so absence of this feature was a small price to pay for its outstanding performance.

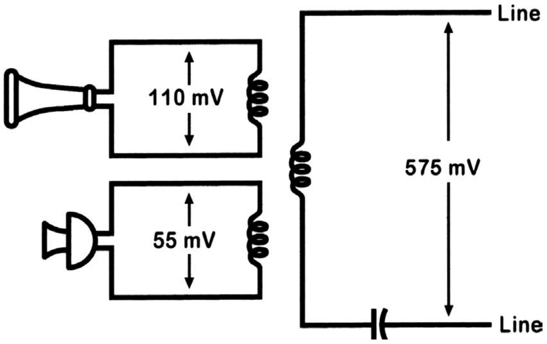

Fig. 18-16. Typical ac voltages in the Automatic Electric local-battery isolation circuit when receiving.

In summary, this simple isolation circuit (a) puts a larger signal on the line than all other circuits described in this book (lower line losses), (b) puts a larger voltage on the receiver than all other circuits described in this book (louder sound transmission), (c) does not have an objectionable sidetone, (d) does not require a retardation coil to keep dc out of the receiver as does the Wheatstone bridge circuit, and (e) does not require a retardation coil to avoid short circuiting the voice signal as do the modified common-battery circuits (next section). This is simply a great circuit.

Example of the Automatic Electric Isolation Circuit

Automatic Electric's isolation circuit is also found in the Type 60 metal wall phone. Figure 18-17 shows the wiring diagram for a Type 60 metal wall phone with this isolation circuit. The transmitter loop and the receiver loop are joined in a harmless point of contact at terminal C to accommodate a three-wire cord from the handset. No new current paths are created by this connection. A ringer and magneto are connected across the line in a standard manner. There is a condenser in series with the ringer to block dc in case the phone is used on a line that also has common-battery service.

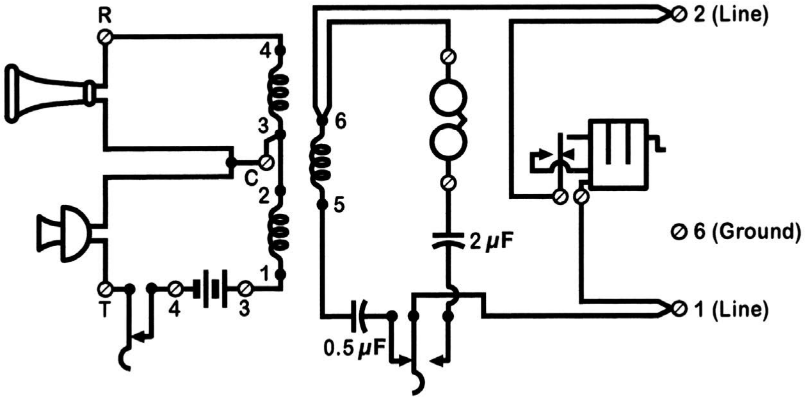

Fig. 18-17. Wiring of Automatic Electric Type 60 wall phone with local-battery isolation circuit.

Principles of Modified Common-Battery Circuits

Obviously, a common-battery telephone circuit would work on a local-battery line if there were some way to provide direct current to the transmitter. This can be accomplished with the addition of a separate local-battery loop around the transmitter. The basic circuit for this modification is shown in Fig. 18-18. Two other refinements are needed. One is the addition of a condenser in the line loop to prevent dc from finding a current path through the line. A large (1-2 microfarads) condenser is used that has a low impedance for the ac voice signal. The second is the addition of a retardation coil in the local-battery loop to prevent the ac voice signal from being short-circuited through the battery, which has a low resistance. Most common-battery circuits also have a current path around the transmitter, through the receiver and the side-tone balancing components. However, the path through the receiver and other components is already designed so that little or no dc bypasses the transmitter through this part of the circuit.

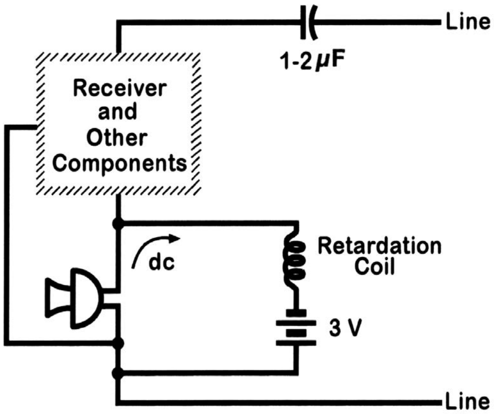

Fig. 18-18. Modification, with a separate local-battery loop, for common-battery circuits to enable their use on local-batery lines.

Examples of Modified Common-Battery Circuits

Automatic Electric Type 40 and 50 Telephones

The third Automatic Electric circuit of this vintage was a modification of the common-battery circuit that was being used in Automatic Electric's Type 40 and 50 telephones. This circuit was also used in some Type 60 metal wall phones. The modification was clever, and the phones with this circuit could be quickly converted to common-battery use when older rural lines were eventually upgraded. Wiring for a Type 40 telephone with this modification is shown in Fig. 18-19.

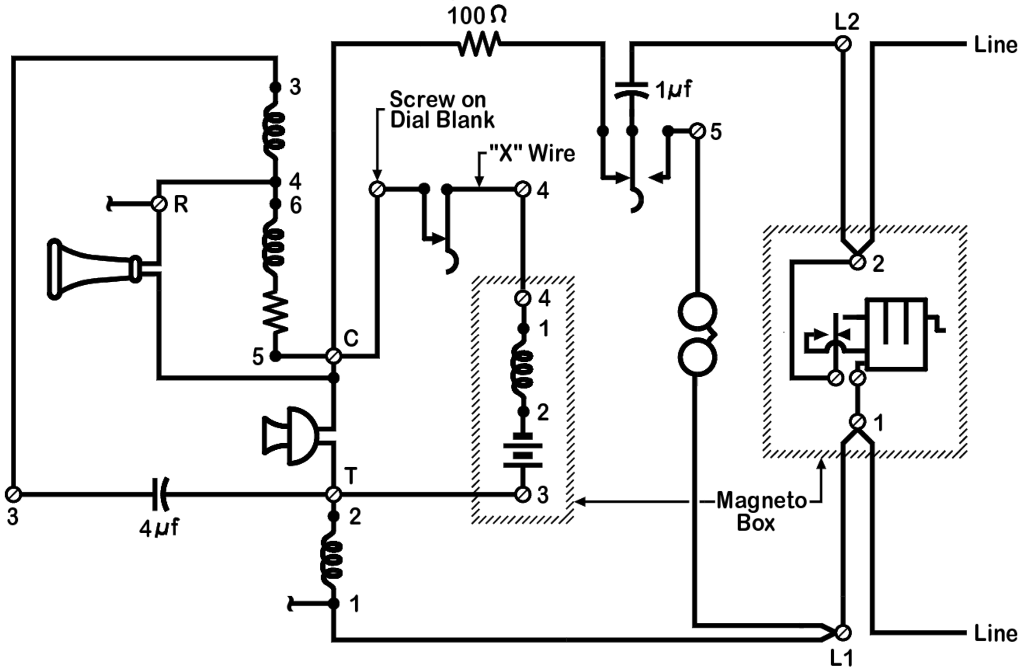

Fig. 18-19. Wiring of Automatic Electric Type 40 with factory-modified circuit for local-battery service.

Automatic Electric supplied these phones with a separate magneto battery box (Fig. 13-12). The retardation coil was in the box along with the magneto and batteries, and properties of this coil are given in Table 18-4. Wiring connections were arranged so that by relocating a single wire and omitting the magneto battery box, the telephone would become a regular common-battery phone. The single wire was called the "X" wire, and by moving its connection from terminal 4 to L2, the circuit is seen to become the same as the common-battery circuit shown in Fig. 17-24. Two extra leads were supplied for installation of a dial, and these leads from terminals R and 1 were parked separately under the two dial-blank mounting screws. There would remain some minor differences in internal connections between a standard Type 40 or 50 and the converted Type 40 or 50, including the need for a slightly different strapping arrangement on the dial, if one were added. Nevertheless, this arrangement provided for very easy conversion from local-battery service to common-battery service as the latter became available. Notice that the 100-ohm resistor at the top of Fig. 18-19 serves no purpose in the local-battery circuit, but it forms part of the radio interference filter when a dial is used in the common-battery conversion (see Fig. 17-24).

Table 18-4. Characteristics of the retardation coil used in Automatic Electric's modified common-battery circuit

Characteristic	**Coil**
Automatic Electric No. D283665-A	
Terminal Markings	1-2
Resistance, ohms	10
Inductance, henrys	0.2
Total Impedance, ohms[a]	1,250

[a] Total ac impedance at 1,000 cycles per second.

Western Electric Type 331B Portable Telephone

Two completely different circuits were used in the Type 331 telephone. When this phone was modified in 1978, an altogether different circuit on a printed circuit board was used in the new light blue colored box. This circuit was a modification of one of Western Electric's latest common-battery circuits.

Instead of using a separate retardation coil in the local-battery loop, this modification used an extra winding in the induction coil as had been done to accommodate the light-emitting diode (LED) dial light in the Trimline. The circuit for the No. 331B is shown in Fig. 18-20.

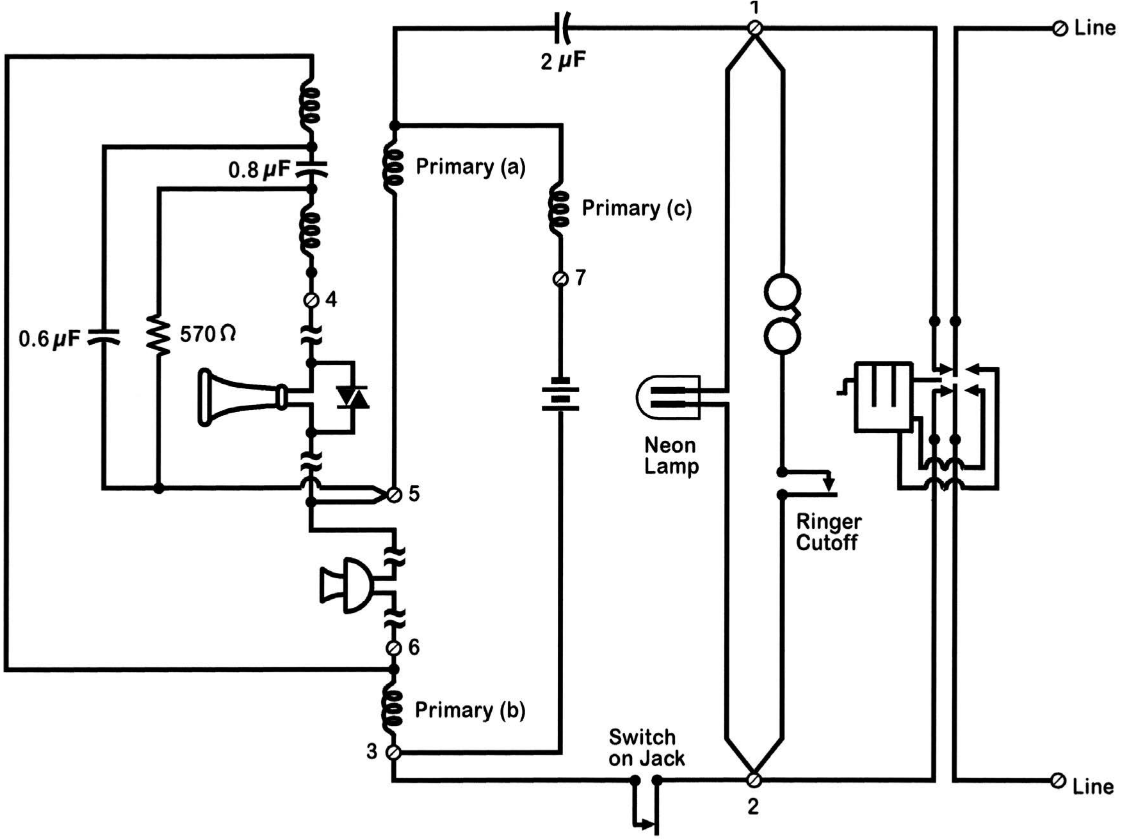

Fig. 18-20. Wiring of Western Electric No. 331B portable local-battery telephone with modified Trimline circuit.

This is, in fact, the same basic circuit used in the Trimline (see Fig. 19-20 in the next chapter), including the use of exactly the same coil, whose properties are given in Table 19-2. By eliminating from the Trimline's network circuit the two varistors and the 24-ohm resistor in series with the transmitter, the No. 331B is utilizing this circuit without any attenuation thus providing maximum signal level and sensitivity at all times. A large 2-microfarad condenser is again used in the line to confine the battery current to the local loop and to prevent any external dc from entering the circuit. The No. 331B was used with a G-type handset, which included a varistor for click suppression, or a Type 52 headset. A P-type ringer with its gong was included in the No. 331B, but as before it had a ringer cutoff switch and a neon lamp for silent signaling. The No. 331B used the same plugs and jacks as the No. 331A to provide the functions of a hook switch.

Chapter 19
Network Circuits

The T1 transmitter and the U1 receiver in the 500-type telephones were more efficient than those in the 300-type sets, and this efficiency was advantageous for raising the level of transmission on long lines. However, a means was needed to attenuate the higher transmission levels on short lines, and a further reduction in sidetone was desired. Improvements in cost and ease of assembly were also sought. All of these objectives were achieved in a new circuit that was packaged in a steel can with a plastic terminal plate on the top (Eppes 1981, 24-26; Tuffnell 1951; Neisser 1951). The circuit in the first of these, the so-called 425A network (or 425A NET), was replaced in just a few years by a revised circuit (in the 425B and later networks) that became the industry standard, so both of these circuits are described here. Although Automatic Electric utilized this standard circuit in its telephones, it did so with modifications. Therefore, several Automatic Electric wiring diagrams are described at the end of this chapter.

Principles of the Western Electric No. 425A Network Circuit

Figure 19-1 shows the basic 425A network circuit, identifying major components of the circuit and the dc current path through the primary coil winding and the transmitter. Only one fundamental change had to be made to the earlier Western Electric circuit (Fig. 17-1 of Chapter 17) to achieve the present circuit, and that was the interchange in position of the receiver and the sidetone-balancing impedance. The sidetone-balancing impedance would have to be more complex than a simple resistor in order to more effectively balance the line impedance, which included capacitance and inductance, and other circuit parameters would have to be altered. Nevertheless, the similarity to the previous circuit is apparent, and the essential feature of a current path bypassing the receiver is present to reduce sidetone.[1]

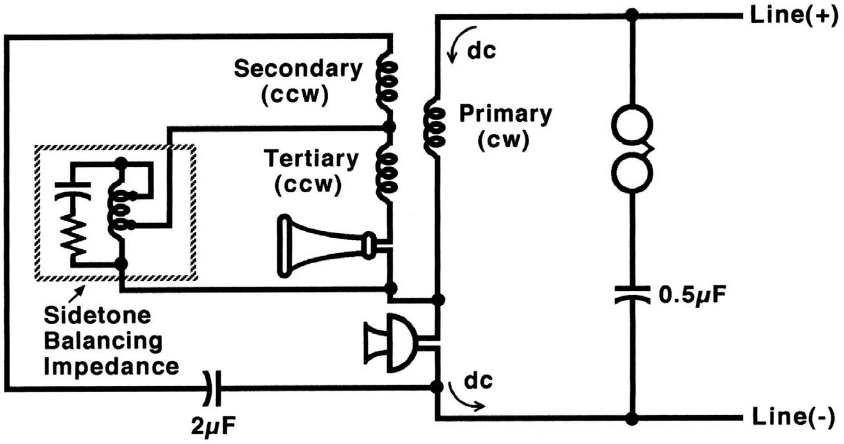

Fig. 19-1. Western Electric's anti-sidetone circuit with the No. 425A network.

It was known from theoretical studies that a sidetone impedance-balancing network like that shown in Fig. 19-2 would be required to achieve ideal sidetone reduction with the new circuit.[2] Such a network

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[1] Although quite similar to the previous circuit, the present circuit is a different one of the 174 circuits analyzed by Campbell.

[2] The term network refers to any group of components with a combination of series and parallel connections. Thus the term is sometimes used to refer to the whole circuit in the steel can, while at other times it is used to refer to just a portion of it, like the sidetone-balancing impedance.

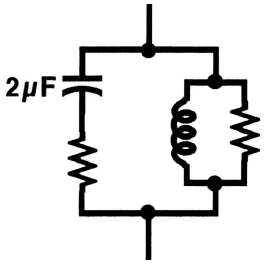

Fig. 19-2. Ideal sidetone-balancing impedance for the Western Electric No. 425A network circuit.

would provide the right mix of resistance, capacitance, and inductance that was needed for a typical line. But a network like this would be expensive to manufacture using conventional parts, particularly because of the large 2-microfarad condenser. That problem was solved when it was shown that a simpler autotransformer network as shown in Fig. 19-1 had the same impedance. An autotransformer is a single coil with several taps, and this equivalent circuit only required a small 0.2-microfarad condenser.

Another economic benefit of this circuit compared to that of the 300-type phone was that smaller induction coil windings could be used because the secondary and tertiary windings now aided each other in providing the booster action (both are wound counter clockwise in the 425 networks) rather than opposing each other as in the previous circuit. The coil in the 425 network thus uses 25 to 30 percent less wire and is much smaller than the previous 101A coil. Also, the new metallized paper condensers were less than half as big as the earlier foil-and-paper condensers, and they were less costly to manufacture as well.

Characteristics are shown in Table 19-1 for the coils in the 425 network (all variations) and two other networks. Because these coils are wired directly to other components in the network circuits, coil terminals are not identified, and in fact some of the coil leads are not accessible through terminals on the network terminal plate (diagrams identifying all terminals are shown later). The primary winding of the coil in the 425A network has a center tap (also shown in later diagrams), such that the primary can be considered to be made of two sections; the primary winding in the 425B and later networks is actually split into sections that are connected separately. The tertiary winding of the coil in the 425 networks has nearly the same turns ratio as the tertiary winding of the 101A coil, although the extra resistance is not present (copper wire is used throughout). However, the secondary winding of the coil in the 425 networks has far fewer turns of wire (much lower turns ratio) than that of the 101A, showing the reduction in the amount of coil wire mentioned.

Table 19-1. Characteristics of induction coils in Western Electric's network circuits

Characteristic	**Pri(a)**	**Pri(b)**	**Secondary**	**Tertiary**
	No. 425 NET			
Resistance, ohms	13.5	17	15	15
Turns Ratio[a]	1.0		0.32	0.36
	No. 4228 NET			
Resistance, ohms	20	21	18	21
Turns Ratio[a]	1.0		0.37	0.45
	No. 4293 NET			
Resistance, ohms	32	27	22	32
Turns Ratio[a]	1.0		0.26	0.42

[a] Turns ratios are relative to the total primary winding.

For the discussions that follow, two electrically identical Western Electric telephones with the 425A network were connected to the common-battery supply shown in Fig. 16-5 of Chapter 16. Each telephone had a T1 transmitter and a U1 receiver. The equalizer was not connected for these measurements. A direct current of about 30 milliamperes was maintained in each telephone for the tests.

Transmitting (ac)

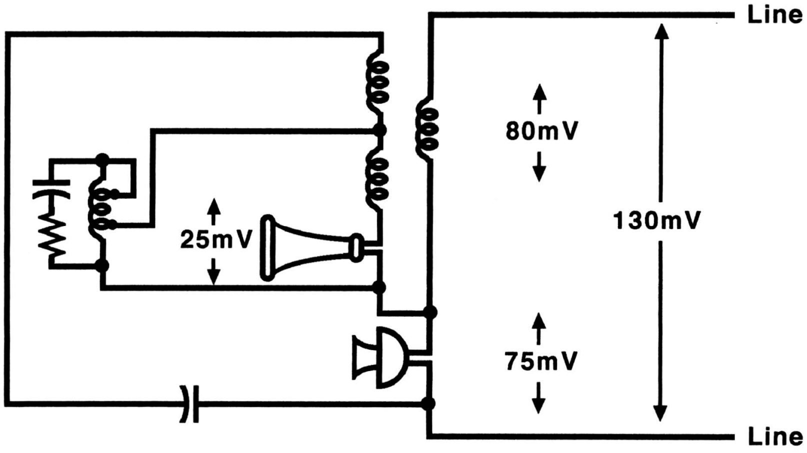

Fig. 19-3. Typical ac voltages in the Western Electric No. 425A network circuit when transmitting.

Figure 19-3 shows the 425A circuit with typical ac voltages measured while transmitting (the ringer has been omitted from the diagram for simplicity). As in the previous anti-sidetone circuit, ac signal current in the secondary circuit flows through the tertiary winding and through the secondary winding, and these two windings together induce a voltage across the primary winding. In this circuit, because the secondary and tertiary windings are wound in the same direction, their magnetic fields add together. The induced primary voltage is about 80 millivolts, which adds to the transmitter voltage of about 75 millivolts boosting the output line voltage to about 130 millivolts, quite similar to the output of the previous anti-sidetone circuit and the original booster circuit.

The anti-sidetone feature of this circuit when transmitting works in a manner similar to that of the previous circuit when receiving because of the interchange in location of the receiver and sidetone-balancing impedance. Currents in the primary and secondary windings induce a voltage across the tertiary winding. In this case, the coil is designed such that the voltage across the tertiary winding is approximately equal to, and of the same sign as, the voltage across the sidetone-balancing impedance.[3] Hence, the voltage across the receiver is nearly zero, resulting in a small sidetone. By using the more complex sidetone-balancing impedance, the sidetone level has been lowered from about 30 millivolts in the previous circuit to about 25 millivolts here. This is a modest but significant improvement.[4]

Receiving (ac)

Figure 19-4 shows the 425A circuit when it is receiving. Consistent with Fig. 19-3, the voltage source is now the line voltage of 130 millivolts, which is dropped across the primary winding (about 110 millivolts) and the transmitter (about 20 millivolts).

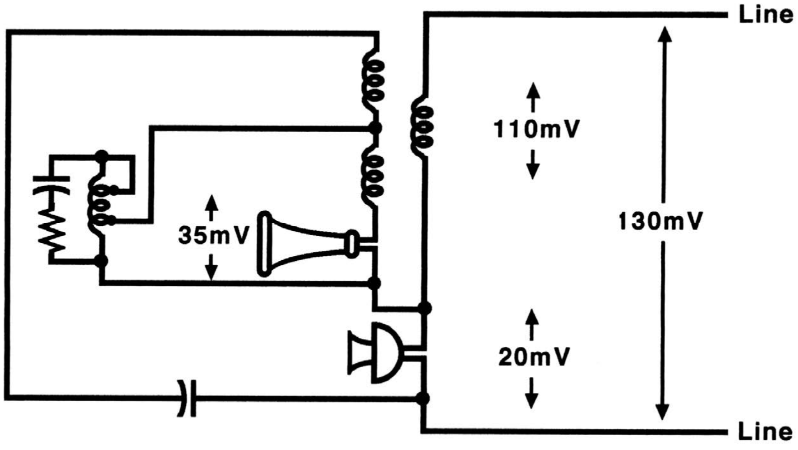

Fig. 19-4. Typical ac voltages in the Western Electric No. 425A network circuit when receiving.

Alternating currents in the primary and secondary windings will again induce a voltage across the tertiary winding. When receiving, this tertiary voltage is

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[3] Because the voltage across the tertiary winding must be of the same sign as the voltage drop in the sidetone-balancing impedance, the tertiary winding is required to have the same polarity as the secondary winding, in contrast to the previous circuit.

[4] Because sidetone balance depends on line impedance, the sidetone level reported here applies only to the short line used in the tests.

approximately equal to, but of opposite sign from, the voltage across the receiver. Hence, the sum of these two voltages is approximately zero. Therefore, the sidetone-balancing impedance sees a near-zero voltage and very little wasted current flows through it; most of the current flows through the receiver, as desired.

The No. 311A Equalizer

With the enhanced performance of the T1 transmitter and the U1 receiver, it was desirable to attenuate some of that performance when the phone was being used on short lines in order to achieve more uniform performance over a range of line conditions. This was accomplished automatically with several components referred to collectively as an equalizer. The equalizer acted simultaneously to reduce the transmitter's output by adding line resistance and to reduce the receiver's sensitivity by shunting current around it. The components of the equalizer are shown in Fig. 19-5.

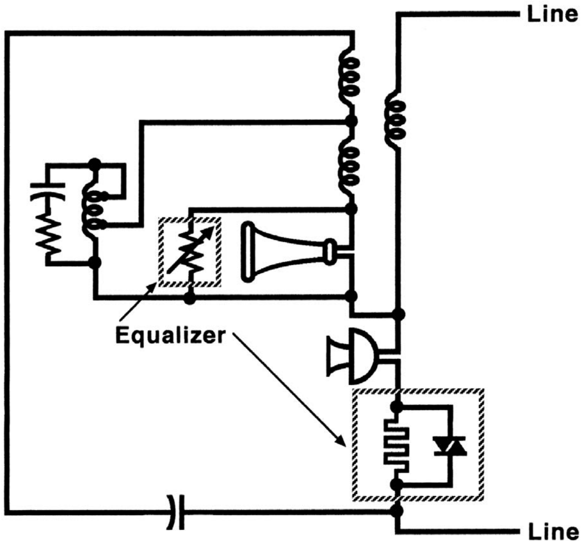

Fig. 19-5. Western Electric No. 425A network circuit with the equalizer.

The heart of the equalizer is a tungsten filament indicated by the square-toothed symbol just below the transmitter in Fig. 19-5. On short lines, when the dc voltage across the telephone is high, the larger current through the tungsten filament causes it to get hot and its resistance increases. The increased resistance increases the voltage drop across the tungsten filament, thus decreasing the voltage across the transmitter and reducing transmitter output as desired. For a high line voltage of, for example, 16 volts, the hot tungsten filament has a resistance of about 150 ohms, roughly equal to that of the transmitter. The cold filament resistance (corresponding to long line conditions) is only 22 ohms, which is much smaller than the transmitter's resistance and therefore has little effect.

The second principal component in the equalizer is a thermistor, shown as a resistor with an arrow through it bridging the receiver. A thermistor is a variable resistor whose resistance decreases as temperature increases (just the opposite of a heated filament). By placing the thermistor close to the tungsten filament, the thermistor's resistance will decrease when the filament gets hot. This shunts part of the receiver current through the thermistor, thereby reducing receiver level on short lines. For the high, 16-volt line condition just mentioned, the thermistor has a resistance of about 150 ohms, which is about the same as the receiver's total impedance. However, when the tungsten filament is cold, the thermistor's resistance is approximately 2,500 ohms; this is much larger than the receiver's own resistance and under these conditions, the thermistor has a negligible effect.

The final component of the equalizer is a varistor, which is connected across the tungsten filament. The sole purpose of the varistor, as used here, is to protect the tungsten filament from abnormally high voltages. Because a varistor's resistance decreases at higher voltages, its reduced resistance will shunt high-voltage surges around the filament, and thus prevent burnout. The varistor does not play a role in the normal ac operation of this circuit as it will in the improved circuit of the 425B network described later.

Example of the Western Electric No. 425A Network Circuit

Early 500-Type Telephone

Figure 19-6 shows the complete wiring diagram for an early Western Electric 500-type rotary dial telephone with the 425A network and the 311A equalizer.[5] Terminals B, L, W, and RW are located on the equalizer, whereas all other marked terminals shown in Fig. 19-6 are on the network. Like terminal YL2 on the coil of the earlier No. 302 telephone, terminals L1, L2, G, and E are not connected to anything inside the network and serve merely as tie points. Several additional features are present in the full wiring diagram shown.

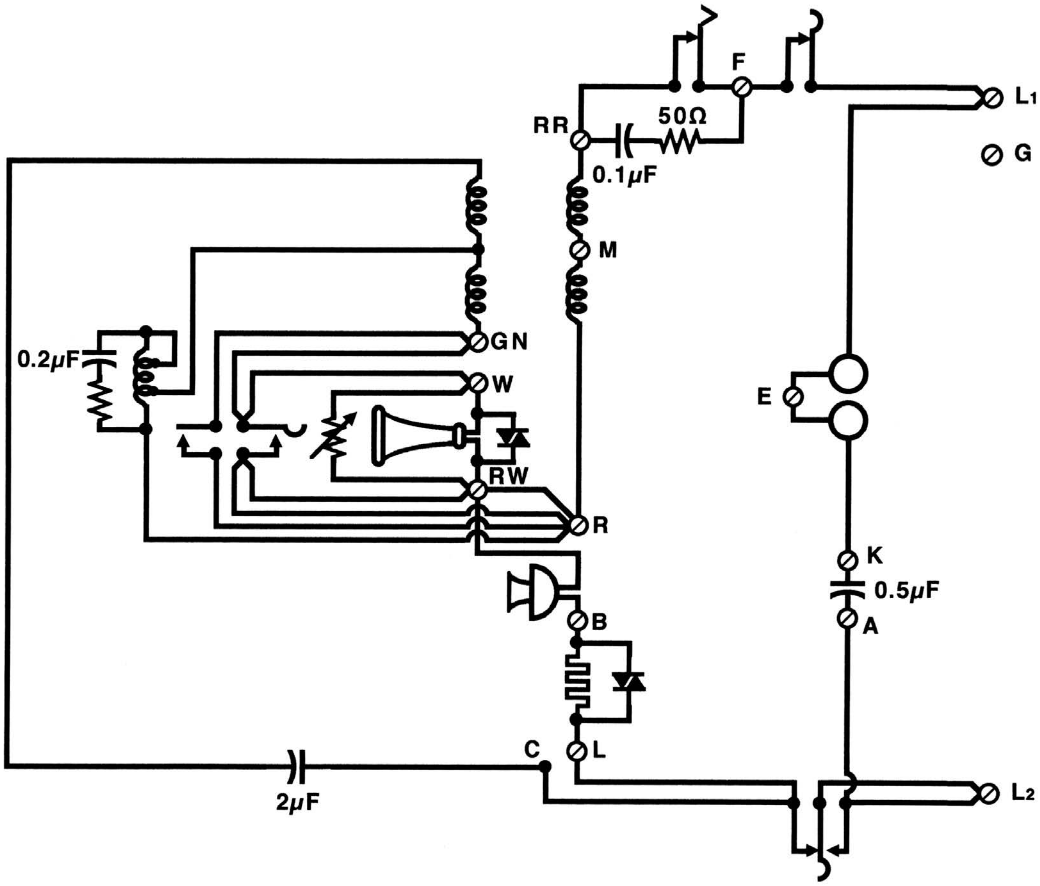

Fig. 19-6. Wiring of a Western Electric No. 500 A/B telephone with the No. 425A network and the No. 311A equalizer.

First, an additional varistor is seen across the receiver terminals. This varistor is located on the back of the U1 receiver element inside the handset. At normal millivolt signal levels, this No. 44A varistor has a resistance that is very much higher than that of the U1 receiver, therefore having no effect on the receiver's performance. However, for abnormally high signal levels, such as with electrical noise from switching, the varistor's resistance is lower than the receiver's resistance. Noise pulses are thus shunted around the receiver, greatly reducing loud clicks and popping sounds. Characteristics of this varistor are described in the Appendix.

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[5] This circuit appeared only in Western Electric's 500 A/B telephone and was not used by other manufacturers as the later No. 425B network was available when the cross-licensing patent agreement was signed in 1951.

Second, the handset now uses a four-conductor cord, and two of the conductors go to the same terminal (RW) in a seemingly redundant manner. There is a good reason for this, however. If a common conductor were used as in earlier circuits for one transmitter and one receiver terminal, the dc transmitter current would produce a small voltage across the length of that conductor. This voltage would then cause the varistor to have a lower resistance that could short-circuit the receiver. A typical handset conductor in good condition will have a resistance of about 3 ohms, and the typical transmitter dc current will be about 30 milliamperes. Under these conditions, the voltage across that conductor would be 0.09 volts. This would not be a problem as can be seen from Fig. A-6. However, in some cases one could readily expect the resistance to be as high as 10 ohms (the loop current can be higher, also), and in those cases the voltage would be 0.3 volts or more. From Fig. A-6, it is clear for those cases that the varistor would have a constant low resistance and shunt the voice signal around the receiver. By using a separate conductor for the receiver with no direct current in it, there is no dc voltage to produce an unwanted bias on the varistor. Thus, after almost 25 years of using circuits that minimize the number of conductors in the handset cord, the fourth conductor was finally added.

Third, a center tap M is now routinely provided in the primary coil winding along with a split-winding ringer to accommodate caller identification on party lines. Wiring for caller identification would be just like that described in Chapter 17 for the 300-type telephones.

Fourth, a new radio interference filter is used, and it is included in the network enclosure. Radio-frequency pulses are shunted around the dial impulse switch through a resistor and a 0.1-microfarad condenser. The inductance of the primary winding is used in this design to provide a high impedance to these radio-frequency pulses so that they will not move through the rest of the circuit. The dial shunt switch that was previously used to short out the transmitter has been omitted altogether, simplifying the wiring (and the dial) somewhat.

Finally, the 3-section hook switch that would be needed when wiring for caller identification is provided on all 500-type sets. One of the hook switch sections is a 3-contact single-pole, double-throw switch that is connected like a 2-contact, single-throw switch in straight bridging applications as shown. The hook switch contacts across the receiver, which are closed in the on-hook position, open last after all direct currents have been established thus achieving quieter hook switch operation, as in most designs.

Principles of the Standard Network Circuit

Although cost of the 425A network was lower than for equivalent components in the earlier 300-type telephones, the autotransformer in the sidetone-balancing impedance and the glass tube in the equalizer were still expensive to manufacture. The design objective of the 425B network was, therefore, to retain the performance of the 425A while reducing its cost. This was accomplished with a circuit modification that used a pair of varistors for both sidetone-balancing and equalizing functions (Bennett 1953).

The circuit of the 425B network is shown in Fig. 19-7. The induction coil in the 425B network has a split primary winding, rather than merely having a center tap, as in the 425A. Otherwise, however, the coil in the 425B network is the same as the coil in the 425A with exactly the same resistances and turns ratios. Other similarities between the two circuits are apparent. The 2-microfarad condenser is present to prevent direct current from flowing through the receiver, although the exact location of the condenser has been changed. And a sidetone-balancing impedance provides an alternate current path around the receiver to reduce sidetone.

In contrast to the 425A, however, the new circuit has three dc current paths instead of only one. The main dc path through the transmitter is, of course, present. The other two paths go through the two varistors; relocating the 2-microfarad condenser was necessary to create one of them. These paths establish dc voltages across the varistors, and those dc voltages control the varistors' resistances that will be seen by the ac voice signal.

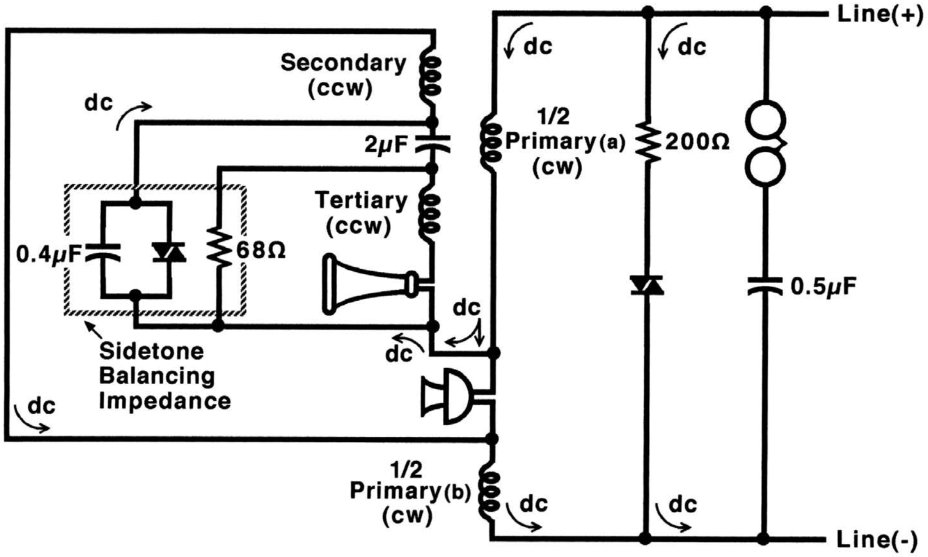

Fig. 19-7. Western Electric's standard anti-sidetone circuit employing two varistors.

The varistors used in this circuit function as variable resistors that are germane to the ac performance of the circuit, rather than merely serving as voltage limiters as in previous applications. The shunt path across the set (shown parallel to the ringer path) uses a No. 312D varistor, and the 200-ohm resistor in series with it places that varistor in its desired dc voltage range. When dc line voltages are high (short line), the varistor's resistance drops, shunting some of the excess transmitter output through the varistor, rather than placing it all on the line.

Similarly, the lower-voltage No. 312E varistor in the sidetone-balancing impedance is placed in its desired dc voltage range by the resistances of the primary and secondary coil windings. When dc line voltages are high, this varistor's resistance also drops, shunting excess ac signal around the receiver. Thus, these two varistors perform the same function as the equalizer in the previous circuit.

Several observations can be made about sidetone balancing. First, the sidetone-balancing impedance in the 425B does not have an inductive component as in the 425A. Therefore, the 425B cannot achieve ideal balance with the typical line impedance assumed for design of the 425A. But line impedance varies widely from one location to another, and the 425A cannot adjust to varying line conditions like the 425B can. Further, the varistor shunted across the set (in series with the 200-ohm resistor) loads down the line for short loops, and makes the line impedance more resistive (less inductive) because the varistor is a resistor. This improves sidetone balance of the non-inductive, sidetone-balancing impedance. Both varistors are, therefore, required to get good sidetone balance, and sidetone performance of the 425B, while operating a little differently from the 425A, is just as effective.

Examples of Rotary Dial Telephones with the Standard Network Circuit

500-Type Telephones

Figure 19-8 shows the complete wiring diagram for a standard 500-type rotary dial telephone with the 425B network. This wiring diagram, with very minor changes, would also apply to later versions of the 425 network used with rotary dial telephones. The part of the circuit that is in the network enclosure is also virtually identical to other versions of the 425 network used with touchtone phones, except that the 0.1-microfarad condenser at terminal F is omitted because there is no dial impulse switch in those phones. As in the earlier network, terminals L1, L2, and G (and also F in the networks used for touchtone dialing) are not connected to anything inside the network and are used merely as tie points. Although Fig. 19-8 is readily comparable to the basic circuit in Fig. 19-7, several features shown here are worth noting.

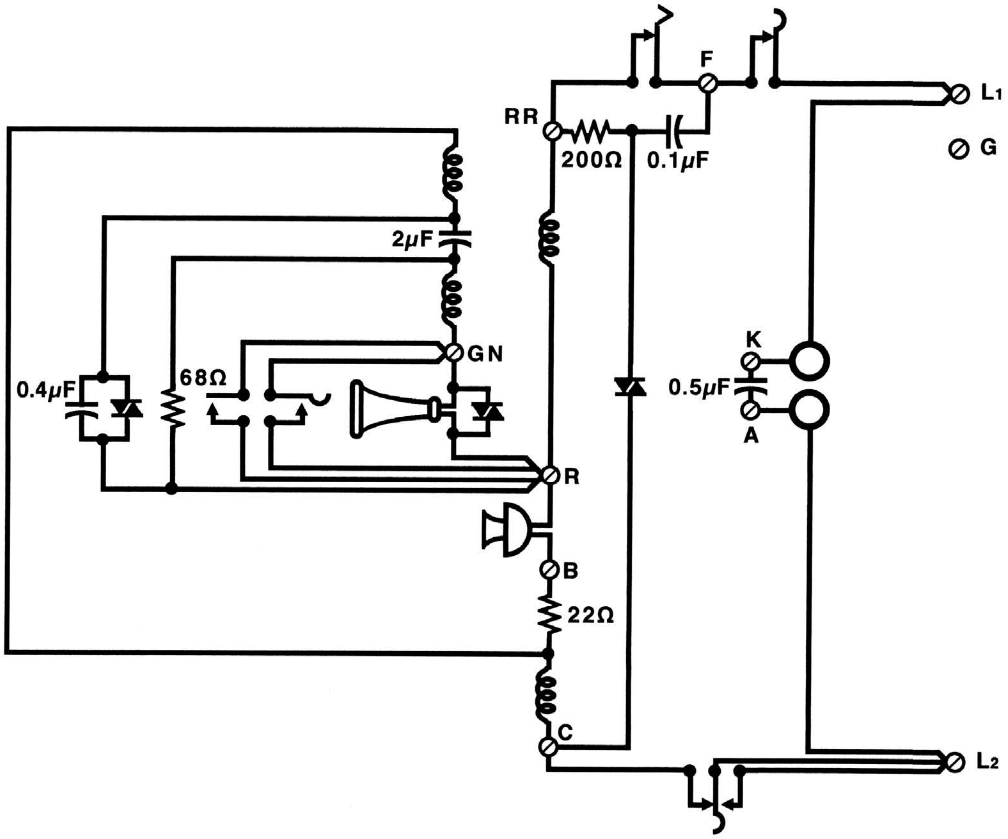

Fig. 19-8. Wiring of a typical 500-type telephone with a No. 425 network (425B and later).

First, a 22-ohm resistor has been added just below the transmitter at terminal B. Because as the dc resistance of a T1 transmitter ranges from about 75 to 275 ohms and is quite variable, this extra 22 ohms accomplishes very little. However, the cold resistance of the tungsten filament in the equalizer used with the earlier 425A network was 22 ohms. Consequently, the addition of a 22-ohm resistor in the 425B network ensured that there would be no increase in transmitter current over the earlier phones. Such attention to small details is interesting, and the persistence of this 22-ohm resistor in later circuits -- long after the short-lived equalizer was forgotten -- is remarkable.

Second, the 200-ohm resistor at terminal RR provides the dc bias needed for the varistor, as well as functioning as part of the radio-interference filter. A precise value of resistance is not needed for the filter, and the 200-ohm value required for the varistor works satisfactorily.

Third, the ringer condenser is shown connected between the two split windings of the ringer, rather than on one side of the ringer. Because the condenser and the two sections of the ringer winding are in series, it makes no difference electrically whether the condenser is in the middle or on either side. However, some wiring convenience results from this arrangement, and the practice of putting the condenser in the middle is used in most later telephones. Caller identification can be connected as for the earlier 300-type phone with a connection made to terminal B, rather than terminal M, which is no longer present.

Other features, such as a varistor (No. 44A, 100A, or 104A) across the receiver, dial switching, and hook switch operation, are just like the earlier 500-type telephone represented in Fig. 19-6.

Princess-Type Telephones

No change was made in the speech circuit of the 500-type telephone to produce the rotary dial Princess phone, although some repackaging was required. In fact, the only significant electrical change in the Princess was the addition of a dial light that doubled as a night light.

Components of the No. 425B network were repackaged in a flatter No. 495A network to fit inside the smaller housing of the Princess telephone. Figure 19-9 shows the wiring of the Princess phone with this network. An extra terminal R1, connected internally to terminal R, was added for convenience, and terminals L1, L2, and D were located on a separate terminal block. Because the early Princess telephone did not have its own ringer, an external ringer could be connected to terminals L1 and D.

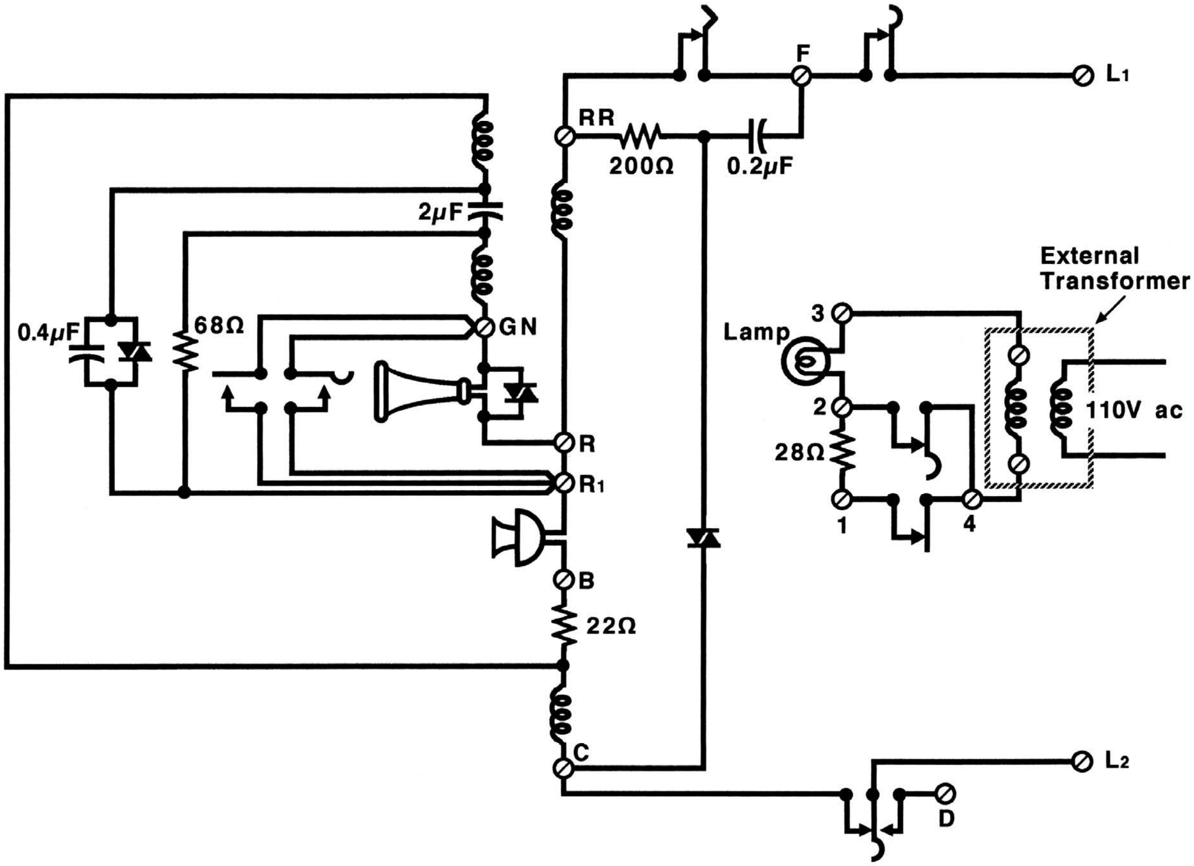

Fig. 19-9. Wiring of a rotary dial Princess telephone with a No. 495A network, showing the night light (early model without a ringer).

Wiring for the combined dial light and night light is also shown in Fig. 19-9. Power for the light is provided by a Western Electric No. 2012A or 2012C plug-in transformer, the secondary (load) of which is connected to two leads of a standard 4-conductor line cord from the phone. The primary winding of this transformer has an unusually high dc resistance for a transformer (about 740 ohms) so that the output voltage is a strong function of load. Its voltage with no load connected to the secondary is 14 volts, whereas that voltage drops to about 8 volts with the light bulb fully illuminated. The inherent high resistance of this transformer provides self protection against short circuits in the secondary side, which is connected to the telephone.

When the handset is on hook, the light bulb is in series with a 28-ohm resistor, and the bulb glows dimly as a night light. The night light can be disabled by a small switch on the rear of the phone. However, when the handset is lifted off the hook, the dial light glows brightly whether the night light is being used or not. Early Princess telephones used a 6-volt bulb with a screw base, whereas later phones used a wedge-base, automotive-style bulb.

Touchtone Dials

Touchtone dialing uses an electronic tone generator in each telephone. To understand the tone generator, first consider a transistor amplifier, such as that shown in Fig. 19-10. An ac signal of some frequency can be put in on the left, and a higher power ac signal of the same frequency can be taken out on the right, provided that appropriate dc voltage biases are maintained as indicated. Because the output power level is higher than that of the input, a fraction of the output signal could be fed back to the input, replacing the external input signal, and a sustained output signal would continue to be generated.

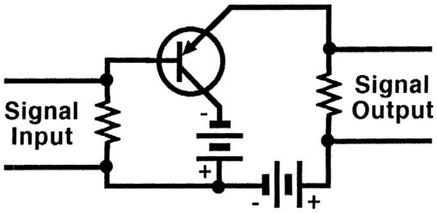

Fig. 19-10. Basic circuit of one type of transistor amplifier.

Several additional features are required to complete the conversion of an amplifier with feedback to a tone-generating oscillator. One is a means of starting the oscillations with some external input signal of a temporary nature. Another is a means of tuning the input and output loads -- shown as resistors in Fig. 19-10 -- so that they present a high impedance only at the desired tone frequency. Finally, some means is needed to limit the amplitude of the oscillations to avoid ever-increasing (runaway) signal levels. All of these features are covered in the following paragraphs, with the method of starting the oscillations described last.

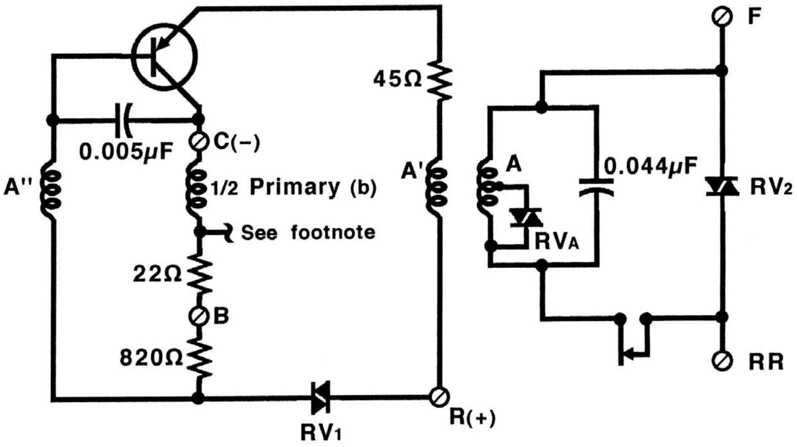

Fig. 19-11. Simplified diagram of tone-generating transistor oscillator for touchtone dialing.

Figure 19-11 shows a simplified version of the oscillator circuit used to generate touchtone signals. As shown, this oscillator would produce a single tone, whereas the complete circuit (shown later) generates two tones simultaneously. Notice that a portion of the speech circuit between terminals C and B on the network is used as part of the oscillator circuit. [6]

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[6] From the point between “½ Primary (b)” and the 22-ohm resistor, there is another dc path to R through the network -- even when the transmitter is disconnected (see e.g., Fig. 19-8 or 19-9). Current through this path is small and does not affect the bias voltages, so the rest of that current path has been left out of Fig. 19-11.

When connected to the speech circuit at terminals R, B, and C (as shown), line current flows from R to C, producing dc voltages across the resistances in that path. By comparison, little direct current flows through the transistor because of its higher resistances. Therefore, the dc voltage drops between R and C produced by the line current establish the dc biases needed for transistor operation. A 100-type varistor (RV_1) is used for one of the resistors to keep the bias voltages relatively constant -- even for short lines with high line current.

The heart of the oscillator is a pair of 3-winding coils with ferrite cores: one for the column frequencies and one for the row frequencies. Part of these 3-winding coils is shown in Fig. 19-11. Winding A forms a tuned circuit with the 0.044-microfarad condenser. Because a coil's impedance goes up with increasing frequency, whereas a condenser's impedance goes down, a parallel combination (as shown) has a high impedance at one well-defined frequency. Such a combination of a coil and a condenser is called a tank circuit. The transformer coupling between winding A and windings A' and A" couples the tuned impedance of this tank circuit to both the input and output parts of the amplifier circuit, providing the tuned input and output loads required. Furthermore, transformer coupling between winding A' and winding A" provides feedback from the output to the input of the amplifier to sustain oscillations as desired.[7]

The tuned impedance presented by A' forms only part of the oscillator's output impedance: the 45-ohm resistor and all the components between terminals R and C form the rest of it. A significant part of the oscillator voltage is therefore developed between terminals R and C. This voltage appears in the speech circuit, thus putting substantial oscillator voltage on the line.

Amplitude limitation for the oscillator is provided by another 100-type varistor RV_A, which is shunted across part of the primary coil winding A of the tank circuit. When the signal level gets large, the varistor's resistance goes down, short-circuiting some of the signal current around the lower portion of the coil. This change reduces the impedance of the tuned circuit, thus limiting the oscillator's output.

The mechanism for starting oscillations works as follows. Line current flows through a third 100-type varistor RV_2, which is inserted between terminals F and RR of the network, and this current produces a dc voltage across the varistor. The switch shown in Fig. 19-11 is closed when the dial is not in operation, so a small direct current, driven by the voltage across RV_2, normally flows through coil winding A. When any button on the dial is pressed, this switch opens just after other switches (shown later) close, interrupting the direct current flow. This cessation of current causes the magnetic field in the coil to collapse, and the collapsing magnetic field of coil winding A induces the desired signal in the other coil windings. This method of starting oscillations is called shock excitation. The switch shown in Fig. 19-11 remains open while the tone generator is oscillating.

One final detail in Fig. 19-11 is the 0.005-microfarad condenser, which is connected directly to two elements of the transistor. At audio frequencies, the impedance of this condenser is so high (32,000 ohms at 1,000 cycles per second) that the condenser can be considered to be non-existent and Fig. 19-11 would look essentially like Fig. 19-10. However, at radio frequencies (around a million cycles per second), this condenser's impedance is quite low, effectively shorting out radio frequency harmonics that might be produced.

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[7] The coil winding “½ Primary (b)” is part of the induction coil in the speech circuit (the lower half of the primary winding in Fig. 19-7 with the 17-ohm resistance, as indicated in Table 19-1). Therefore, it is not magnetically coupled to any of the coil segments of the oscillator coils.

Circuit for No. 25 Dial

The complete circuit for a Western Electric No. 25 touchtone dial (7-wire hookup) is shown in Fig. 19-12. The first thing to notice is that both 3-winding coils (i.e., A, A', A", and B, B', B") are connected in the circuit, and their respective sections are simply hooked up one after the other. The oscillator shown in Fig. 19-12 thus has two tuned tank circuits that are coupled to the amplifier's input and output, and the tone generator oscillates at two frequencies simultaneously.

Next, notice that the coil winding in each tank circuit is broken into five segments, which are connected in series, thus still acting as a single coil winding. One segment is used for connecting the amplitude-limiting varistor, and the others are available to provide four different frequencies in each tank circuit, although one of those in the high frequency tank circuit is not used.[8]

The mechanical switching arrangement for the touchtone dial is complex. When a number (e.g., 5) on the key pad is pressed, the following sequence occurs. First, the switches close at 770 cycles per second and 1,336 cycles per second in the tank circuits, tuning the oscillator to the frequency pair for the number, five. Next, the switch at terminal R makes contact, establishing dc bias voltages on the transistor (switch sections at terminals 10 and 11 are covered later). Finally, the switch at terminal RR opens to start the oscillations by shock excitation.

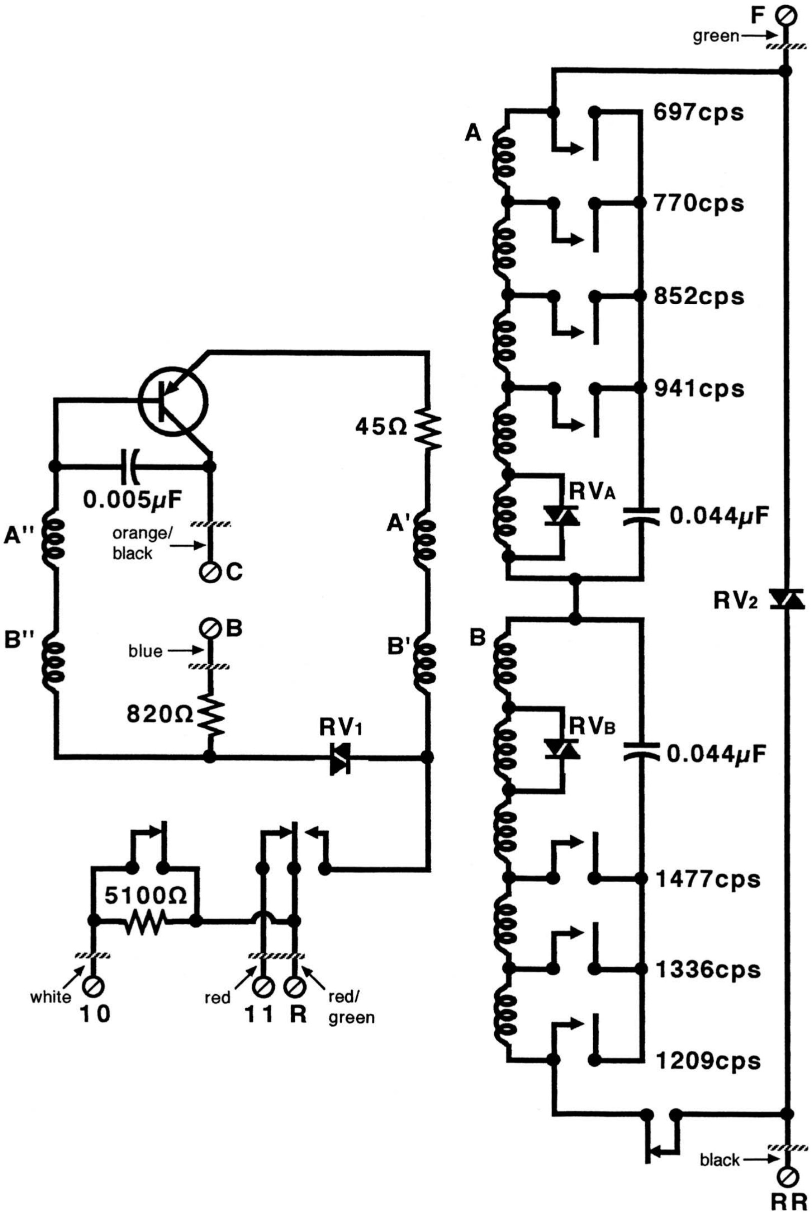

Fig. 19-12. Complete circuit of the Western Electric No. 25 touchtone dial (7-wire hookup).

All four of the varistors in Fig. 19-12 are of the Western Electric 100 type (see the Appendix for their electrical properties). The varistor RV_2 between terminals F and RR is a No. 100D varistor (green band), whereas the others are the No. 100E varistor (yellow band).

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[8] The original concept had a four-by-four matrix of frequencies, but an array of only three by four (twelve frequency pairs) is used in standard telephones. See Chapter 7.

Variations of the No. 25 Dial

Several variations of the No. 25 dial were later used by Western Electric. The most prevalent of these is the No. 35 dial (8-wire hookup), which is electrically identical, except for the way the 5,100-ohm attenuation resistor is switched into the receiver circuit. The part of the tone generator's circuit that is altered is shown in Fig. 19-13.

A very similar tone generator in the No. 82 dial is used on the early Trimline telephones. That tone generator uses two transistors connected in parallel such that one is coupled to coil A and the other to coil B. Connection to the speech circuit is made at seven points, as with the No. 25 dial.

More recently, a 10-transistor chip was developed to replace the circuit shown in Fig. 19-11 (Berry 1966). That chip is used in the No. 72 dial (9-wire hookup) for standard telephones and in the No. 83 dial in the newer Trimline phones. The extra hookup wire is used to accommodate a polarity guard, which allows the tone generator to operate even if the line connections have been reversed.

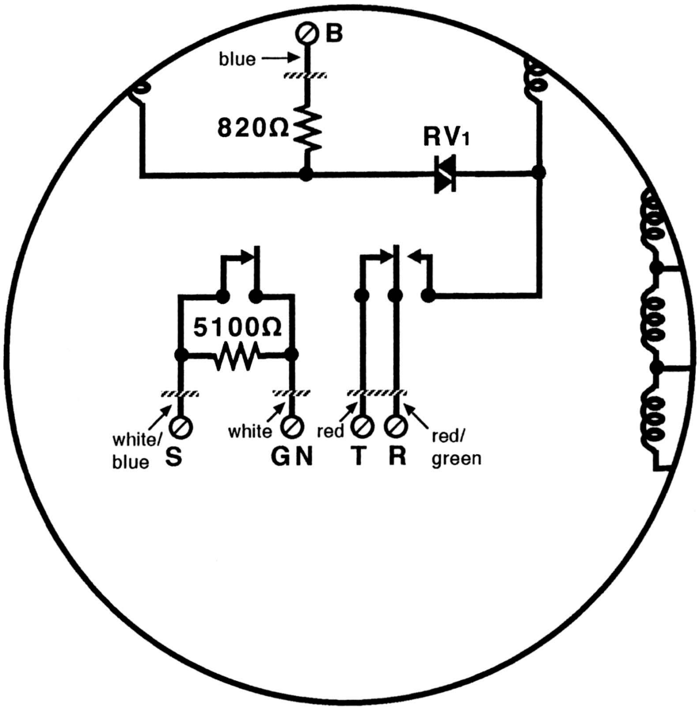

Fig. 19-13. Portion of circuit of the Western Electric No. 35 touchtone dial (8-wire hookup) that is different from Fig. 19-12.

Polarity Guard

A polarity guard consists of four diodes in a bridge array so that the dial always has the same polarity. The principle of the polarity guard is illustrated in Fig. 19-14; equivalence in the figure is achieved by treating the high resistance of a reverse-biased diode as infinite, and the low resistance of a forward-biased diode as zero. Western Electric also made a separate polarity guard in a small plastic case that could be retrofitted in the desk phone, wall phone, and Princess phone with the No. 25 and No. 35 dials. The polarity guard is connected across the line, inside of the hook switches in those cases.

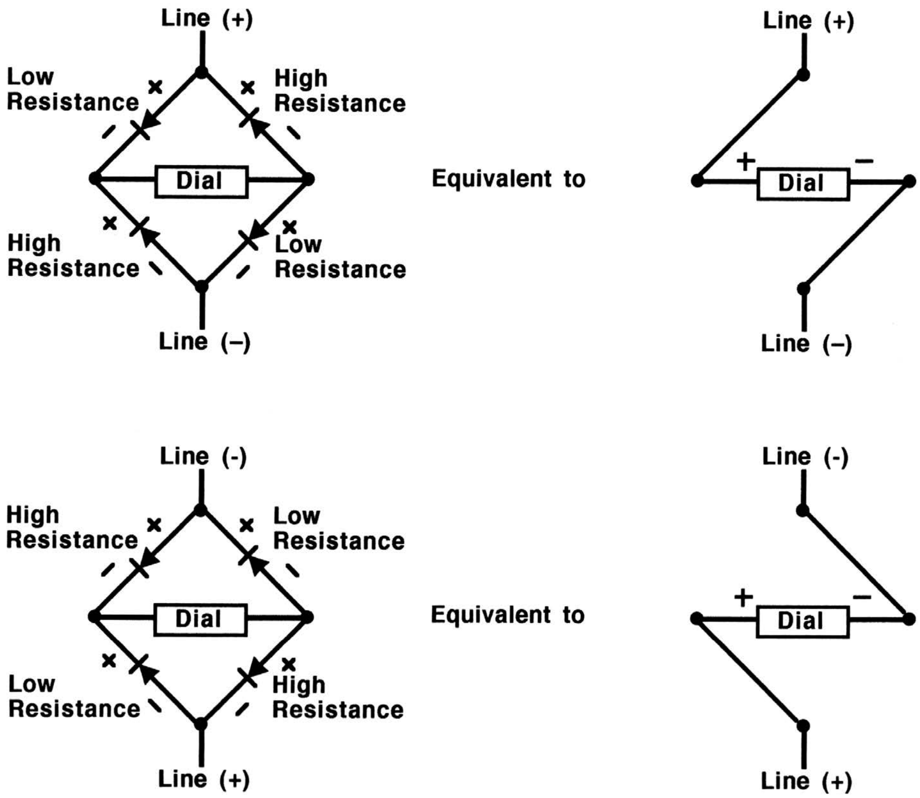

Fig. 19-14. Polarity guard in which biased diodes establish the same polarity for the touchtone dial, regardless of line polarity.

Examples of Touchtone Telephones with the Standard Network Circuit

Touchtone telephones used the same speech circuit as the 500-type telephones. In the early touchtone phones, this circuit was housed in an ordinary 425-type network package (e.g., No. 425K). Although the speech circuit was not modified, the tone-generating circuit tapped into the speech circuit at several locations, requiring a number of leads and an altered hookup of some components. Extra terminals were needed to make all of those connections, and a separate terminal strip was utilized with the No. 425 networks. In later years, the speech circuit was repackaged in several flatter, more compact envelopes with the extra terminals built in. Examples described in the following paragraphs cover the 1500, 2500, 1554, 2554, and Princess-type touchtone telephones.

Early Touchtone Telephone

Figure 19-15 shows the wiring of an early touchtone desk phone with the No. 25 (7-wire) dial and a No. 425 network. Early touchtone wall phones used a No. 4010 network that was contained in a broader and flatter enclosure, but it was the same internally and had the same terminals as the No. 425. As long as current paths exist where unconnected leads are shown, this circuit is seen to be just like the 500-type phone (Fig. 19-8), except that the rotary dial and its radio-interference condenser have been removed. The circuit is broken or tapped to accommodate the seven wires from the touchtone dial, and each of these seven connections will be discussed below. Terminals 10 and 11 are not on the network itself, but are provided on a separate terminal strip.

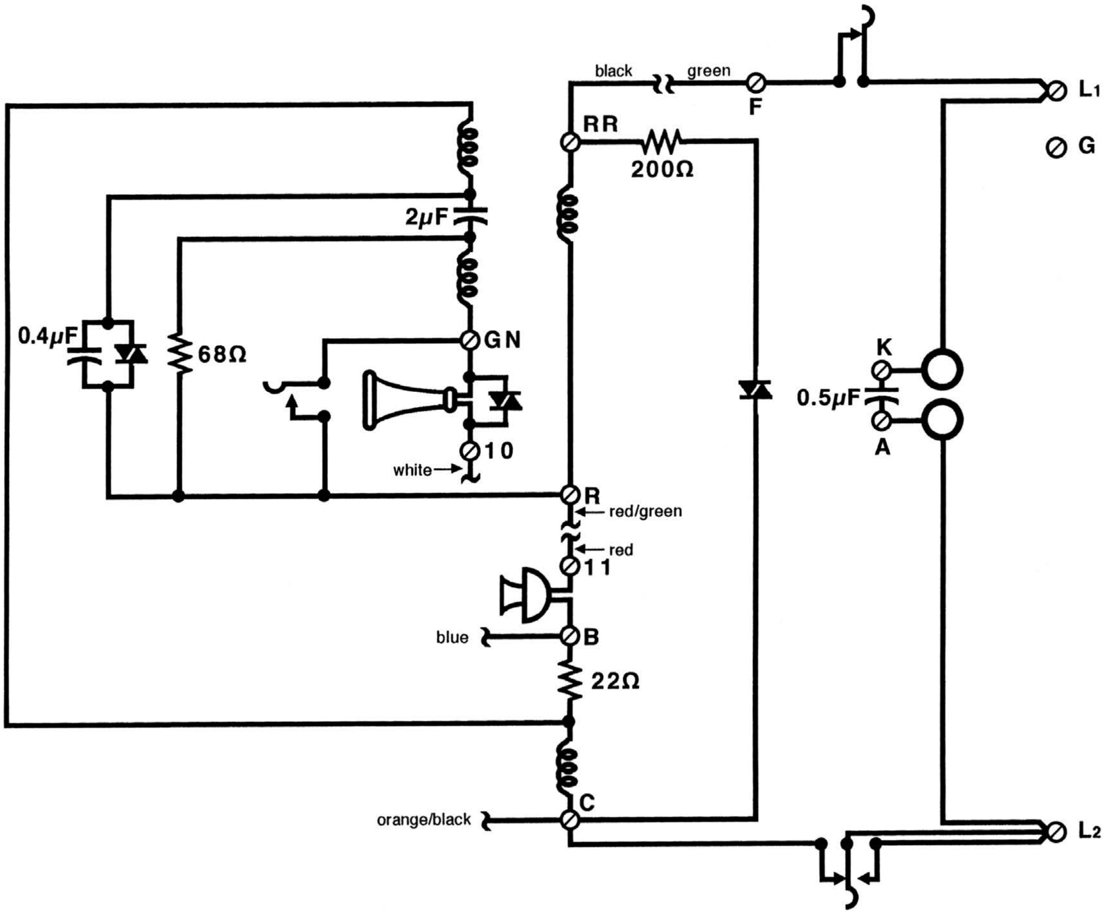

Fig. 19-15. Wiring of a touchtone telephone with the No. 25 dial (7-wire hookup) and a No. 425 network.

The black and green leads between terminals F and RR are connected to a 100-type varistor in the No. 25 dial. This low-voltage varistor is similar to that used across receiver elements. Because line current, which now passes through this varistor, will be at least 25 milliamperes, the resistance of this varistor will be under 20 ohms (see the Appendix), providing a suitably low-resistance current path between F and RR.

The white lead from terminal 10 and the red/green lead from terminal R are shorted together by a shunt switch in the dial during speech transmission, so this current path exists, as required. During dialing, when the shunt switch is open, a large resistor (5,100 ohms) is placed in series with the receiver to reduce the sound level of the tone pairs in the receiver of the dialing telephone.

The red and red/green leads at terminals 11 and R are also shorted together by a shunt switch in the dial during speech transmission, so the desired current path exists there as well. During dialing, however, this contact opens, removing the transmitter from the circuit and connecting terminal R to the tone generator, as desired.

Finally, the blue and orange/black leads are permanently connected to terminals B and C without any switching action. The ac and dc impedances provided by the alternate path through the dial from B to C are high enough that the normal operation of the speech circuit is not disturbed.

Typical Touchtone Telephone

Figure 19-16 shows the complete circuit of a more typical touchtone telephone with a No. 4228 network and the No. 35 (8-wire) dial. Some minor variations of the No. 425B circuit were made to produce the No. 4228 network: coil parameters were changed slightly, the sidetone-balancing resistor was increased to 120 ohms, and the resistor at terminal RR was reduced to 180 ohms. Extra terminals S and T needed for hooking up the dial were added right on the network, but these terminals along with L1, L2, G, and F are not connected internally. Other than these minor tuneups, the No. 4228 network is seen to have the same speech circuit as the No. 425B.

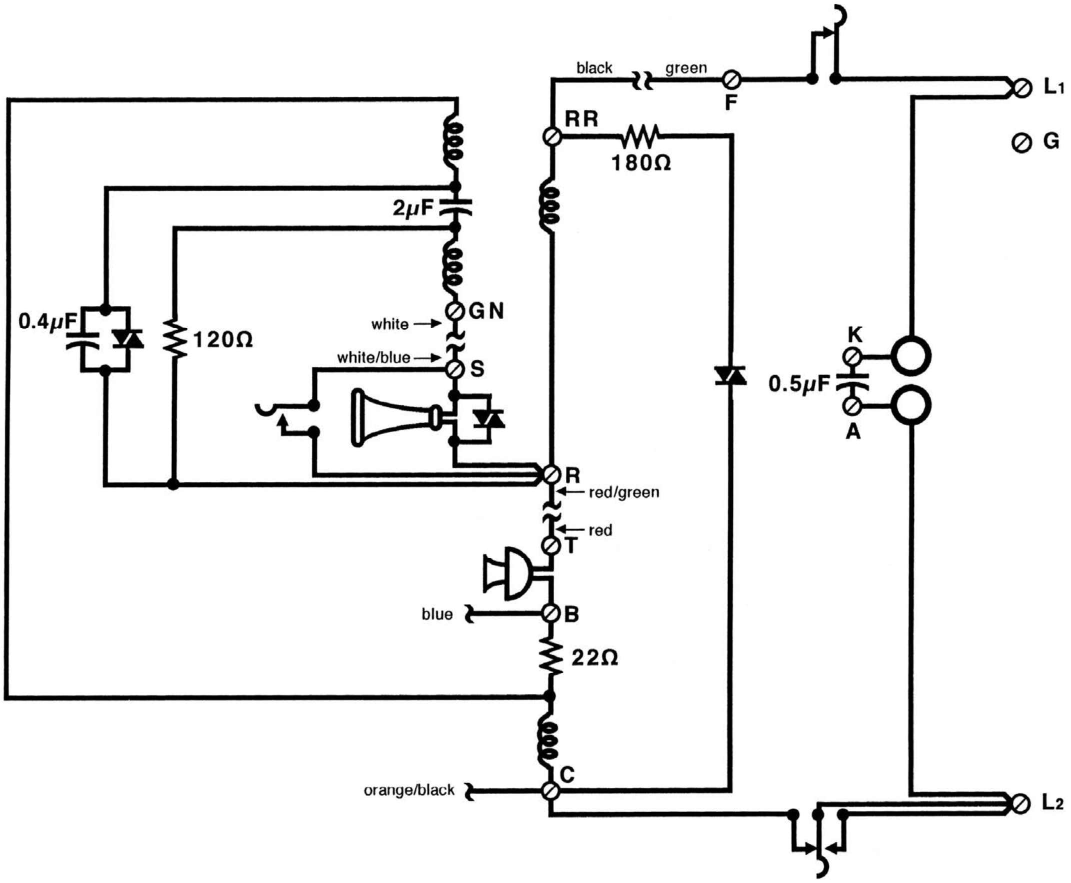

Fig. 19-16. Wiring of a touchtone telephone with the No. 35 dial (8-wire hookup) and a No. 4228 network.

Comparison of Fig. 19-16 with Fig. 19-15 will show that the only difference between the hookup of the 8-wire No. 35 dial and the 7-wire No. 25 dial is in the manner the 5,100-ohm attenuating resistor is connected to the receiver. The extra lead (white/blue) is used with the white lead to place this resistor between GN and S, which has replaced terminal 10. Terminal T has replaced 11, but no change was made in the connection at that point.

Low-Cost Touchtone Telephone

About a year before the breakup of the Bell System, Western Electric introduced a less-expensive version of the standard touchtone telephone with a No. 4293 network and a No. 72 (9-wire) dial. The circuit for that phone is shown in Fig. 19-17, which is seen to be quite similar to the previous figure; the circuit for the No. 72 dial has not been shown.

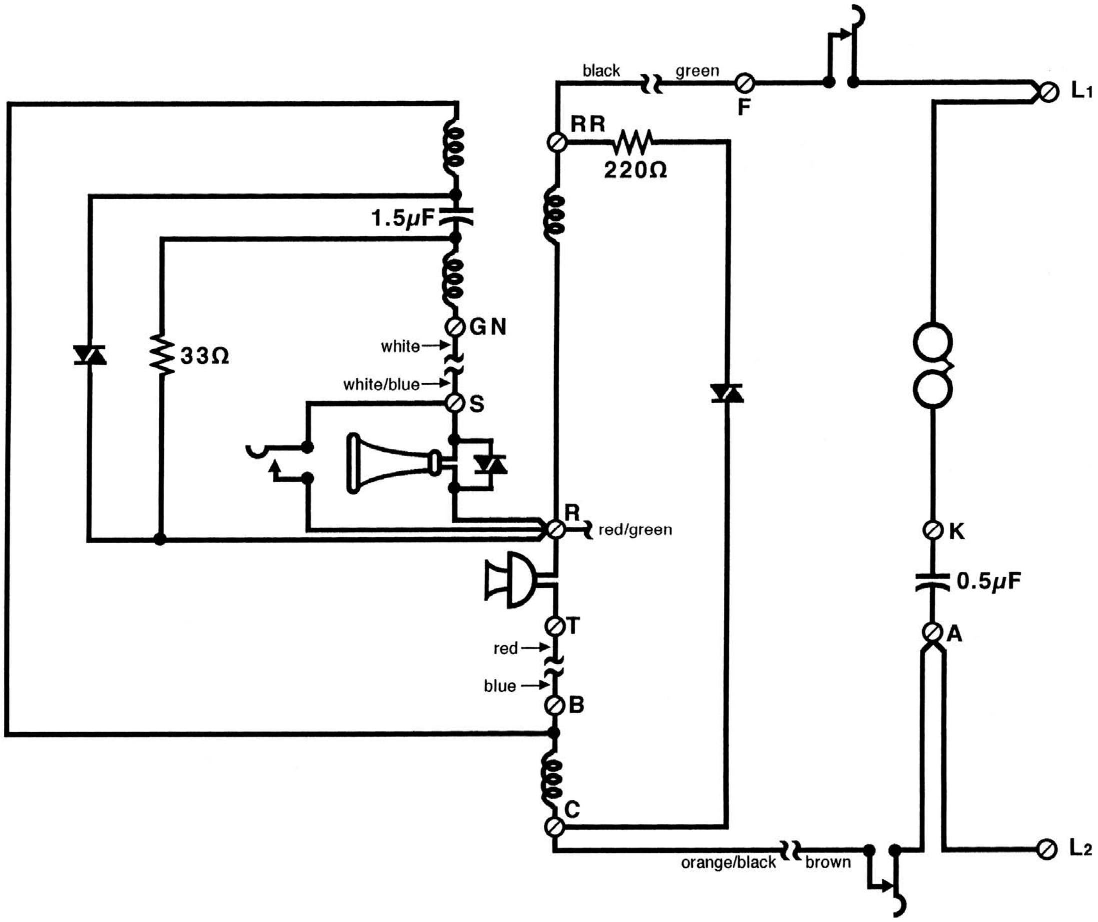

Fig. 19-17. Wiring of a touchtone telephone with the No. 72 dial
(9-wire hookup) and a No. 4293 network.

Several shortcuts were taken in the No. 4293 network. First, a much smaller and lighter weight coil was used. Second, the condenser in the sidetone-balancing impedance was eliminated. Third, the dc blocking condenser in the receiver circuit was reduced to 1.5 microfarads. Fourth, the 22-ohm resistor usually used in series with the transmitter was omitted. And resistances of the remaining two resistors were also changed again. These changes resulted in a sacrifice in performance, but they reduced cost and weight. In fact, the entire No. 4293 network weighs no more than the coil alone from the No. 4228 network. This circuit is identical to that used previously in the early Trimline telephones (see below), where shortcuts were necessary to get everything to fit inside the handset.

Hookup of the 9-wire No. 72 dial is almost the same as that of the earlier dial with the addition of one extra wire (brown). Rather than merely tapping into the L2 lead at C, the new circuit breaks the L2 lead to insert a polarity guard, and this requires the extra wire. It should be clear from these diagrams that any of the touchtone dials can be used interchangeably with any of the networks.

Trimline-Type Variations of the Standard Network Circuit

Although the same principles of the 425B circuit were also used in the Trimline phones, modifications were made. The most significant modification resulted from incorporating light-emitting diodes (LEDs) in the handset of the more recent Trimlines. Thus, older Trimlines with incandescent bulbs and newer Trimlines with LEDs are covered separately.

Older Trimline-Type Telephones

Figure 19-18 shows the complete circuit of an early rotary dial Trimline telephone. In this figure, the handset is to the left of the hatch marks, and a 5-conductor handset cord was required.

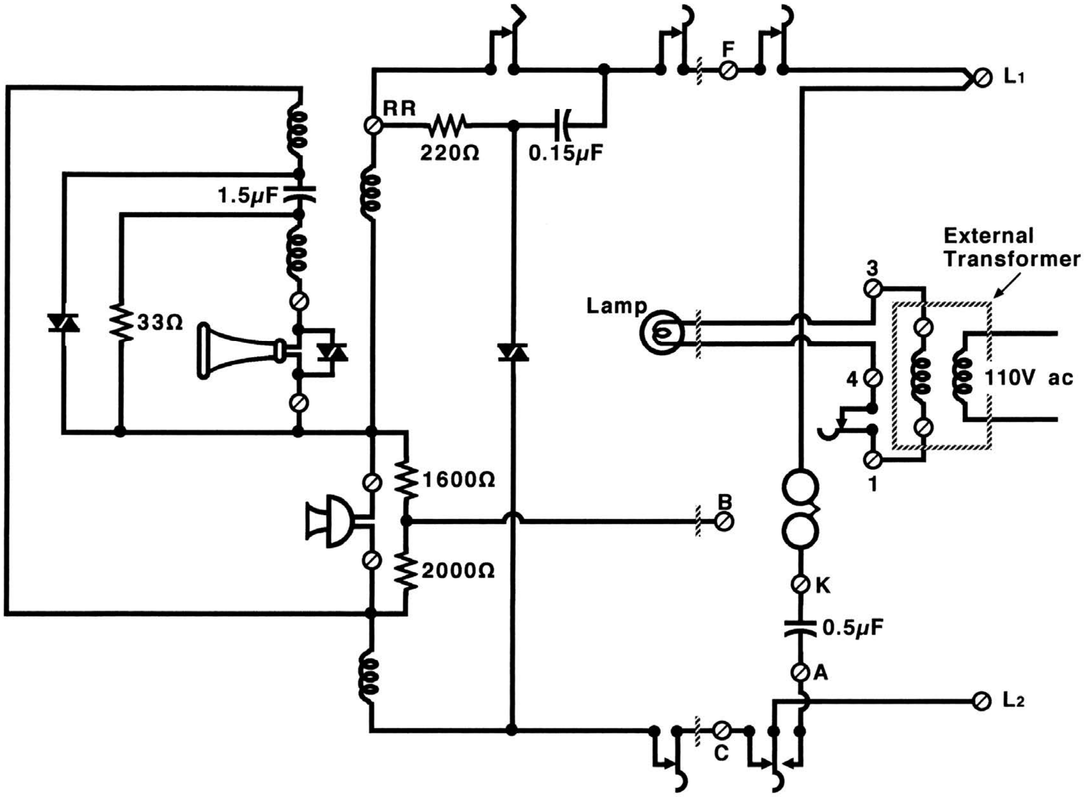

Fig. 19-18. Wiring of an older rotary dial Trimline telephone with an incandescent dial light.

The coil and basic speech circuit are the same as in the No. 4293 network. This circuit variation was developed first for the Trimline, where space was at a premium. Condenser sizes were reduced in the dc blocking condenser (2 microfarad down to 1.5) and the radio-interference filter (0.2 microfarad down to 0.15), and the condenser in the sidetone-balancing network was eliminated altogether because there was simply no room for three condensers.

A resistance voltage divider was used across the transmitter to facilitate caller identification. Terminal B in the telephone base could be connected to appropriate taps on the ringer coil to provide party-line service (party-line hookup is not shown in Fig. 19-18, however).

Convenience features of the Trimline phones were a dial light and a recall button. An incandescent dial lamp powered by an external transformer was used to illuminate the dial on the early Trimlines, and the transformer was the same one used for the Princess telephone. The recall button depressed two extra hook switch contacts, which are shown just left of the hatch marks near terminals F and C.

Figure 19-19 shows the circuit of the early touchtone Trimline telephone. The speech circuit, incandescent dial light, and recall hook switches are just like those in the rotary dial Trimline shown in the previous figure. One of the varistors of the tone generator (RV_2 in Fig. 19-12) is built right into the speech circuit of this phone, but otherwise the No. 82 dial is quite similar to the No. 25 dial in Fig. 19-13. In fact, the seven screws that fasten the printed-circuit speech network to the No. 82 dial form electrical connections, exactly like the 7-wire hookup in Fig. 19-15.

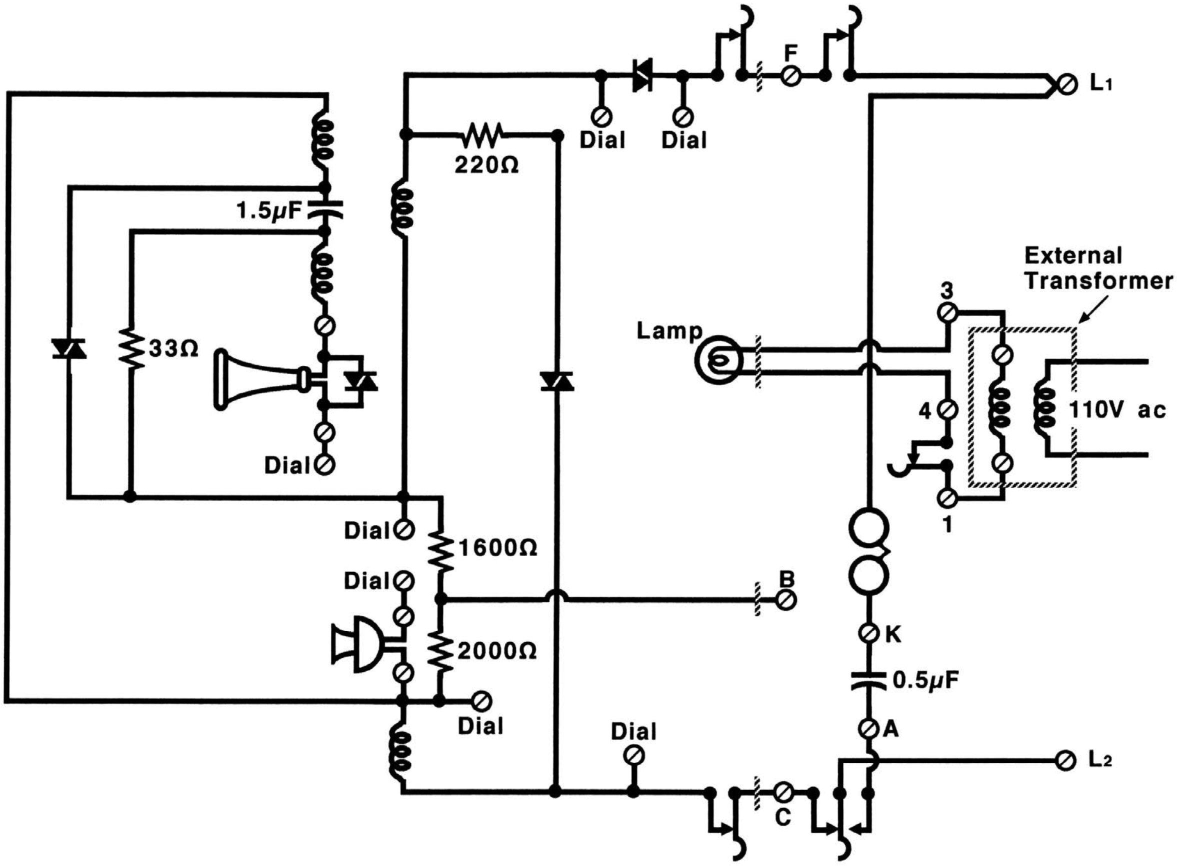

Fig. 19-19. Wiring of an older touchtone Trimline telephone with an incandescent dial light.

Newer Trimline-Type Telephones

More recent Trimline phones use LEDs powered directly by the telephone line to illuminate the dial, and these Trimlines are generally not set up for party-line caller identification. Consequently, these phones are fitted with a handset cord requiring only 2 conductors, and two conductors of a standard 4-conductor modular handset cord are often used. The complete circuit for a recent rotary dial Trimline telephone is shown in Fig. 19-20.

The major new feature of this circuit is the additional dc current path through the LED. Because the LED requires 2.1 volts dc and the total dc line voltage will only be about 5 volts, the LED cannot be placed in series with the transmitter without seriously degrading its performance. Consequently, a means had to be developed to shunt direct current around the transmitter and through the LED without short-circuiting the ac speech signal. This was accomplished with an additional coil winding shown as Primary (c). The 30-ohm resistor provides the right dc voltage bias for the LED under minimum line-voltage conditions, and the 100-type varistor around the LED and the 30-ohm resistor protects the LED against overvoltage.

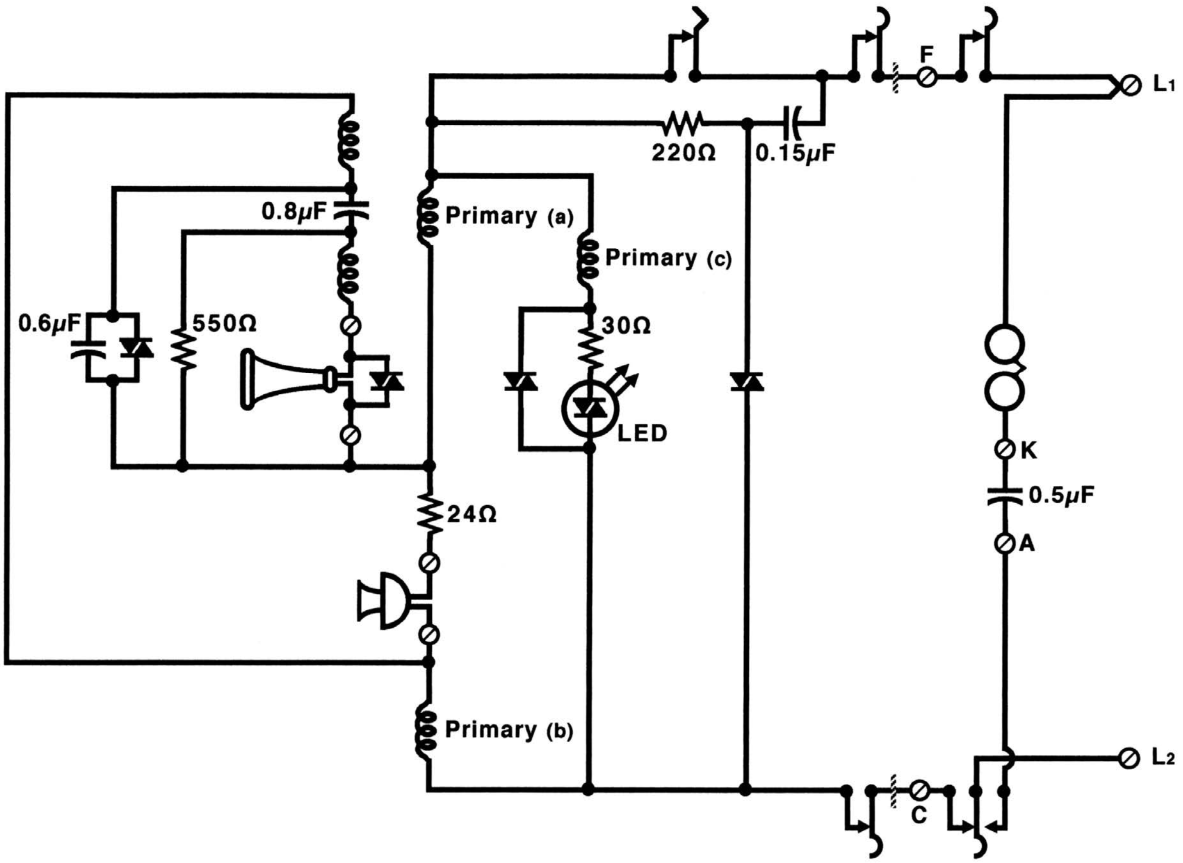

Fig. 19-20. Wiring of a newer rotary dial Trimline telephone with an LED dial light.

The extra coil winding provides the high ac impedance desired in the LED path, but it obviously alters the relation between the other coil windings, which had to be adjusted accordingly. The overall effect of the extra winding can be determined by examining the compound primary winding (Fig. 19-21). Coil properties have been measured using this arrangement and they are given in Table 19-2. Although some changes in the important turns ratios were made, the result is still quite similar to the original coil in the 425 network.

The condenser has been restored to the sidetone-balancing impedance in these more recent Trimline telephones. This was made possible by the use of a miniature sintered tantalum condenser (0.8 microfarad) for blocking dc in the receiver circuit.

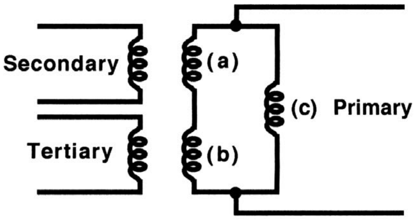

Fig. 19-21. Equivalent coil configuration for newer Trimline telephones with LED dial lights.

Table 19-2. Characteristics of the induction coil in Western Electric's Trimline telephone with light-emitting diodes (LEDs)

Characteristic	**Pri(a)**	**Pri(b)**	**Pri(c)**	**Secondary**	**Tertiary**
Resistance, ohms	24	22	97	26	36
Turns Ratio[a]		1.0		0.37	0.58

[a] Turns ratios are relative to the total compound primary winding (see Fig. 19-21).

The same coil and speech circuit of this rotary dial Trimline are used in the recent touchtone Trimlines. Thus, with minor variations, the same circuit that was used in the No. 425B network of the 500-type telephones was used in all other phones manufactured by Western Electric right up to the end of its existence in 1984.

Automatic Electric Variations of the Standard Network Circuit

Although Kellogg and Stromberg-Carlson switched completely to standard Western Electric designs after the cross-licensing agreements were signed in the 1950s, Automatic Electric did not. Nevertheless, Automatic Electric also had licensing agreements with Western Electric and borrowed heavily from the Bell System for features in the Automatic Electric Type 80, Type 90, Starlite, and Styline telephones.

Four variations of the same basic circuit that was used in these phones are described briefly in the following paragraphs. The coils used in these circuits are described in Table 19-3. Although the parameters of these coils are not identical to the Western Electric coils, they are quite similar as are the circuits in which they were used.[9]

Table 19-3. Characteristics of induction coils in Automatic Electric's network circuits

Characteristic	**Pri(a)**	**Pri(b)**	**Secondary**	**Tertiary**
	Manually adjusted potted network			
Resistance, ohms	39		8	12
Turns Ratio	1.0		0.24	0.41
	Self compensating potted network			
Resistance, ohms	39		12	6.6
Turns Ratio	1.0		0.40	0.25
	Network on printed circuit board			
Resistance, ohms	24	13	12	10
Turns Ratio[a]	1.0		0.40	0.40
	Mini network in Styleline			
Resistance, ohms	37	31	38	34
Turns Ratio[a]	1.0		0.37	0.40

[a] Turns ratios are relative to the total primary winding.

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[9] Details of these wiring variations can be found in a series of GTE Standards in General Telephone's Station Installation and Maintenance Handbook, June 1976.

Type 80 and Type 90 Rotary Dial Telephones with Manual Adjustment

The components for this circuit are in a potted network in a plastic case. The wiring diagram for phones with this network is shown in Fig. 19-22, and this circuit can be compared with the typical 500-type diagram in Fig. 19-8. The first thing to notice is that there is a receiver circuit, connected around the transmitter, and this circuit goes through the receiver, the secondary and tertiary coil windings, and a condenser. While the order of appearance of these components is different from that in the typical 500-type receiver circuit, that change in order is inconsequential. Further, the receiver and the tertiary winding are bypassed by several sidetone balancing components. This is, therefore, the same basic circuit as used in the 500-type telephones.

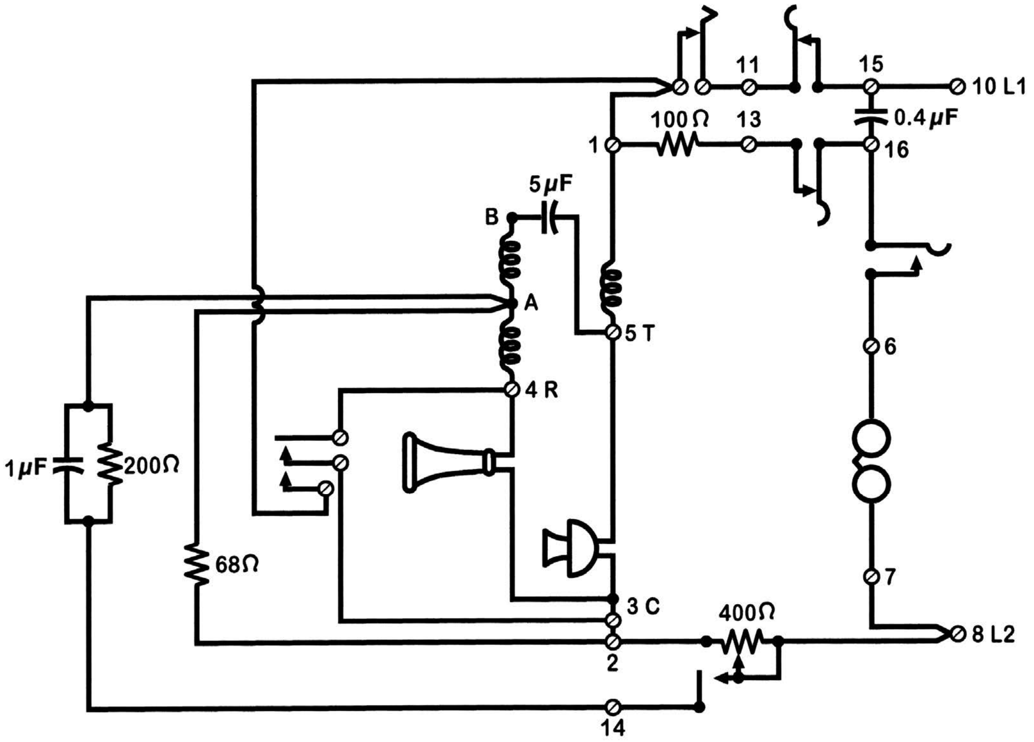

Fig. 19-22. Wiring of Automatic Electric Type 80 and Type 90 telephones with manual adjustment.

The most significant difference between the two circuits is that this early Automatic Electric circuit did not incorporate varistors, but rather accomplished the adjustment to line conditions manually with a 400-ohm variable resistor (a linear potentiometer) that could be adjusted with a screwdriver. For short loops of low resistance, the resistor could be adjusted for the full 400 ohms (4 on the adjustment scale) and the contact near terminal 14 would be open. This would put the maximum resistance in series with the transmitter and leave part of the sidetone balancing impedance out of the receiver circuit. For long loops of high resistance, the 400-ohm resistor could be shorted out of the circuit (0 on the adjustment scale) and the remaining components of the sidetone balancing network would be switched into the circuit by the contact near terminal 14.

In the upper right corner of Fig. 19-22, the 100-ohm resistor and the 0.4 microfarad ringer condenser form a radio-interference filter that is equivalent to that found in the 500-type telephones. While the size of the resistors, condensers, and other components in this circuit are not identical to their counterparts in the Western Electric 500-type circuit, they are all quite similar.

Type 80 and Type 90 Rotary Dial Telephones with Automatic Adjustment

A later variation of this circuit, with varistors instead of a manual adjustment, also appeared in a potted network. The wiring for this version of the circuit is shown in Fig. 19-23. This circuit is seen to be even more like the standard 500-type circuit in Fig. 19-8, although the order in which the components are connected in the receiver circuit is still reversed, with no effect on performance. Varistors are employed in exactly the same location as in the standard 500-type circuit. A varistor is also used across the receiver terminals to reduce switch noise, and a four-conductor handset cord was introduced just as in the 500-type telephones.

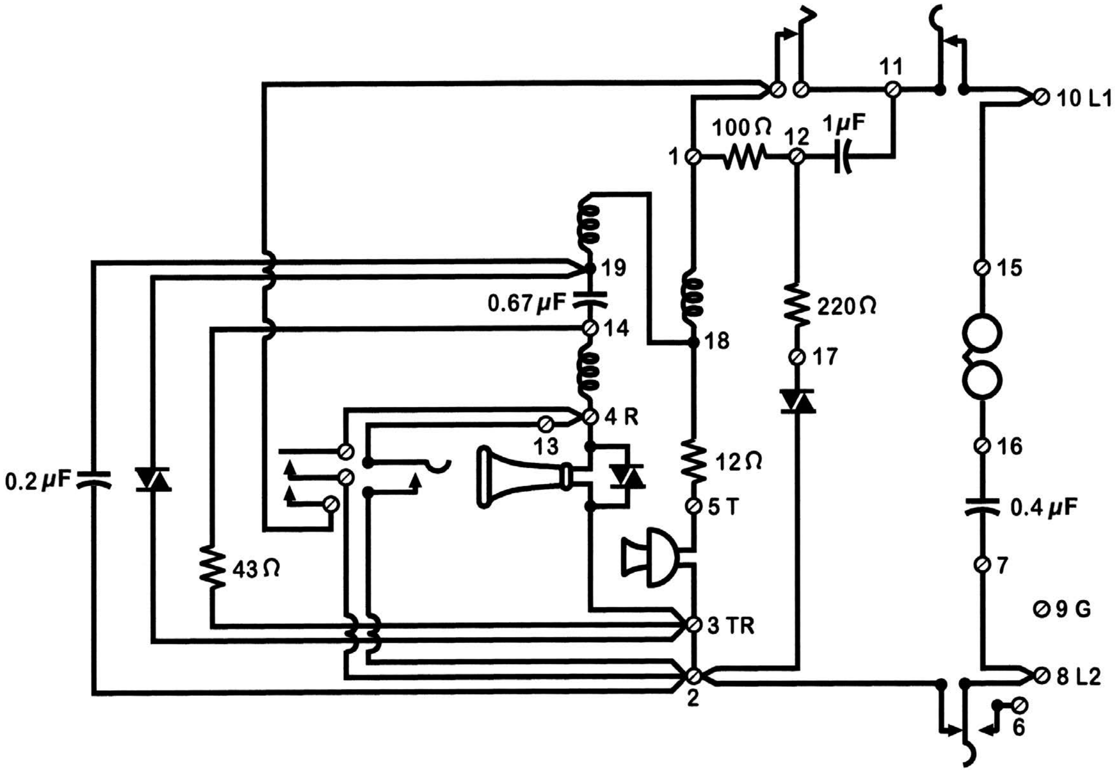

Fig. 19-23. Wiring of Automatic Electric Type 80 and Type 90 telephones with automatic adjustment.

Type 80, Type 90, Type 80E, and Starlite Telephones with Touchtone Dialing

A still later variation of this circuit appeard on a printed circuit board. This circuit was used with rotary dials and with touchtone dials, which Automatic Electric called touch calling units. There were only minor differences between the circuit boards for rotary and touchtone applications; a 0.33 microfarad condenser was added for the radio interference filter for the rotary dials, and an extra row of terminals (A-E) was added for the touchtone dials. Figure 19-24 shows the wiring for this printed circuit board with the newer of two touch calling units that were made. Although this newer unit has seven color-coded hookup wires (colors identified in the figure), it is almost identical to Western Electric's No. 35 dial with the 8-wire hookup except that the Automatic Electric dial includes a polarity guard. The earlier Automatic Electric touch calling unit is almost identical to Western Electric's No. 25 dial, although it, too, has fewer hookup wires, includes a polarity guard, and is connected into the circuit a little differently. The values of resistance, capacitance, and other parameters have again been adjusted and can be seen to be even more similar to those used in the standard Western Electric 500-type circuit.

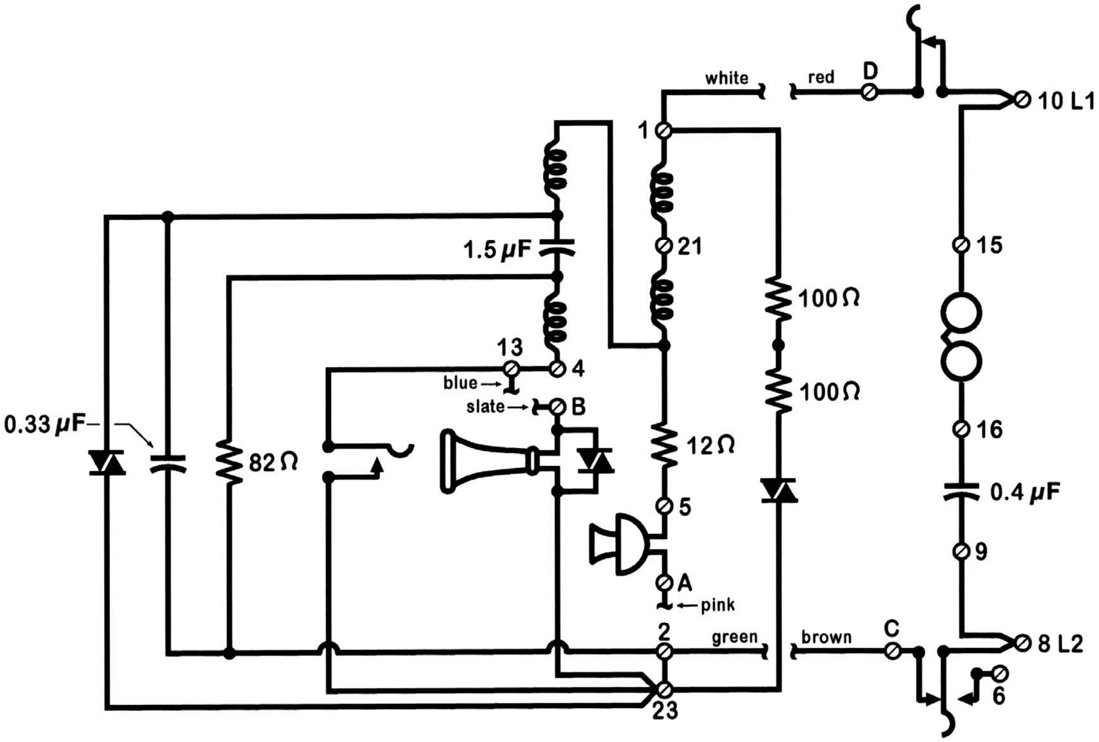

Fig. 19-24. Wiring of Automatic Electric Type 80, Type 90, Type 80E, and Starlite telephones with touchtone dialing.

Mini Network used in Styleline Telephones

The Styline telephone has a very small printed circuit board for the voice circuit, and a similar board is used in rotary dial and touchtone applications. The circuit for the rotary dial Styline is shown in Fig. 19-25, where it can be seen to be almost identical to the circuit in the older Trimline telephones (see Fig. 19-18).

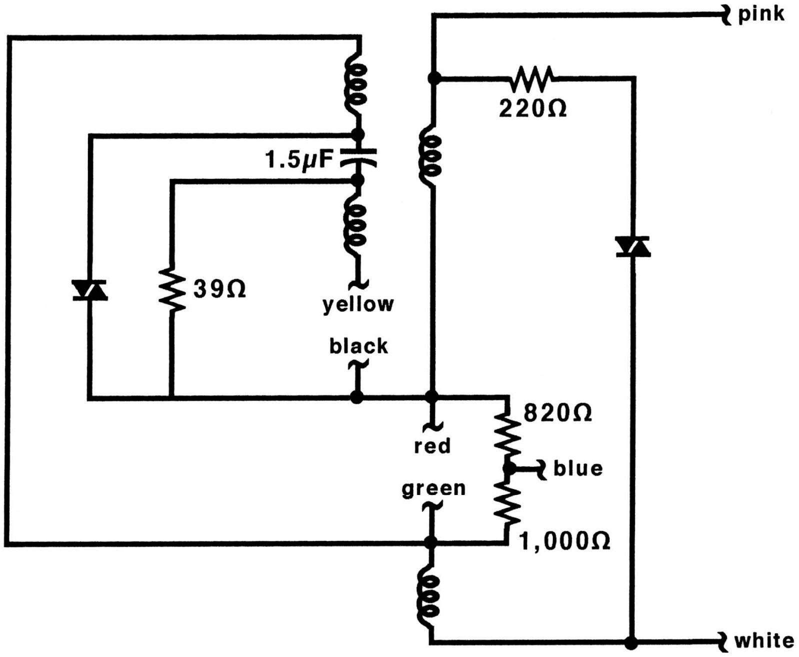

Fig. 19-25. Wiring of mini-network in Automatic Electric Styleline telephone.

The only minor difference is in the resistances of the voltage divider for party-line caller identification, but the resistance ratios are the same. For rotary dial applications, the radio-interference filter is located elsewhere in the handset. Equivalence of color-coded leads of this mini network and standard terminal markings on Western Electric networks is given in Table 19-4, and a photo of the network is in Fig. 19-26.

Table 19-4. Equivalence of color-coded leads on Automatic Electric's mini network and standard network terminals

Automatic Electric Colors	Standard Terminal Markings
Pink	RR
Red, Black	R
Yellow	GN
Green	B
White	C
Blue	(not used)

The circuit for the touchtone Styleline is the same except that the redundant red lead has been omitted, and the yellow, white, and pink leads have been replaced by screw terminals or push-in connectors (varies with date of manufacture). In the touchtone phones, the touch calling unit uses two transistors just as in Western Electric's Trimline dial.

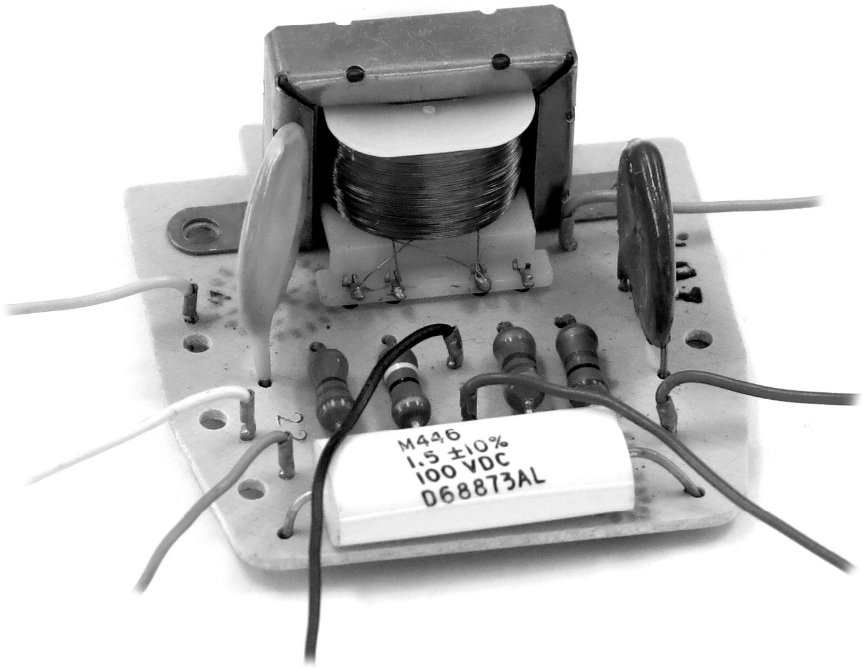

Fig. 19-26. Automatic Electric mini network from a rotary-dial Styleline telephone.

* * *

Part Four
Restoration

Chapter 20
Mechanical Restoration

Several facts stand out regarding the restoration and repair of old telephones. One is that these rugged electromechanical instruments were designed for long service lifetimes and were made of passive components that do not normally wear out. Another is that these telephones were intentionally compatible from generation to generation -- and even between local-battery and common-battery types -- so that all of these phones can be made to work with each other. It is, therefore, not only possible to restore old telephones to their original external appearance, but it is also possible to restore them to working condition and to construct privates line serving a variety of telephones. It is also true that these old phones will operate satisfactorily on the public telephone network. There are, in fact, grandfather provisions of the Federal regulations, which allow these non-registered, non-certified telephones to be connected to the network (see the end of Chapter 22).

Replacement Parts

A wide variety of replacement parts are available, but generally not from the corner store.[1] Because telephones have been produced in large quantities for nearly a hundred years, original surplus or used parts can still be found for most phones. Reproduction parts are also available for older, more popular styles (such as magneto wall phones and candlestick desk stands). For example, reproduction mouth pieces and receiver shells are made for several manufacturers' phones, and some of the receiver shells are even designed to hold a modern U-type receiver element. Reproduction decals are available for a number of manufacturers including Western Electric, Automatic Electric, Kellogg, and Stromberg-Carlson.

Reproduction cloth-covered cords are also available for receivers, handsets, and desk stands. These cords are available with various terminals, such as spade lugs and pin connections, and with stay cords or hooks for strain relief. Some of the reproductions are quite authentic, right down to the color of the tracer threads in each lead. Modern coiled cords with modular connectors and household wiring accessories are available at local hardware, electronic, and phone stores.

Disassembly

In a few cases, fasteners have been hidden for aesthetic purposes; in some other cases, the methods of release are not obvious. Several of the more common situations like this are described below.

Magneto Cranks and Switch Hooks

Magneto cranks and switch hooks were designed for easy removal from most magneto wall phones. Magneto cranks merely unscrew from the magneto shaft by turning the crank counterclockwise. Switch hooks, which hold the receivers on these phones, are usually held in place by a single pin, which is retained by screw threads or a spring clip that can be quickly removed to release the hook.

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[1] Sources for parts can be readily found on the internet. Additional help is available from Telephone Collectors International and Antique Telephone Collectors Association, both of which maintain on-line resources.

Western Electric E1 Handset

The Western Electric E1 handset has six threaded, mating surfaces in fittings that attach the transmitter and receiver to the handle. All of these threaded parts have different diameters, and they are made of three different materials: brass, aluminum, and bakelite. Although they unscrew in a conventional and rather apparent manner, they often stick together and cannot be removed by hand. Western Electric made a special tool for disassembling this handset, but an ordinary strap wrench often works well.

Alternatively, an effective home-made tool can be fabricated as shown in Fig. 20-1. The tool can be made from a piece of 1" x 4" wood that is long enough to be clamped in a vise or to a bench. A large hole is first cut so that the handset part to be unscrewed fits loosely in the hole. Small holes are then drilled to line up with the diameter of the large hole, and these small drill holes will position pins to grab the handset parts (in holes that were provided for that purpose during manufacturing). Common 4-penny nails have the right diameter and can be used for pins by grinding their ends square. After drilling two additional holes for the clamping screws, saw cuts are made to detach a portion of the clamp, as shown.

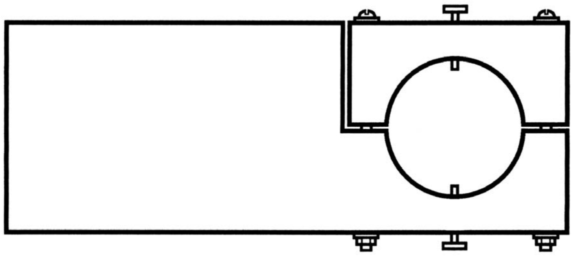

Fig. 20-1. Design of a tool for disassembling the Western Electric E1 handset.

The handset part to be removed should then be wrapped with friction tape for a snug fit in the clamping tool. Adequate leverage will then be available to unscrew the part. Penetrating oil can be used to make removal easier. Some penetrating oils will cause corrosion of the aluminum parts if they are left for several months. Such corrosion can be removed with a fine wire brush, and the parts can be washed in light detergent and water. Because all the parts of the E1 handset are of different diameters, a separate tool, such as that in Fig. 20-1, will have to be made for each stuck part.

Monophone Handset

The handset used on Automatic Electric Type 1A desk stands and other early Monophones has a receiver cap shaped like an elephant's ear. It screws onto the handle in an obvious way, but alignment of the elephant ear is not obvious. This receiver cap comes apart into three pieces (a metal retaining ring, a bakelite ear cap, and a brass or bakelite bushing, see Fig. 20-2). The bushing has an octagonal hole in it and can be unscrewed with the aid of a square tapered plumber's tool for replacing washer seats in sink faucets. The bakelite ear cap has a series of small holes on the inside that can be matched up in many positions with two small protrusions on the metal retaining ring to achieve the desired alignment. Re-tightening the bushing locks this position in place.

Fig. 20-2. Disassembled receiver cap from Automatic Electric Monophone handset, showing the three parts and a plumber's tool that can be used to unscrew the bushing.

Automatic Electric Early Wall Phones

Automatic Electric's Type 35 and Type 50 jukebox wall phones have two large screws on the front that obviously hold the cover in place. Not visible, however, is a third fastener. Figure 20-3 shows a close-up of the cradle area with the hook switch plunger removed. This plunger is held in place by a collar, which not only captures the plunger, but also holds the bakelite cover to the base of the phone. When this collar is removed, and the two screws are unscrewed, the cover lifts off. On phones with the two-position switch latch, the collar is found underneath the latch plate, which is removable.

Fig. 20-3. Close-up of disassembled hook switch plunger and collar that holds the cover to the base of the Automatic Electric Type 35 and Type 50 wall phones.

500-Type Wall Phones

On 500-type wall phones, there is a lever inside the cutout where the handset cord enters the base. Pushing this lever inward releases the plastic cover, which can then be removed.

Touchtone Wall Phones and Trimline-Type Phones

On touchtone wall phones and Trimline-type handsets and bases, the covers are held by two screws located underneath the rectangular number card holder or similarly shaped logo tab. By inserting a sharp tool or a straightened paper clip into the small hole at one end of the plastic tab, and pushing toward the center of the phone, the plastic tab will buckle enough to release its end from the housing. The screws that hold the cover can be found underneath.

Rotary Dials

Disassembly of an older rotary dial with a metal finger wheel is begun by removing the round number-card holder in the center. On the Western Electric dials, this ring is held in place by a friction catch at the top. This catch can be released by pushing down on the tab at the top of the ring. The holder can then be lifted upward to remove a lower tab from its slot. On the Kellogg and Automatic Electric dials, however, there is a hidden latch that must be rotated underneath the dial card. To accomplish this, insert a small screw driver underneath the rim of the card holder (Fig. 20-4), and push the latch from the number-5 position to the number-6 position, releasing the card holder.

Fig. 20-4. Use of a small screw driver to rotate the hidden latch on Kellogg and Automatic Electric dials.

A different, but equally obscure, method is required to remove the plastic fingerwheel from a 500-type phone or a Princess-type telephone. On those fingerwheels, there is a very small hole through the plastic between the numbers 9 and 0. After the fingerwheel has been rotated through its full circle, a straightened paper clip can be pushed through that hole (Fig. 20-5); when dial rotation is continued in the same direction (while pushing on the paper clip), the fingerwheel will come off. On some Automatic Electric phones with clear plastic fingerwheels, the procedure is about the same, but the little hole is near the number 6. To reinstall the fingerwheel, place it in position with the number 0 hole near the number 9 and rotate the fingerwheel counterclockwise.

Fig. 20-5. Use of a paper clip to release the plastic finger wheel from the dial on 500-type telephones.

Colored Western Electric 302 telephones also have a clear plastic finger wheel that is tricky to remove. Between the numbers 6 and 7, there is a small tab that must be pushed to the right with a small screw driver blade to rotate a retaining ring counterclockwise. This releases the fingerwheel.

Trimline-Type Cords

Early Trimline-type phones used handset cords with modular connectors that are different from the current standard modular connectors. A small slit or hole will be found where the old modular plug enters the handset or the base. By inserting a straightened paper clip in that hole and pushing toward the connector body, a spring will be depressed, permitting the plug to be withdrawn. Later Trimline-type telephones use today's standard modular connectors with an external release tab on the plug.

Mechanical Repairs

Most mechanical repairs will consist of cleaning, adjusting, oiling, straightening, or replacing a missing screw. Detailed instructions are not required.

Transmitters, Receivers, and Coils

There are no adjustments or parts to be oiled in these components; cleaning out accumulated debris is about all that is required. Diaphragms and other hard surfaces on transmitters and receivers can be cleaned with a solvent such as alcohol, acetone, or trichlorethane. These will not harm painted surfaces or leave a residue. On old solid-back transmitters, extreme care must be taken with the fine wire that is connected to the rear electrode of the carbon button. Also, note that the diaphragm-retaining spring clips in these old transmitters were often positioned asymmetrically (one on the rim, and the other near the center), as mentioned in Chapter 2.

Magnetos

Magnetos require periodic oiling because their numerous bushings and sliding contacts bear heavy loads. Oiling tubes and holes are provided in many of these locations, and some of the oiling tubes have wicks inside. Gear teeth can be cleaned with a fine bronze-wire brush and then lightly oiled. Some of the main gear shafts have a collar, whose position can be adjusted to limit end play of the shaft, thus maintaining gear alignment.

Ringers

Some older ringers have an adjustment on the armature pivot. The pivot itself should be clean, and the adjustment made so that the armature and clapper move freely without wobbling. Gong spacing is also adjustable on most ringers. Some have cam-operated pivots on the frame; others have off-center mounting holes in the gongs; and more recent ringers have an external wheel, lever, or slider (loudness control). For clear tones on the older ringers, gongs should be positioned close to the clapper without having the clapper resting on the gongs at either end of its travel; the thickness of a stiff piece of paper is about the right gap.

Dials and Switches

Unlike magnetos, dials do not require periodic oiling. However, if the dials have been idle for 50 or 60 years, they will benefit from a little sewing-machine oil on their many moving parts (except in the governor chamber). Removing the fingerwheel and number plate will expose the moving parts sufficiently for cleaning and oiling. Before applying oil, make sure that dust and loose dirt have been removed by blowing out with compressed air. Excess oil should also be removed.

Timing of the impulse switch should be set so that it breaks contact 10 times per second. This can be checked without special equipment by noting if complete dial rotation (10 digits) is completed in approximately one second. Adjustment can be made, if necessary, by moving the slider weight on the rotating wheel in the governor.

Switch contacts on dials and hook switches are not usually adjustable, but occasionally the spring contacts get bent. They can be straightened. An analog multimeter can be used on a low-resistance scale to check the functioning of the switch contacts. In some applications, switch sections are sequenced to connect the receiver to the circuit after the other connections have been made (see Part Three). This sequencing can also be checked.

Switch contacts can be cleaned by inserting a strip of paper between the contacts, closing the contacts, and then gently pulling the paper through the closed contacts. The paper will remove surface dirt and corrosion.

Modular Cords

Although modern modular handset and line cords are quite rugged, they do tend to fail from abuse at the cord plug. Cords can be trimmed and new plugs crimped on with a special tool such as the Allen Tel crimping tool No. AT682 (Fig. 20-6). Crimping tools and plugs are readily available on the internet.

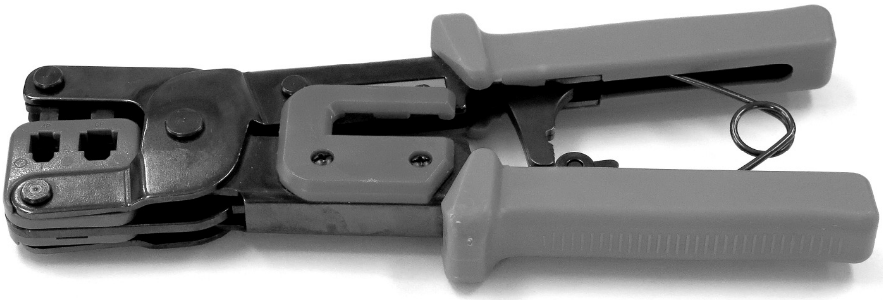

Fig. 20-6. Crimping tool for attaching modular plugs to line cords and handset cords.

Modular line cords can also be fitted to older phones by using crimp-on spade lugs for attachment in the telephone. In early 500-type telephones and most touchtone phones, modular jacks can also be added to the telephone. The jacks simply slip over the edge of the metal base, and their wire leads connect normally to the network. It is only necessary to enlarge the line-cord cutout in the plastic cover so that it will slip over the jack. These jacks are considered to be telephone parts, rather than wiring accessories, and they might not be available locally. Adapters that accept the new standard modular plugs were made for the early Trimline-type phones, and those adapters merely slide into the old jacks like the early plugs.

Restoration of Cabinets and Housings

As a general rule, repair work should be completed before finishes are restored. The latter subject is in the next section, and it is usually desirable to disassemble the phone to the extent that is practical before working on the finish.

Cleaning and Refinishing Wood Surfaces

If the finish has not popped up, it should be possible to restore the original finish to a surprising degree. This can be accomplished starting with mechanic's waterless hand cleaner and super fine (#0000) steel wool. This strong degreaser, when applied with steel wool, will readily remove built-up deposits of grime, and its lanolin base is an ideal moisturizer for the wood. Several applications might be required if a lot of dirt is removed, and care should be taken not to get the cleaner on cloth wiring because it will leave stains. The cleaner should be removed thoroughly, and the excess should be blown out of cracks and screw holes with compressed air. After drying for several days, a dark-colored oil furniture polish can be applied to restore the luster.

An alternate method, which does not require removal of the original finish, utilizes a solvent to liquefy the old finish. A mixture of one part lacquer thinner and one part denatured alcohol can be applied with a brush to dissolve and re-flow the original finish. If the layer of old finish is very thin, it might all soak into the wood and an additional top coat might be required. Even if this occurs, this method might be preferred because the original coloring will be retained and sanding can be avoided.

Some early finishes deteriorated badly in sunlight, however, and complete refinishing might be required. Liquid paint remover that can be washed off with paint thinner after scraping will generally be adequate. After the wood dries, it should be sanded lightly with fine (e.g., 150 grade or finer) aluminum-oxide or garnet sandpaper. Stain may have to be applied because the paint remover may also remove a lot of the original color. Varnishes are still available, but they have been almost universally replaced by lacquers and polyurethanes. Most restorers prefer a semi-gloss lacquer like Deft Clear Wood Finish, which may be applied by brush or is also available in spray cans. For walnut and cherry phones, stains might not be necessary and the lacquer finish might be sufficient. This finish can be rubbed with #0000 steel wool and polished with paste wax, if desired.

Oak has such an open grain that some filler is usually needed, and products like Zinsser Bulls Eye shellac sealer and finish (also in spray cans) work well. Mountjoy found the original finishing procedure used on oak telephones by Western Electric in unpublished AT&T archives (Mountjoy 1995, 48). The procedure involved stains, fillers, shellac, and a rubbed varnish top coat. A modern-day analog of that original procedure would be (a) sand with fine paper, (b) stain with oak, walnut, or mixture of stains, (c) spray or brush with clear or amber shellac sealer, (d) rub with #00 steel wool, (e) spray or brush clear lacquer, (f) rub with #0000 steel wool, and (g) apply paste wax.

Cleaning and Refinishing Metal and Bakelite

Black metal parts and bakelite pieces can often be restored by polishing with a white-colored automotive polishing compound. If a coarse rouge-colored rubbing compound is needed to remove deep scratches, it will be necessary to follow this with polishing compound to remove residual small scratches. Lightly rubbing painted metal or bakelite parts will remove surface dirt and oxidation and produce a semi-gloss finish that is similar to the original finish. A paste wax can then be applied to bring out the shine, and black shoe polish is often preferred because it tends to hide scratches. Polishing compound and rubbing compound can also be used to loosen threads in bakelite handset caps simply by rotating the threads back and forth with the compound inside. Residue should be thoroughly removed and wax should be applied to the threads after cleaning.

Bakelite, composition, and hard rubber parts can also be cleaned with #0000 steel wool and paste wax such. Whether using polishing compound or fine steel wool, care must be taken on bakelite and composition parts not to remove the surface layer. These materials are porous underneath their dense surface layer, and it will not be possible to restore a nice finish after that layer is gone.

Occasionally, painted metal parts have some varnish or other finish on them from a previous restoration that was done without disassembly. It is often easy to remove that finish with paint remover without damaging the underlying paint. This can be done successfully because the original baked paints are generally much more durable than air-dried finishes, so the unwanted finish will dissolve more rapidly. The operation should be performed quickly, however, and as soon as the unwanted finish loosens, the part should be immersed in paint thinner to stop the paint-removing action. The painted parts can then be polished and waxed.

Number plates on older dials are generally made of porcelain on a metal base. These can be cleaned with polishing compound, just like metal and bakelite parts. Because the number plates are not black, a clear paste wax should be applied after cleaning instead of using black shoe polish.

Metal parts that have chips or bare spots can be repainted with excellent results using automotive touch-up paints from spray cans, but considerable effort must be put into preparation. All rough edges must be feathered using a relatively coarse silicon-carbide paper (e.g., 320 grade) with water. Then, a heavy coat of combined scratch-filler and primer should be applied. This should also be wet-sanded, this time with ultra-fine (e.g., 600 grade) silicon-carbide paper. Several thin, but wet, coats of gloss black acrylic lacquer can be applied without intermediate sanding. After thoroughly drying, the new paint should be rubbed with white polishing compound to reduce the gloss and produce a satin finish that looks like the original. Finally, a coat of paste wax can be applied to bring out the luster.

Although repainting can be done with inexpensive materials from an automobile parts store, considerable skill is required for good results. An alternative is to take the parts to an auto body shop where good results should be obtained. Although either painting method can produce an excellent appearance, air-dried paints are not as durable as the baked japans used by the manufacturers, so repainted parts should be handled carefully.

Cleaning and Polishing Plastic Parts

Thermoplastic housings and handsets used extensively since World War II can be restored using commercial solutions made for this purpose such as Arrow-Magnolia general telephone cleaner and glaze (Glayz-it). The first is a liquid cleaner that is applied with a rag and rubbed thoroughly to remove dirt and surface scratches. The cleaner reacts with (dissolves) the plastic surface, and must be completely washed off with water. After drying, a glaze is sprayed onto the parts from an aerosol can, and the surface is then buffed with a towel.

More readily available general plastic polishes are also very effective. An example is Novus No. 1, No. 2, and No. 3, which consists of two grades of scratch removers (liquid rubbing and polishing compounds) and a clean-and-shine liquid. Deep scratches can even removed from plastic by wet sanding with graded silicon-carbide papers (through 600 grade) prior to using the liquid scratch removers. The cleaners and polishes can also be used on coiled plastic cords, which can then be totally immersed in water without harm to clean them or remove polish residue.

Nickel Plating

Nickel-plated brass parts were used extensively on early telephones because bare brass was not regarded as an attractive metal. When those phones were manufactured, there were no durable clear enamels to hold the shine of polished brass, and all brass parts were either painted black or plated with nickel. Although nickel plating is relatively durable, its surface does become dull with age. The shine can be restored with super fine (#0000) steel wool. Local metal plating shops will usually do nickel plating, so it is also possible to completely restore these parts.

Cloth Cords

If cloth telephone cords are frayed, they will of course have to be replaced, but if they are merely dirty or have a little paint on them, they can be cleaned. Ordinary paint remover can be used to remove dried paint from cloth cords without damaging them. Even if rubber insulation is used underneath the cloth covering, paint remover can still be used as long as the cord is washed quickly to halt continued action of the paint remover. Dirty cords can be immersed in hot soapy water and scrubbed with a brush. Dishwashing soap works fine, and the cords can be hung up to dry after rinsing.

Desk Stand Base Coverings

Fabric and leather coverings were used on the bottom of candlestick and handset desk stands. These coverings are usually held in place by a metal band inside the base, and the band and covering are easily removed. Brown pool-table felt makes an excellent replacement. A wrinkle-free covering can be obtained by spraying the base with rubber cement from an aerosol can and applying the new felt before the rubber cement dries. Edges can then be trimmed and the retaining ring re-installed.

Chapter 21
Tests and Measurements

Making electrical repairs and modifications might require circuit tracing and functional testing of components. Therefore, electrical tests and measurements will be discussed before proceeding to other topics.

Test Instruments

Analog Multimeter

A simple analog multimeter that reads volts and ohms is all that is needed for most diagnostic work. Many older multimeters have a single k-ohm (1,000-ohm) scale for resistance measurements, with the smallest division on the scale being 100 ohms. This type of meter is not adequate for telephone work because coil resistances, which will have to be measured, are in the range of a few ohms. Such a meter will not be accurate enough to distinguish between a direct short and a normally low coil resistance, and approximate coil resistances are needed to identify coil windings. However, inexpensive multimeters with scale divisions of 1 ohm are now widely available, like the Radio Shack No. 22-221 shown in Fig. 21-1, and these are adequate for circuit tracing and component testing.

Fig. 21-1. Radio Shack analog multimeter with a 1-ohm resistance scale that is adequate for telephone work.

Digital Multimeter

Although nearly all repair work can be done using a simple analog multimeter, precision measurements of the kind reported in earlier chapters will require a more sophisticated instrument. These measurements can be made with a modern digital multimeter, such as the Fluke No. 83 (Fig. 21-2). This meter will measure resistances to 0.1 ohm, which is adequate for measuring even the lowest resistance found in a local-battery coil. It will directly measure capacitance with an accuracy far greater than that required for telephone condensers. The meter will measure frequency to 0.1 cycles per second up through the audio-frequency range. And it will measure ac voltages to 0.1 millivolt in the audio-frequency range (e.g., at 1,000 cycles per second) enabling voice signals, like those shown in Part Three, to be determined precisely. For the purposes of interest here, a modern digital multimeter will perform functions that would have required an oscilloscope just a few decades ago.

Fig. 21-2. Fluke digital multimeter for making precision measurements.

Versatile Test Set

Test measurements in the audio-frequency range require the presence of stable test signals, and suitable test signals can be generated with a home-made signal generator. The test set that is described in the following paragraph will not only provide such signals, but it will also perform several other useful functions that will become apparent.[1]

Fig. 21-3. Versatile test set made from a standard touchtone telephone.

Figure 21-3 shows a test set made from a standard touchtone telephone that will generate appropriate signals. There are several interesting characteristics of this test set, but its success is the result of a fortuitous design peculiarity of the No. 25 and No. 35 touchtone dial types. As a result of the mechanical switching arrangement in those dials, when any two or more buttons in a row (or column) are pressed simultaneously, only the frequency of that row (or column) is generated. That is, instead of generating a pair of frequencies, as would normally be the case when a button is pressed, the tone generator produces a single frequency of sufficient sine-wave purity for test purposes. The test set, thus manipulated, will produce seven clean frequencies from 697 to 1,477 cycles per second (see Chapter 7), and the frequency of 941 cycles per second (produced by pressing star and zero together) is quite close to the nominal 1,000 cycle per second frequency desired for voice-signal measurements.

Figure 21-4 shows the circuit modifications that will convert a standard touchtone telephone to a test set like that in Fig. 21-3. The heart of the modification is a 1:1 audio isolation transformer, in series with a battery, connected across the line terminals of the phone. This arrangement provides appropriate dc line current to operate the tone generator, yet it keeps dc out of the signal output at the Fahnestock clips, as desired. Because the touchtone generator produces signal levels somewhat higher than average speech levels, the signal strength is ideal for telephone measurements -- good and strong, but still in the right range.

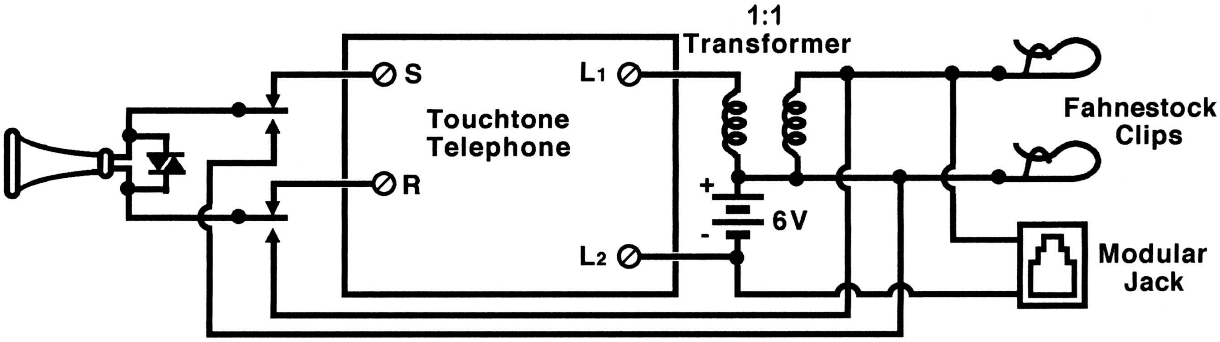

Fig. 21-4. Circuit modifications to convert a standard touchtone telephone to a versatile test set.

Some measurements (such as coil properties or receiver tests) require electrical test signals, while other measurements (such as transmitting and receiving voltages in a telephone circuit) require audio signals. This test set produces both. The Fahnestock clips in Fig. 21-4 provide electrical test signals, whereas the receiver in the handset provides audio signals that can be directed at the transmitter of a phone being tested.

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[1] The author has used this test set for years and made many of the measurements reported in the book with this set.

Without some further modification, however, the audio signal would not be very strong because (a) the test set circuit is of the anti-sidetone type, and (b) the receiver's output is further reduced during dialing by the 5,100-ohm attenuating resistor (see Chapter 19). Maximum sound output from the receiver can be achieved by moving the receiver from its normal location in the circuit and connecting it directly across the test set's output. A double-pole, double-throw (DPDT) switch is used for this purpose. In Fig. 21-4, switch contacts are shown in their position for maximum electrical output; the other DPDT switch position produces maximum audio output.

It should be noticed that, with the DPDT switch in the position shown in Fig. 21-4, the test set will also function as a local-battery telephone. Just connect the local-battery line to the Fahnestock clips for normal telephone operation.

The test set will also operate as a self-powered common-battery telephone that will provide power for itself and another common-battery phone plugged into its modular jack. This is accomplished by connecting the two coil windings together just above the battery in Fig. 21-4 so that the modular jack is connected across a coil winding and the battery. In this manner, the battery and coil windings, shown in Fig. 21-4, are exactly like those in Fig. 16-5 of Chapter 16, which shows the common-battery dc supply used for measurements made by the author. When the test set is being used as a signal generator or a local-battery phone, it will be recognized that the coil connection above the battery is one of those inconsequential single points of contact between two current loops that do not affect performance.

To construct the test set shown in Fig. 21-3, the ringer was removed and a plastic holder with four AA batteries was mounted in its place. Connections for the transformer were made on an added solder-terminal strip. A very small (3/4-inch long) and inexpensive audio isolation transformer (e.g., Radio Shack No. 273-1374, see Fig. 21-5) was used. Any transformer with two windings that have a turns ratio of around 1 will work. The DPDT switch and Fahnestock clips were mounted on the dial cover plate, which is relatively uncrowded. Fahnestock clips are particularly convenient for attaching wires, spade terminals, pin terminals, or clip leads. A regular line cord modular jack at the rear of the phone was simply rewired (Fig. 21-4). The normal hook switch contacts in the test set's original telephone provide switching for the batteries, and the test set is turned off when the handset is placed on the hook.

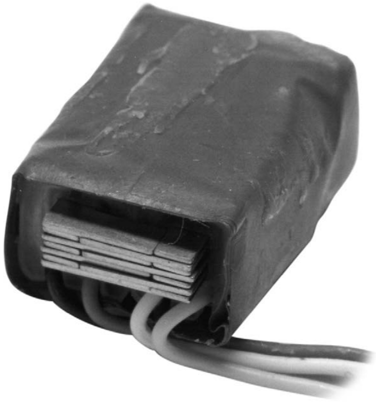

Fig. 21-5. Small audio isolation transformer used in the test set and in several applications in Chapter 22.

Component Testing

It is usually necessary to disconnect from the circuit one electrical lead (or contact) of each component to be tested. Occasionally, depressing the hook switch will accomplish this, but that will depend upon the circuit. Disconnecting components in older equipment is generally easy, but components inside modern sealed networks and on printed circuit boards cannot be disconnected without damaging the unit. Even in those cases, however, some tests can be made for circuit continuity, resistance, and capacitance to look for abnormalities.[2]

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[2] Western Electric’s No. 4228 network is notorious for loose connections in the coil.

Transmitters

Before making any measurements, the transmitter unit should be tapped around its edges to loosen the carbon granules. Then, its dc resistance can be measured with an analog multimeter. The resistance should be within the broad range given in Table 2-1. The value of this resistance is relatively unimportant, however, as it is the resistance fluctuations that make the transmitter work. If the needle on the multimeter moves as a result of blowing gently into the transmitter, the transmitter is probably good. Testing the quality of voice transmission can be done in the transmitter's operating telephone, which can be connected to the test set for this purpose.

All of the solid-back transmitters used in magneto wall phones and candlestick desk stands are highly position-dependent. If laid on their back, for example, the carbon granules will fall away from one electrode and cause an abnormally high resistance. It is therefore necessary to test older transmitters in their normal operating position. Although it might be more convenient to work on an old wall phone while it is lying on a work bench, it will be necessary to lay the phone on its side or mount it on a vertical test stand for successful transmitter diagnosis and operation.

Receivers

A simple dc resistance check with an analog multimeter should yield resistances similar to those in Table 3-1. A resistance check will also accomplish a crude operational check as the act of connecting and disconnecting the test leads of the meter will cause audible scratching noises in a functioning receiver. A better operational test can be performed by connecting the receiver to the Fahnestock clips of the test set and pressing the touchtone buttons. This will allow operational testing over the full range of frequencies of the touchtone dial.

Impedances at audio frequencies and phase angles like those given in Table 3-1 can be obtained with a digital multimeter and the test set operating as a signal generator. The test arrangement for this is shown in Fig. 21-6, and any resistor within a factor of 2 or 3 of the receiver's impedance will do (e.g., 100 ohms), but the resistor's resistance needs to be known accurately. Results are generally desired at 1,000 cycles per second, and the 941 cycles per second frequency available from the test set is close enough.

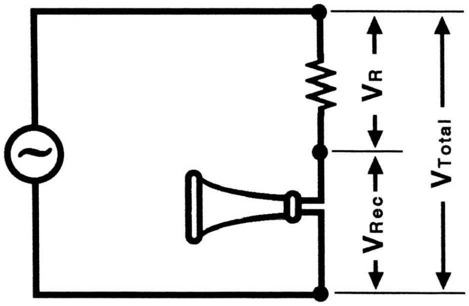

Fig. 21-6. Test arrangement for measuring the impedance of a receiver.

The ac impedance is obtained in two steps. First, the current from the signal generator through the components is determined from the known resistance R (it must be measured accurately) using Ohm's law:

$$I = V_R/R.$$

Then, the impedance Z_{Rec} of the receiver is obtained using Ohm's law again:

$$Z_{Rec} = V_{Rec}/I = V_{Rec}/(V_R/R),$$

where the previous equation has been substituted for I. Phase angles can be deduced trigonometrically from the three measured voltages, as indicated in Fig. 21-7.

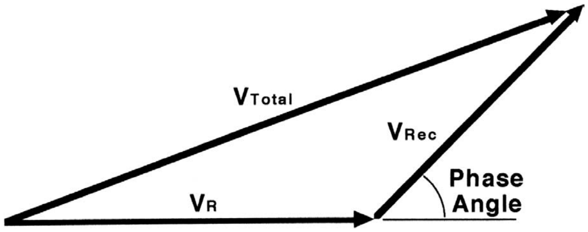

Fig. 21-7. Relationship of voltages measured according to Fig. 21-6, showing the phase angle.

Condensers

Condensers are the only components in telephone circuits that are prone to deterioration with age. Modes of failure include open circuits and short circuits, and both can be tested crudely with an analog multimeter using its resistance function. A good condenser should have an infinite dc resistance, as would a bad condenser with an open circuit. However, a good condenser will charge up under the voltage applied by the multimeter in its resistance mode, and this charging up constitutes a small current of short duration that will give the meter's needle a little kick. Thus, if the multimeter's needle moves initially when the meter's test leads are first touched to the condenser, the condenser is probably good. The largest needle displacement will be obtained on the highest resistance range where the meter is applying its highest test voltage. If this check is to be repeated, the condenser must either be discharged or the meter's leads reversed. Otherwise, the condenser will remain charged up and no more current will flow to move the meter's needle.

With a digital multimeter, capacitance of a condenser can be measured directly. Although these meters will measure capacitance with an accuracy of about 1 percent, condensers in telephone circuits only need to be within about 20% of the specified value to work satisfactorily; one-percent accuracy is not necessary.

Capacitance can be measured through resistances that are connected in series with the condenser in question. Accurate measurements result because the meter is measuring the total flow of charge (current), which is the same with or without the series resistance. This is one situation where the component under test does not have to be completely isolated from the circuit (there must not be other current paths around the condenser, however).

Coils

It is usually sufficient to measure the dc resistances of the windings of an induction coil or a retardation coil. If the winding resistances match the appropriate values tabulated in Part Three, then the coil is probably good.

A more thorough assessment can be made, however, by measuring the turns ratios of the windings of an induction coil or the impedance of a retardation coil. Figure 21-8 shows a typical setup for measuring turns ratios for a 3-winding coil. The test set functioning as a signal generator is connected directly to the primary winding. The 941-cycle-per-second frequency can be used to get values at the nominal 1,000 cycles per second desired because the result does not depend much on frequency. It is important that nothing be connected to the secondary or tertiary windings for the test as loads will somewhat alter the results. Turns ratios are then simply given by voltage ratios:

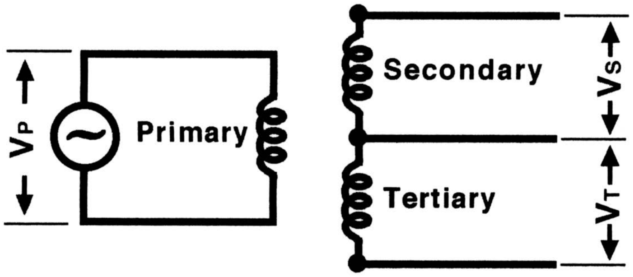

Fig. 21-8. Test arrangement for measuring turns ratios of a multiple-winding coil.

$$N_S/N_P = V_S/V_P$$

$$N_T/N_P = V_T/V_P$$

Functionally, retardation coils are just like the voice coils in a receiver. The impedance of a retardation coil can thus be determined in the same manner as for receivers (see Fig. 21-6). If desired, the inductance of the coil in henrys can be obtained from the impedance and frequency using the expression given in the Appendix. For such a calculation, the exact test frequency should be used (941 cycles per second), rather than the approximate value (1,000 cycles per second).

Magnetos

It is more difficult to make precision ac measurements on the windings of magnetos and ringers because a stable voltage source at 20 cycles per second might not be available. However, dc resistance measurements and continuity checks can be made, and functional tests are quite easy. Simply connect the magneto's output to the ac voltage input of an analog multimeter and turn the crank. A voltage range of 50 volts or more should be used to avoid damaging to the meter. The meter's needle may not be steady or accurate because the magneto frequency (15 to 20 cycles per second) is considerably lower than 60 cycles per second for which the multimeter was designed, but an approximate reading will demonstrate that the magneto is working.

An even simpler functional test can be performed with an electrician's neon test lamp. Ample voltage and power are produced by a magneto to light a test lamp, even at moderate cranking speeds.

Ringers

Continuity checks and dc resistance measurements are again valuable, and correct results should indicate that the ringer will work. Functional testing for ringers is best done with a magneto, and any old telephone magneto will work well. Except for frequency ringers, a magneto cranked rapidly will ring any functioning ringer, old or new, and the connection can either be made directly to the ringer terminals or through a ringer condenser. Because ringers are usually connected to the line terminals inside a phone, a magneto can be simply connected to the line terminals of an on-hook telephone and cranked to test the ringer.

Mechanically tuned frequency ringers are difficult to test because they will only respond to a magneto that is being cranked at precisely the right speed (not easy). There is, however, one way to test these ringers with a digital multimeter, and to determine their tuned frequencies in the process.

Terminals of a tuned ringer can be connected to the ac voltage input of a digital multimeter with the meter's frequency readout selected. When the clapper on the ringer is plucked, it will vibrate momentarily at its tuned frequency, moving the armature in the magnetic field near the pole pieces. The moving armature will perturb the magnetic field and the resulting varying magnetic field will induce a voltage in the ringer's coils (magnetic induction). This small voltage will have the frequency of the vibrating clapper and it will be read out digitally, indicating that the ringer is operational.

Precision measurements on ringers can, of course, be made using a stable signal generator that will produce 20 cycles per second (or other desired frequencies). Test procedures are just like those described in the previous section on receivers. Solid-state generators are now available, such as the little (1⅛ x 1⅛ x ⅜ in.) PowerDsine unit shown in Fig. 21-9.[3] This generator was powered by 12 volts dc (two lantern batteries) and required the addition of several condensers for frequency adjustment. Such generators have pins for soldering to a printed circuit board or can be mounted on a solderless breadboard.

Fig. 21-9 Small solid-state ring-signal generator that was used for measuring ringer properties.

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[3] This generator was used by the author in measurements of the ringer properties listed in Table 6-1 and the ringer-equivalence numbers (RENs) listed in Table 22-2.

Switches and Dials

Hook switch contacts, and the shunt switches and impulse switches in rotary dials, can be tested for proper continuity by measuring their resistance (zero or infinite) with an analog multimeter. Electrically, their function is simple and there is nothing more to test.

Touchtone dials, on the other hand, are complex. They are whole circuits containing many components, rather that merely being single components themselves. Some circuit tracing and component testing can be done within a touchtone dial, but success might be limited because of their permanent integral construction. Functional testing of a touchtone dial can be accomplished, however, using the preceding test set. The dial to be tested must be connected to its host telephone circuit (or a substitute) so that it will be properly energized. That telephone should then be connected to the test set using its modular line cord. When the handsets of that phone and the test set are taken off hook, the dial should generate tones when its buttons are pressed.

Frequencies of the dial tones can be checked to see if they are in their appropriate ranges (see Chapter 7). To accomplish this, a digital multimeter can be connected to the Fahnestock clips on the test set and the meter set for frequency readout. If the dial in question is like the prevalent No. 25 or No. 35 types, all seven frequencies can be checked separately by pressing buttons, two at a time, in each row and column. For later dials, individual frequencies cannot be generated, and the digital multimeter will record only the higher frequency of each pair -- in effect, checking only the three column frequencies.

Fig. 21-10. Test setup for measuring voltage ratios (turns ratios) for a Western Electric No. 101A coil.

Chapter 22
Electrical Repair and Modification

In this final chapter, an approach is outlined for making electrical repairs, and several examples are given of modifications that can be made and of private lines that can be constructed. Because there are restrictions on equipment that may be connected to the public telephone network, a brief summary of relevant Federal regulations is presented at the end of the chapter. This summary includes the grandfathering of many of the older telephones described in earlier chapters.

When this book was first written, most telephone service was provided by landlines of either copper wires or optical fibers. As the 3rd edition is prepared, many subscribers now rely totally on wireless cell phones or phone service over the internet (voice over internet). Phone service provided by internet service providers routinely includes an analog telephone adapter (ATA) that establishes conditions just like the old public switched telephone network. Thus most or all of the old phones described in this book will work normally when plugged into voice-over-internet service. An equivalent setup can be established for wireless cell phone service using a Bluetooth gateway. This is a powered modem into which a plain old telephone is plugged and which lets the phone work normally via a cell phone using a Bluetooth connection. The internet analog telephone adaptors and the wireless Bluetooth gateways generally accept pulse dialing as well as touchtone dialing. Therefore, regardless of the type of telephone service being used, antique telephones can still be connected and work normally.

Electrical Repairs

In most cases, the electrical repair of telephones requires no more than the replacement of damaged cords and the connection of wires to the proper terminals. Generally, a 3-step approach can be followed to diagnose and repair telephones of any vintage. The first step is to determine if the line is providing correct voltages and continuity. The second is to see that the phone's internal hookup is correct. And the third is to locate and replace inoperative components.

Line Conditions

Common-battery lines must supply a dc voltage. As seen in Chapter 16, common-battery lines typically produce 48 volts dc with the receiver on hook and about 5 volts dc with the receiver off hook. These voltages can be checked with a multimeter. For private lines, the voltages might be different, but in any event an off-hook voltage in the range of 4 to 16 volts should be available for common-battery telephones.

Many common-battery telephones will operate with either line polarity, but older touchtone dials will not. Touchtone dials without polarity guards (No. 25, No. 35, No. 82, etc.) must have terminal L1 connected to the tip side of the line: the positive lead. By convention, this should be the green wire (or the white wire with the blue band), but telephone wiring is not always installed correctly and the polarity should not be taken for granted.[1] If such a telephone will not produce touchtone dialing tones, reverse the line and try again. Line polarity can also be checked with a multimeter.

No dc voltage should be present on a local-battery line, but line continuity must be maintained. It can be seen that the secondary (receiver) loop on a local-battery line is open until the party at the other end lifts the receiver off the switch hook. Therefore, for phones with the standard local-battery circuit (Chapter 15), there will be no sidetone in the calling phone until line continuity is established by answering the called phone or by shorting out the line. There will be a small sidetone in the anti-sidetone sets (Chapter 18), but the secondary circuit is still not complete until the called party answers.

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[1] See the Appendix for more information on color codes.

Finally, local-battery phones must have good batteries. Original telephone batteries were 1.5-volt dry cells, and two or three of these batteries were connected in series (3 or 4.5 volts). Any source of dc will work, and two or three 1.5-volt D cells (flashlight batteries) in a plastic holder will provide good service life.

Internal Hookup

Older sets that have been out of service might have internal wires that are disconnected or connected to the wrong terminals. A wiring diagram will be needed to facilitate proper connection, and a method for developing a diagram will be discussed. For the purpose of this discussion, it will be assumed that the circuit type is unknown and that the internal wires are all disconnected to hinder circuit tracing.

Detective work begins with the coil, for if the coil type can be identified, the circuit type will follow. Measurement of dc resistances between coil terminals will allow the coil windings to be mapped out and their resistances to be determined. Having this information alone should permit identification of the coil type by comparison with tabulated values in Part Three. For example, if the coil has two windings, it is probably for the standard local-battery circuit (Chapter 15) or for the common-battery booster circuit (Chapter 16). Referring to Tables 15-1 and 16-1, typical resistances are sufficiently different to distinguish between the two. Similarly, if the coil had three windings, it would probably be for the local-battery anti-sidetone circuit (Chapter 18) or one of the similar common-battery anti-sidetone circuits (Chapter 17 if it is old or Chapter 19 if it is relatively new). Here again, typical resistance values are different and can be used to identify the coil.

Having identified the coil (which might also be possible from manufacturers' markings), a wiring diagram can be constructed from one of the basic circuit diagrams in Part Three. For example, if the coil was found to be a two-winding local-battery coil, construction of the diagram would start with Fig. 15-1. All the components found in the phone would be placed in logical order on the basic circuit to produce a complete wiring diagram. Examples of the use of condensers, switching accessories, and other typical variations, which might be needed to complete the diagram, are found in the numerous wiring diagrams, presented in Chapter 15 in this case. Inasmuch as Part Three covers the majority of telephone instruments used historically in the U.S., it is very likely that the complete wiring diagram needed will be found there, and a new diagram will not have to be constructed.

When the phone has been connected according to the appropriate wiring diagram, it should work. Here again, the test set can be used to see if the phone is in working order. If it is not, there is probably an inoperative component in the phone.

Component Replacement

The testing of individual components was described in the previous chapter, and those methods can be used to locate an inoperative component. Although the repair of some components may be possible, inoperative components must usually be replaced. In some cases, exact replacement parts will be required; in others, substitute parts can be used.

Telephone condensers occasionally fail -- particularly in very old sets containing rolled paper condensers -- but their replacement is particularly easy and inexpensive. Figure 22-1 shows a recent 1-microfarad metallized-film condenser, a quarter, and a turn-of-the-century 1-microfarad foil-and-paper condenser,

Fig. 22-1. Turn-of-the-century (19th) rolled paper condenser and an equivalent modern metallized-film condenser.

which it can replace. The new condensers are so small that they can be tucked away in an old telephone cabinet or housing, often without removing the original condenser (although one lead of the original condenser might have to be disconnected). This particular metallized-film condenser has a high voltage rating (200 volts dc) so that it can be used in ringer circuits as well as in voice circuits.

Transmitters are the next most likely source of trouble. Although transmitters seldom fail outright, they can become noisy, or upgraded performance might be desired. Sealed transmitter elements, such as the F1 and T1 units, merely drop into place in their handsets, and there is not much choice but to replace them with a like unit. However, the old solid-back transmitters in magneto wall phones and candlestick desk stands can be replaced with modern F1 and T1 elements. Electrical leads can be soldered directly to the new transmitter unit, which can then be fastened to the back of the faceplate with adhesive strips. It is preferable, however, when using the T1 element to also use the little plastic cup out of the G-type handset. This cup, which also has the electrical contacts in it, was acoustically designed to suppress frequency resonances of that transmitter (see Chapter 2).

Similarly, modern U-type receiver elements will fit inside the shell of an old hand-held receiver. Some reproduction receiver shells are even designed to take the U-type element. The smaller L-type receiver element from a Trimline phone can also be used if space limitations are a consideration. Styrofoam or other soft material can be fashioned to hold the receiver element firmly in place.

Individual components inside the network circuits cannot be replaced because the units are sealed. However, the various networks described in Chapter 19 are nearly identical in their electrical characteristics, and any network that will fit in the space available can be used. The circuit diagram in Chapter 19 for the network being installed should be used for the hookup.

Generally speaking, the early telephone dials are interchangeable and substitutions are possible. From Fig. 7-3, it can be seen that the No. 2A candlestick dial has a different switching arrangement than the handset dials. However, the only difference between a No. 2A candlestick dial and a No. 2H handset dial is in the set of electrical contacts that fits onto the rear of the mechanism. Although a later dial could be substituted in its entirety, a relatively scarce No. 2H dial can be constructed from a No. 2A dial by substituting the interchangeable contact set from a later dial.

The touchtone dials in standard desk sets and wall phones are all alike in external size and mounting configuration. Although there are electrical differences and different numbers of leads to be connected, many are interchangeable. Reference to Figs. 19-15, 19-16, and 19-17 will show the various methods of connection.

Modification of Local-Battery Phones

The following sections address modifications that can be made to local-battery phones so that they will operate on common-battery lines.

Ringer Condenser

It was pointed out in Chapter 15 that a 1-microfarad condenser was provided by Western Electric to use in series with the ringer when the No. 317 magneto wall phone was used on common-battery lines. A similar provision was made in the No. 417 local-battery anti-sidetone magneto phone. Further, the Western Electric No. 634Y subset, the later No. 634YD subset, and the Western Electric No. 307 combined telephone, all with a local-battery circuit, were expressly designed for use on common-battery lines, as were some of the Northern Electric 500Q variations (see Chapter 18). From these examples, it can be seen that any local-battery telephone will work on a common-battery line with one very minor modification.

The reason for this versatility is apparent from Fig. 15-1. If a condenser were placed in series with the ringer, as it is in all common-battery circuits, and if the line were a common-battery line, dc line current would flow through the secondary coil winding (17 ohms in a No. 13 coil) and the receiver (85 ohms in a No. 144 receiver). This can be compared with the dc path in the booster circuit of Fig. 16-4, which goes through the primary coil winding (14 ohms in the No. 46 coil) and the transmitter (25 to 75 ohms in the No. 323 transmitter). There is no significant difference, and normal dc current flow would be established through the local-battery set to operate switching relays at the central office. Thus, the only modification that is needed is the addition of a condenser in the ringer circuit to eliminate an on-hook dc current path. The negligible effect of this condenser on ringing was covered in Chapter 6.

A second modification was made in the later No. 634YD subset and in the No. 307 telephone, and that was the addition of a retardation-coil shunt around the receiver (see Fig. 18-7 and 18-8). The purpose of this coil was to create a dc current path around the receiver so that the receiver could be switched into the circuit after all dc currents had been established, thus reducing receiver click. An extra hook switch section was required for that purpose. Because an extra hook switch section is normally not available in local-battery sets, this second modification cannot usually be made, and receiver click will be noticeable.[2]

Network Implants

An alternate way to modify a local-battery phone for common-battery usage is to substitute a common-battery circuit for the original one. Any of the circuit networks described in Chapter 19 can be placed inside a local-battery phone to convert the phone to a common-battery type. In effect, the transmitter, receiver, and hook switch are taken out of their original circuit and connected to the network, forming the new circuit.

Figure 22-2 shows the wiring diagram for a No. 4228 network with a transmitter, receiver, and 3-contact hook switch that would be typical of a magneto wall phone. The hatched marks show the interface between the network and the components of the wall phone. Jumper wires are needed between terminals L1 and F, between F and RR, and between A and L2. And an extra 0.5-microfarad condenser can be connected between terminals A and K to increase the capacitance to 1 microfarad for a better match with an old ringer.

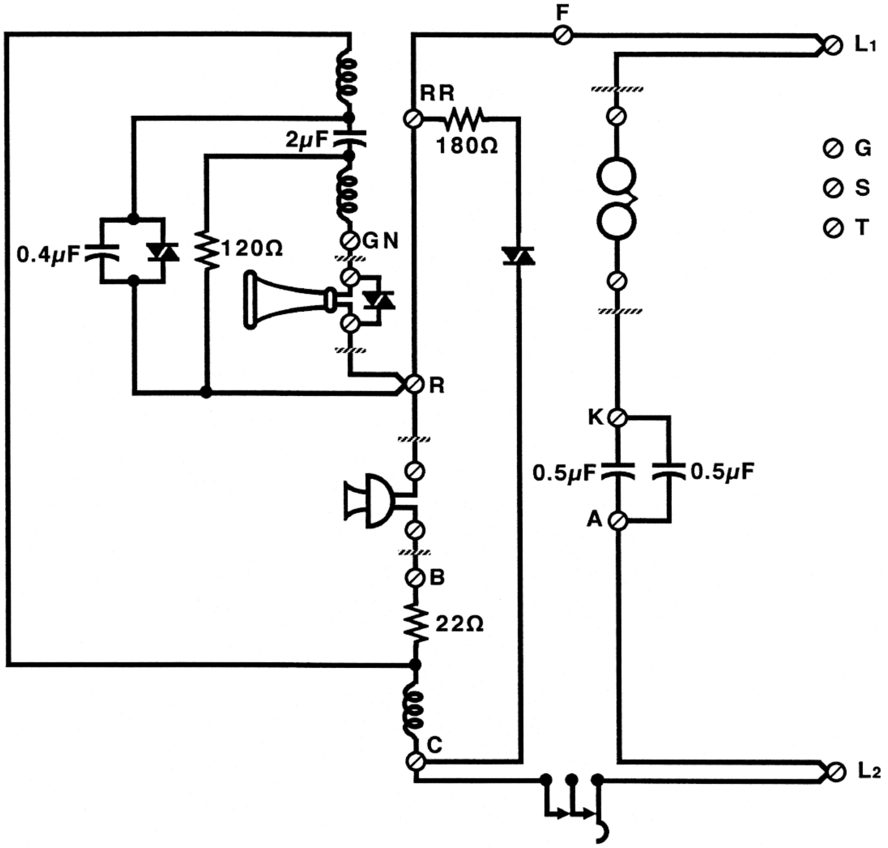

Fig. 22-2. Hookup of Western Electric No. 4228 network in a typical local-battery phone for common-battery operation.

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[2] A varistor cannot be used across a receiver in such an application because the dc voltage across the varistor would cause its resistance to be so low that it would short out the receiver.

An unavoidable compromise occurs in this arrangement as a consequence of using the old 3-contact hook switch. In these network circuits, there are three dc current paths, rather than a single path as in earlier telephones: one through the transmitter and one through each of the main circuit varistors (not the varistor on the receiver). If this switch were placed in its normal location at R, it could interrupt current through the transmitter and disconnect the receiver; however, it would not disable the two dc paths through the varistors. Therefore, the switch must be placed near L2, as shown (or it could be placed between L1 and RR). With this placement, the remaining contact on the hook switch cannot be used to disconnect the receiver, and very noisy hook switch action results. One section of the hook switch is simply left unconnected.

To reduce the excessive hook switch noise, a No. 100A or similar varistor can be connected across the receiver terminals as shown, and this connection can be made inside the telephone, rather than inside the receiver shell. The varistor will greatly improve this situation, but it is not absolutely necessary for operation. Incidentally, the magneto has been intentionally omitted from Fig. 22-2 and it is covered in the following section.

Fail-Safe Magneto Connection

In some applications, it will be desirable in a converted phone to prevent the magneto from connecting to the common-battery line. Three options to accomplish this are apparent. One is to leave the magneto out of the circuit as done in Fig. 22-2. With this option, the ringer will ring for incoming calls, but it will not ring when the magneto is cranked. A second option is to leave the ringer and magneto out of the telephone circuit, but to connect them together. With this option, the ringer will ring when the magneto is cranked, but it will not respond to incoming calls. The third option permits ringing under both conditions, but simplicity is lost.

The third option uses a relay to switch the ringer between the line and the magneto. Circuit diagrams and modules can be found on the internet that use the output from the magneto to energize a relay. A simpler circuit, described here, uses a low-voltage relay (Radio Shack No. 275-004 or equivalent) and a battery. The hookup for the relay is shown in Fig. 22-3, and the relay and 9-volt radio battery can be mounted on a small phenolic board, if desired. The relay, as wired, is seen to operate in a fail-safe manner. In its normal, unenergized position, the ringer is connected to the line and the magneto is not connected to anything. When the relay is energized by the shunt switch on the magneto shaft, the ringer is removed from the line and connected to the magneto. Thus, the ringer will ring when the magneto is cranked, and it will also respond to an incoming ring signal when the magneto is not being cranked. However, the magneto will never be connected to the line -- even if the battery fails.

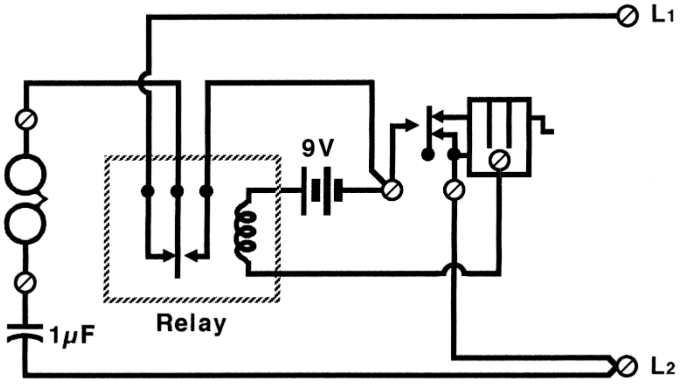

Fig. 22-3. Fail-safe magneto hookup for a typical Western Electric local-battery phone to be used on a common-battery line.

One detail of the magneto connection requires further explanation. Western Electric magnetos generally have only two terminals, neither of which is connected to the magneto's frame; one makes momentary contact with the frame when the magneto shaft moves the shunt switch, and the other is connected to the armature winding. For the hookup shown in Fig. 22-3, a third connection is required on the magneto's frame. This connection can be made at one of the screws that hold the magnets in place. American Electric, Kellogg, and Stromberg-Carlson magnetos usually have a third terminal, which is connected to the frame.

Dialing

A rotary dial can be connected to a local-battery phone for use on common-battery lines. For example, a No. 7 dial out of a 500-type phone could be located in the battery compartment of a magneto wall phone, or it could be mounted in a small case on top of the phone. The complete hookup is quite simple and can be described with the aid of Figs. 7-6 and 15-5.

First, the phone depicted in Fig. 15-5 must be configured for common-battery usage by placing a 1-microfarad condenser between COND1 and COND2 and by moving the lower ringer lead from LINE2 to COND2. This was described in Chapter 15. Then, the upper ringer lead can be moved from LINE1 to GROUND, which is a spare terminal (not connected to ground) that can be used for convenience. Next, the dial impulse leads (blue and green) are connected to LINE1 and GROUND (polarity does not matter), and the dial shunt leads (white) are connected to the REC terminals. Finally, the line is connected to GROUND and L2 (polarity does not matter here either).

If a network implant has been used (Fig. 22-2), the dial impulse switch can be connected between terminals F and RR, which is its normal location in a 500-type telephone. The shunt switch would still be connected across the receiver. The absence of a radio-interference filter at terminal F in this case, or with a local-battery phone with a ringer condenser, will of course not affect the telephone's performance. Some dialing noise might be picked up in a nearby AM-band radio, but current radios are so selective that this interference will not be significant.

Touchtone dials can also be incorporated if a network implant has been used. As before, this dial can be located in the battery compartment or on top of the phone in a separate enclosure. Telephone cables with 4 pairs of conductors will provide enough leads to connect a No. 25, No. 35, or equivalent touchtone dial. Hookups can be made exactly as shown in Figs. 19-16 and 19-17. A 9-wire touchtone dial can also be used (see Fig. 19-18).

Finally, hand-held tone generators are available, like the Radio Shack No. 43-139 tone dialer shown in Fig. 22-4. Although these tone generators were intended for end-to-end signaling, they will also actuate switching equipment. However, they are only marginally successful for dialing for two reasons. One is that the signal level they produce is lower than that of a touchtone dial; the other is that background noise might be present. Both of these situations will reduce successful signal detection, as described in Chapter 7.

Fig. 22-4. Radio Shack tone dialer for dual-tone, multi-frequency (DTMF) signaling.

Modifications of Common-Battery Phones

Pulse-to-Tone Converters

Although most telephone services will still accept pulse dialing, there may be circumstances where it is desirable to convert pulses from a rotary-dial phone to tones (e.g., for selecting from a menu). There are several commercially available pulse-to-tone converters, such as Dialgizmo, that are small and require no external power to operate. These converters usually have a pigtail with an RJ11 plug for connecting to the telephone line and an RJ11 jack into which a rotary-dial telephone can be connected.

Circuit Upgrades

As seen in Part Three, all common-battery circuits -- from the 100-year-old booster circuit to the recent Trimline circuit -- are similar. Most of the circuit improvements have occurred in the receiver loop to reduce sidetone, leaving virtually unchanged the primary loop that is seen by the line. New generations of phones were introduced gradually and placed in mixed service with older phones. The result is that no modifications are needed to make older common-battery phones compatible with current common-battery lines.

Common-battery phones can also be made to operate on local-battery lines. However, those modifications are best made at the central office and they are described in the section on private lines.

It might be desirable, however, to replace the original coil and condensers in an old telephone with a more modern coil and condensers or with a network. For example, an old subset with the booster circuit could be upgraded with a Western Electric No. 101A coil and an extra condenser to obtain an anti-sidetone subset. Western Electric made many such upgrades itself. Or it might be desirable to remove the coil and condensers from a 1930s or 1940s combined telephone and replace them with a network; any network described in Chapter 19 that will fit into the available space will work. The possibilities are numerous, and it is only necessary to find a circuit in Chapter 17 or 19 that uses the coil or network of interest and to wire the old phone accordingly.

Desk Stand Implants

Candlestick and handset desk stands, as seen in Chapters 10 and 11, are not complete telephones. The components they lack, except for a ringer, are all contained in the networks described in Chapter 19. The bases of these desk stands are invariably small, however, so that the standard networks will not fit inside.

Some small networks can be found that will fit inside these desk stands, and one such mini-network was used in Automatic Electric's Styleline telephone. That network is constructed on a printed circuit board about 2 inches by 2 inches and is described in Chapter 19 (see Fig. 19-26 and Table 19-4). The voltage divider for party-line caller identification is no longer used and can be removed by clipping out the two resistors and the blue lead. This will improve performance a little, and the result will then be equivalent to the Western Electric No. 4293 network (see Fig. 19-17). To complete the circuit shown in Fig. 19-25, the yellow and black leads would be connected to a receiver, the red and green leads would be connected to a transmitter, and the pink and white leads would be connected to the line with appropriate switching.

A complete circuit for a Western Electric dial candlestick desk stand with this mini-network is shown in Fig. 22-5 with the voltage dividing resistors and the blue lead omitted. Some ingenuity is required in hooking up the network in this desk stand as there are not enough terminals present for all the connections. However, most of the hookup is straight forward.

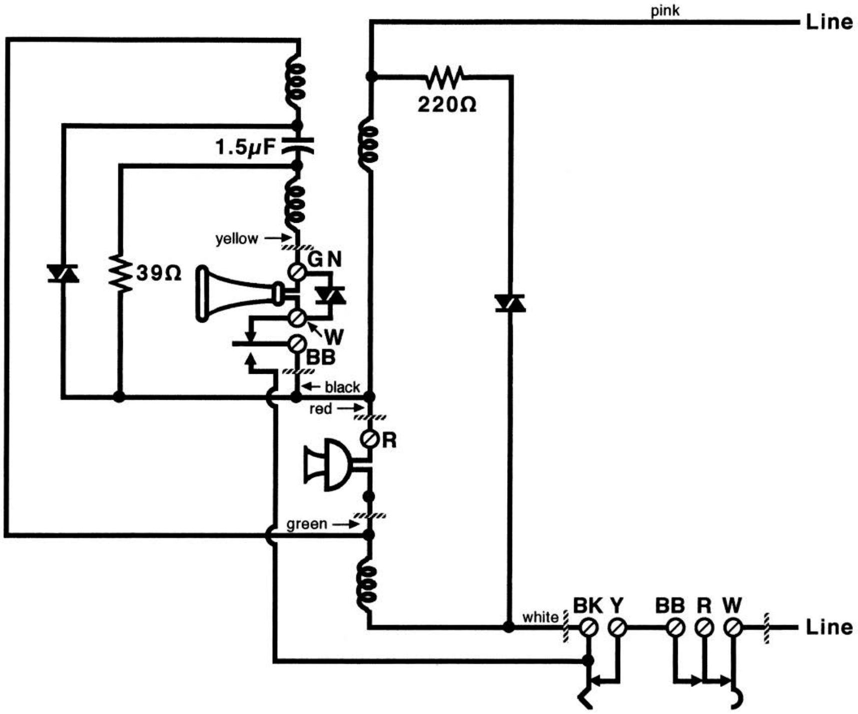

Fig. 22-5. Hookup of an Automatic Electric mini-network in a Western Electric candlestick desk stand.

As with the modification of the magneto wall phone in Fig. 22-2, the 3-contact hook switch has to be located near the line, beyond all dc current paths in the phone. And just as in that application, no switch section will then be available to disconnect the receiver, resulting in very noisy hook switch operation. Use of a varistor on the receiver is thus important, but again not essential. However, the dial shunt in this arrangement does disconnect the receiver during dial rotation so that quiet dialing is achieved.

Figure 22-6 shows the same mini-network connected to a Western Electric handset desk stand. Because switch sections were isolated in the original design to accommodate a 3-conductor handset cord, a switch section is available in this desk stand to disconnect the receiver. Hook switch action is thus quieter in such an application. No varistor should be placed across the receiver terminals in this case, however, because the 3-conductor handset cord might result in a dc voltage that would cause the varistor's resistance to be too low (see the section on early 500-type telephones in Chapter 19). The black lead and the red lead of the network are electrically equivalent, and in this application only one of them has been used. The black lead has thus been omitted from the figure and it can be removed from the network.

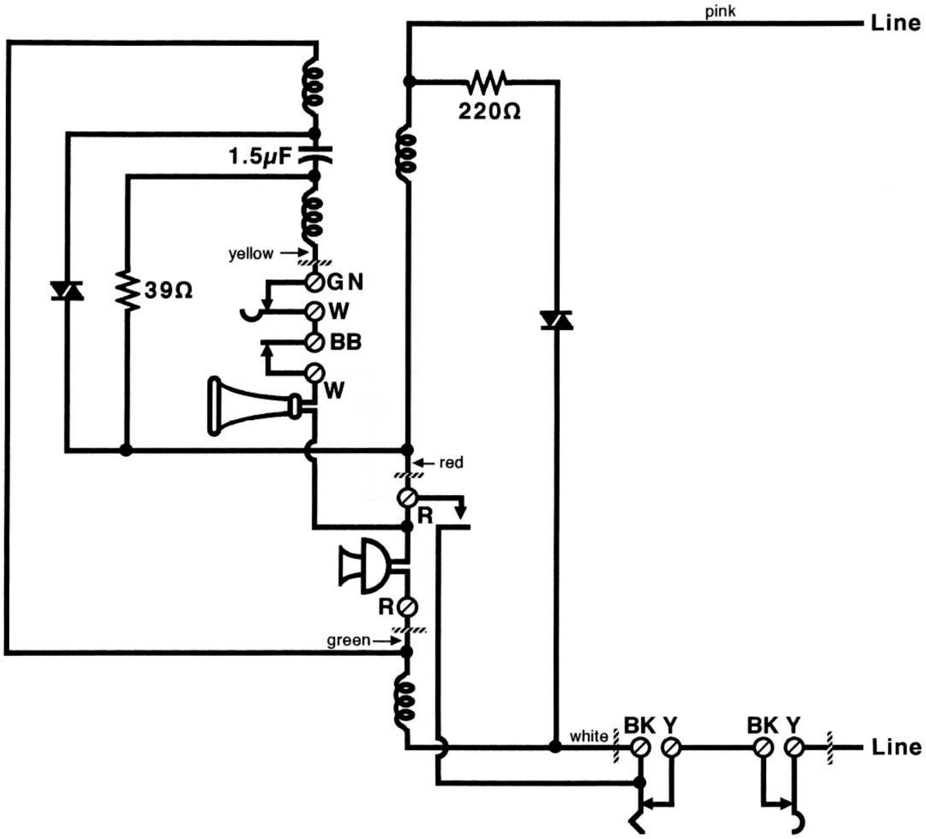

Fig. 22-6. Hookup of an Automatic Electric mini-network in a Western Electric handset desk stand.

An alternative to the mini-network implant is the use of a standard network in a small utility box, connected to the phone by a cord, to form a small subset. Telephone cables with four pairs provide more than enough leads for this application. Connection of a No. 4293, 4228, 425, or other network would be exactly like the applications shown in Figs. 22-5 and 22-6 (refer to Table 19-4 for the equivalence of standard terminal markings and the color-coded leads of the Automatic Electric mini-network).

Conversion for Local-Battery Operation

The method described in Chapter 18 (see Fig. 18-19) of utilizing a modern common-battery anti-sidetone circuit for local-battery operation can be used with other phones. This Automatic Electric Type 40 circuit was pre-wired at the factory and conversion to common-battery operation was made easy. Of course, a Type 40 that was factory wired for common-battery operation could be modified to produce the circuit in Fig. 18-19. However, this would require a number of wiring changes, many of which would involve soldered connections. By using some different terminal connections, this basic circuit can be formed with fewer alterations, and such a circuit that was used widely in Canada is shown in Fig. 22-7.

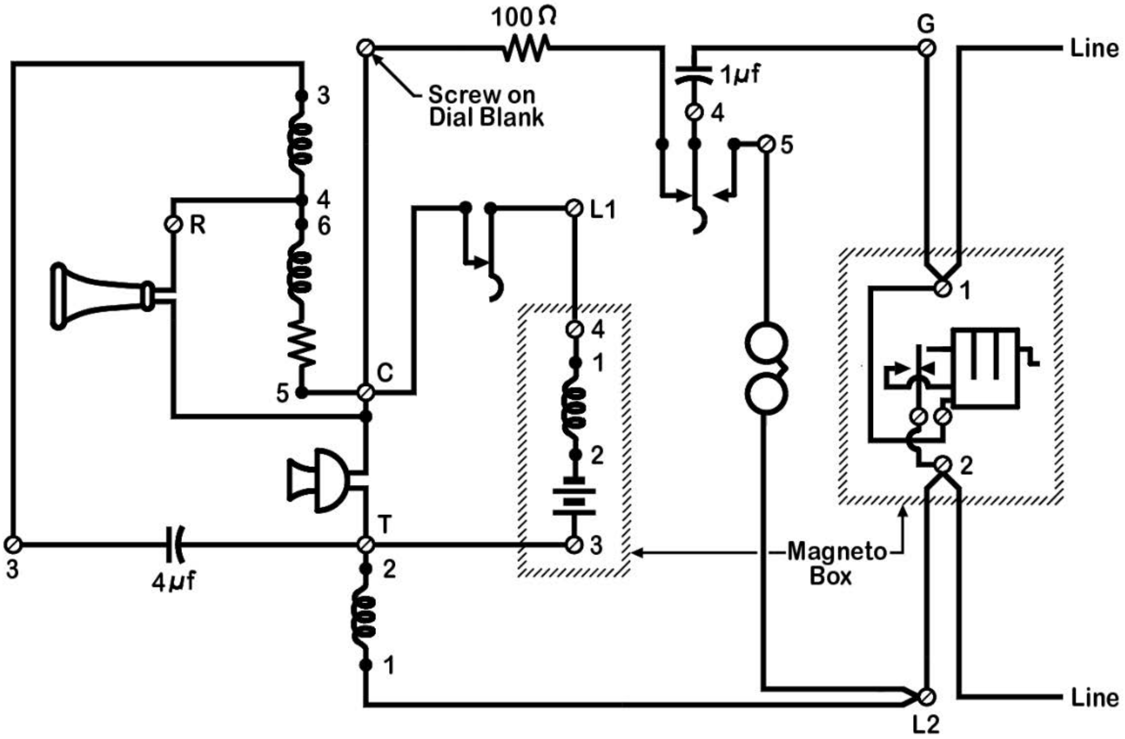

Fig. 22-7. Modified hookup of an Automatic Electric Type 40 common-battery phone for local-batery operation.

This same arrangement can be made even more easily in a Western Electric 302 telephone because there are no soldered connections and all the changes can be made by simply moving a few wires. The diagram for this modification is shown in Fig. 22-8. In this phone, the two hook switch sections are usually single-throw-single-pole switches; thus, there is no way to use the 0.5-microfarad ringer condenser for blocking ac current in the line and then switching it to the ringer when the handset is on hook. Therefore, it is simpler just to disable the ringer in the phone and utilize a magneto ringer box, which will then provide the ringer, magneto, and retardation coil (secondary winding of its induction coil). Figure 22-8 shows the connections for a Western Electric 302 telephone in combination with a Western Electric 300 or 315 magneto ringer box. Terminals Y-BK and W-BB are on the dial blank in the telephone.[3]

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[3] However, if a ringer box is going to be used in connection with a No. 302 (or other desk telephone), better performance and quieter hook switch operation will be obtained by disregarding the coil and condensers in the desk phone and connecting the other components to the ringer box as in Fig. 15-10 to achieve the standard local-battery circuit.

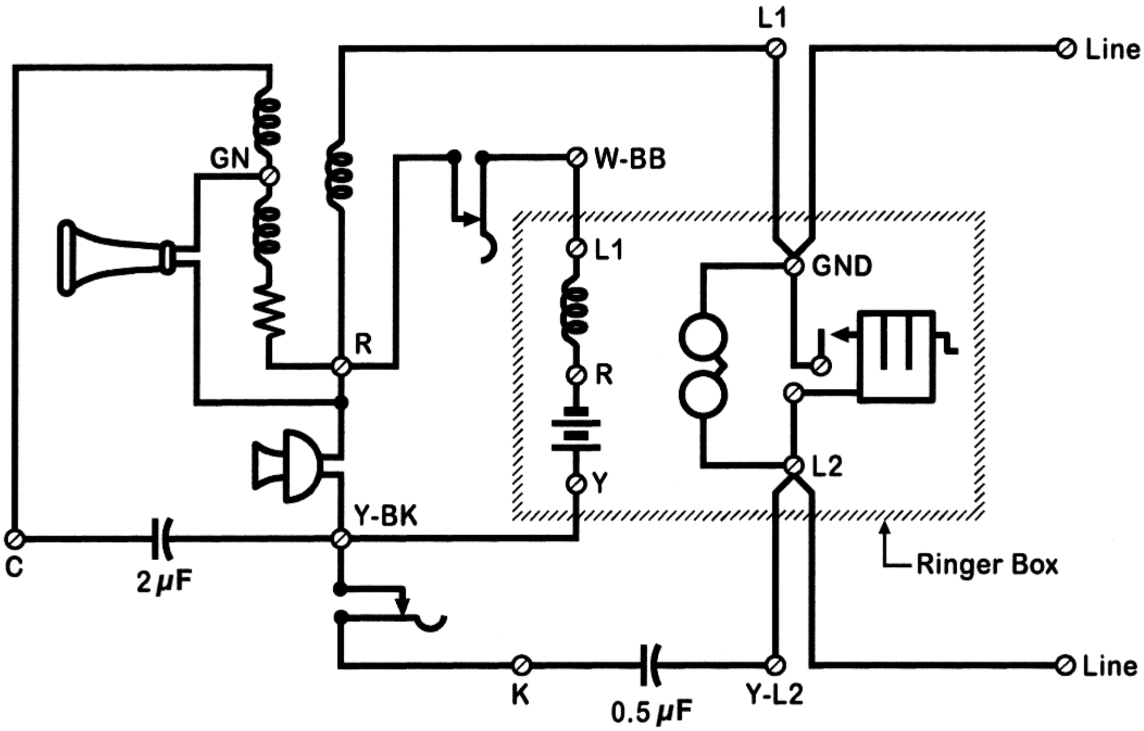

Fig. 22-8. Modified hookup of a Western Electric No. 302 common-battery phone for local-battery operation.

Construction of Private Lines

No attempt will be made here to describe commercial or public lines for the transmission and switching of telephone signals. However, some very simple arrangements can be constructed for experimental or other purposes.

Local Batteries

Local-battery lines are the ultimate in simplicity and require little description. For a party line, local-battery phones are merely connected across two wires in a bridging manner as shown in Fig. 22-9. All phones will ring when a magneto is cranked, and code ringing can be adopted. Alternatively, each phone could be routed to a central office where connections can be made between lines as desired. No circuitry is required, except switches.

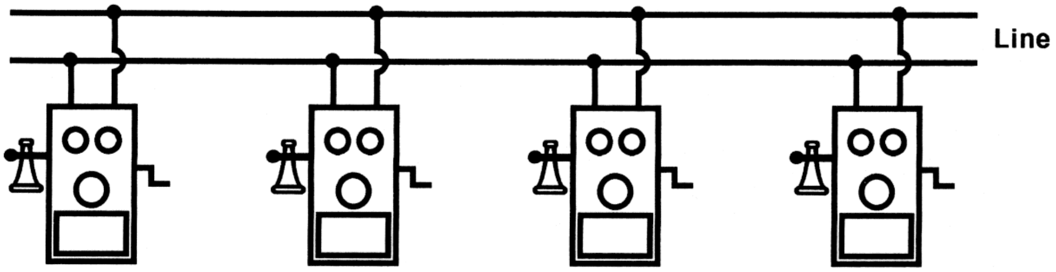

Fig. 22-9. Local-battery party line.

Common Batteries

A Hayes-type common-battery system can be constructed using an audio isolation transformer, such as that used in the test set above, as a repeater coil for each phone. Figure 22-10 shows such a system with a 6-volt battery (a lantern battery is ideal). As shown here, all lines are connected together at the central office so that any two (or more) phones taken off hook could communicate. Switching, of course, could be added at the central office to connect lines selectively.

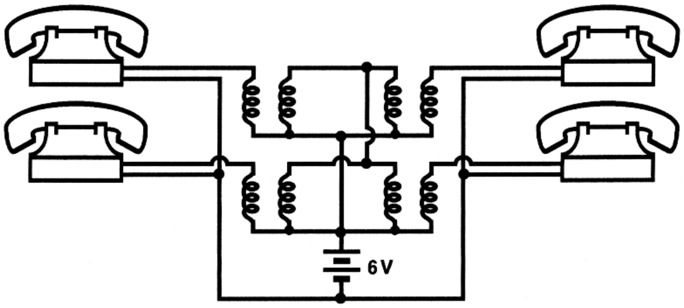

Fig. 22-10. Hayes-type common-battery line with repeater coils.

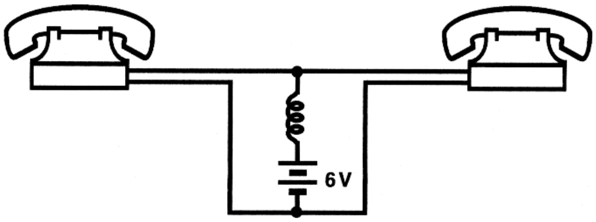

Fig. 22-11. Common-battery party line with a single retardation coil.

A simpler hookup resembling a party line or an extension line could be made using a single retardation coil (or substitutes described below), and such a hookup is shown in Fig. 22-11. Only two phones are shown in the figure, but more could be added. A convenient substitute for a retardation coil can be obtained by using only one winding of the audio isolation transformer. In fact, nearly any winding from a telephone coil, audio transformer, or power transformer (like a doorbell transformer) with a high ac impedance and low dc resistance will work. When using one winding of a multi-winding coil or transformer, the other windings should be left open to avoid loading down the system. If a 1:1 audio transformer is used, however, the unused winding could be connected to other telephones.

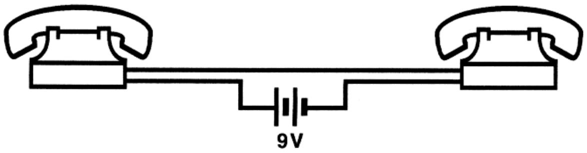

Fig. 22-12. Two-phone common-battery line without coils.

Finally, two common-battery telephones can be connected together through a series battery without using any coils or transformers. This hookup is shown in Fig. 22-12. A 9-volt battery (e.g., a radio battery) is indicated here because the series connection results in only half the battery voltage (4.5 volts) being applied to each phone. Because there are no dc voltage losses through any coil windings at the central office, a higher voltage like 12 volts (double that in previous examples) is not needed. This arrangement works well because a battery has a very low internal resistance, thus adding essentially no ac impedance to the line while providing the dc voltage.

If touchtone telephones without polarity guards are used, line polarity at each phone must be correct for the dials to work. Notice that, with this series battery hookup, no battery current flows until both receivers are lifted off their switch hooks. Therefore, one telephone could be left off hook to provide for one-way signaling of sorts when the second phone is taken off hook and touchtone buttons are pressed.

Signaling on experimental and private lines is not straight forward because a high-voltage, low-frequency signal generator would be required to operate the telephone ringers and because interlocking relays would be needed to prevent ring signals from being applied while talking. Substitute signaling can be provided with external buzzers or bells, and it is noted that common telephone cables have at least two extra conductors that can be used for this purpose.

Mixed Service

It was seen above that local-battery phones with ringer condensers will operate normally on common-battery lines. Hence, one way to achieve mixed service is to construct a common-battery line and simply connect local-battery phones (with the condensers) to it. As long as magneto signaling is avoided, such a system would be satisfactory. Magneto signaling on such a system would ring the ringers on all phones, but relays would be needed to avoid transmitter damage in off-hook, common-battery telephones.

An alternate hookup is shown in Fig. 22-13 that will permit magneto ringing on all phones and uses a separate ringer box or magneto generator as a companion for each of the common-battery phones.[4] The 1-microfarad condenser shown in Fig. 22-13 functions exactly like the sure-ring condenser described in Chapter 15. It presents an impedance at 20 cycles per second (ring frequency) that is so high that very little current at that frequency goes through it. Consequently, no significant ring-signal voltage gets through the 1:1 transformer to get on the common-battery line. As shown, however, the ring signal reaches the ringer box by an alternate route, and the ringer box will respond to incoming signals and ring out with its own magneto.

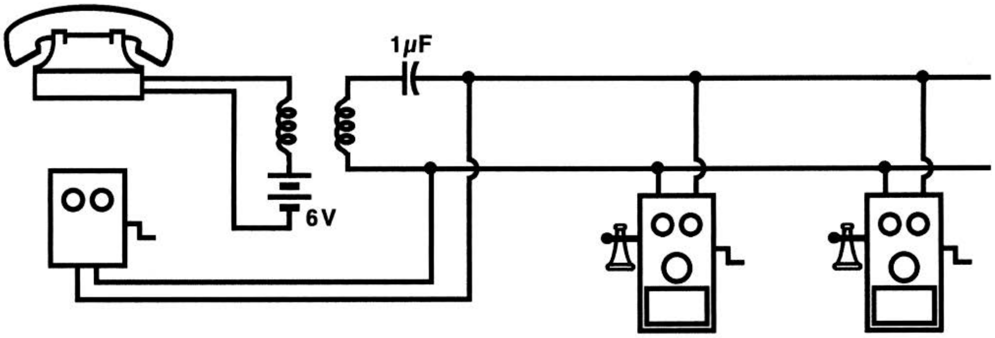

Fig. 22-13. Mixed common-battery and local-battery service with magneto signaling.

A minor variation of Fig. 22-13 would be to use one of the magneto generators that does not have a ringer and to wire the telephone's ringer in parallel with that magneto. The ringer must be completely disconnected from the common-battery line for that arrangement. In either case, it is again noted that common telephone cables have at least four conductors, which will conveniently connect both the telephone and magneto to the central office.

Intercom

The 500-type phones, with minor modifications, make ideal intercom phones that can talk and signal from one 6-volt lantern battery. Signaling with buzzers is accomplished by spinning the rotary dial, and the battery is disconnected when the phones are on hook. The system requires 4 wires as shown in Fig. 22-14. Because the talking parts of the phones are used in their original configuration, there is no problem if one of these special 500-type phones is inadvertently connected to the outside line or conversely a regular phones is connected to the intercom line. The phones will both talk on either line; they will just not dial, ring, or buzz on the wrong line.

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[4] Ringer boxes are described in Chapter 12. Separate magneto generators without ringers are shown in Figs. 13-3, 13-12, and 14-6.

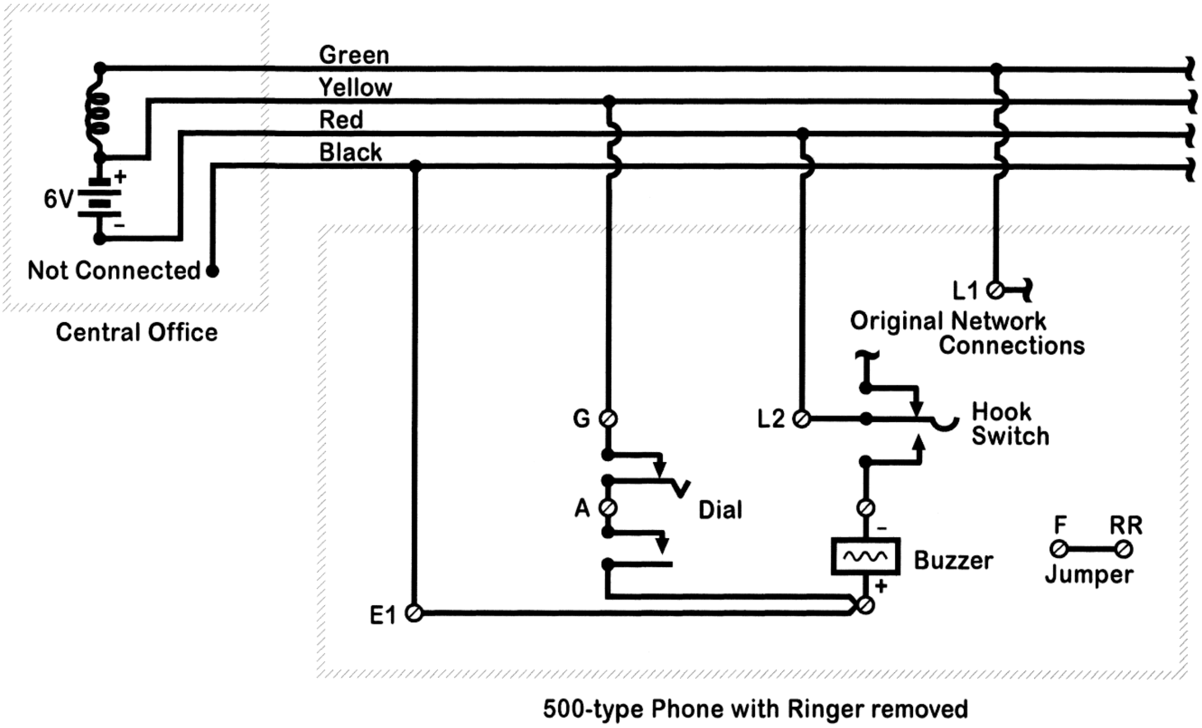

Fig. 22-14. Four-wire common-battery intercom hookup with 500-type telephones and 6-volt buzzers.

The phone modifications require removal of the ringer and substitution of a 6-volt buzzer (e.g., Radio Shack #273-054A), which can be mounted on a small piece of wood and provided with two extra screws for electrical connections if needed. All other connections can be made on the telephone's network as shown in Fig. 22-14. The rest of the modifications simply involve moving a few wires to create the hookup shown in the figure. Terminals G, A, and E1 (if present) are used as convenient tie points and do not make any connections inside the network. For reference, Fig. 19-8 shows the rest of the circuit of a 500-type phone. Standard line cords with RJ11 modular connectors can be used to connect these phones to the intercom line. The coil in the central office can be the primary winding of a small audio output transformer (e.g., Radio Shack #273-1380) with nothing connected to the secondary winding.

For operation over short distances, where impedance matching or the booster action of a coil is not needed, another circuit can be constructed that uses only a transmitter, a receiver, and a battery. This circuit, often used for intercoms, is shown in Fig. 22-15. The way this circuit works is very interesting because its dc and ac operation are so different.

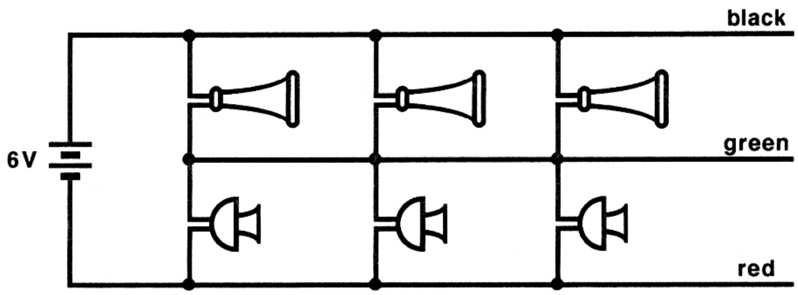

Fig. 22-15. Three-wire common-battery intercom circuit without induction coils, repeater coils, or condensers.

Figure 22-16 shows the equivalent dc circuit for this intercom. If all receivers have the same dc resistance and, likewise, if all transmitters have the same resistance, then the dc voltage would be the same at all points along the green line conductor. Hence, no direct current would flow through the green line conductor -- like a balanced Wheatstone bridge -- and the green line conductor can be omitted for dc circuit analysis. Consequently, Fig. 22-16 shows that, for dc purposes, each transmitter is in series with its receiver, and the dc transmitter current must flow through that receiver. Because of this, a varistor cannot be used across the receiver terminals to suppress noise pulses because the dc voltage would place the varistor in its low-resistance range and it would short-circuit the ac signal around the receiver. If the receiver to be used has a varistor, it must be removed.

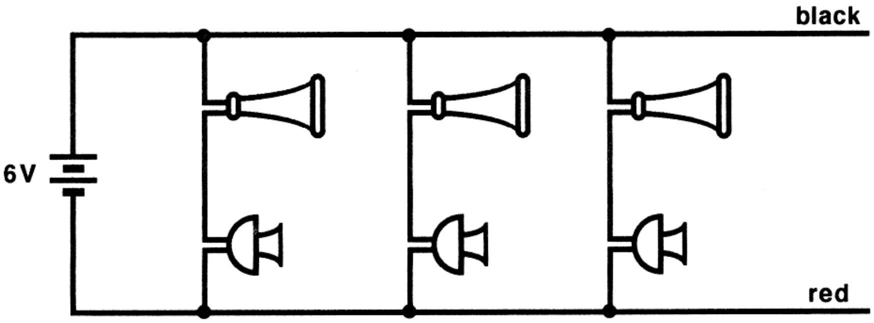

Fig. 22-16. Direct current (dc) equivalent of the 3-wire intercom circuit showing effective series connection of receivers and transmitters.

The equivalent ac circuit is quite different. The battery introduces no ac voltages into the circuit and a transmitter is now the ac voltage source. However, the impedance of a battery is so low (on the order of 1 ohm) that for ac considerations the battery effectively connects the black and red line conductors together, which produces the ac circuit shown in Fig. 22-17. Therefore, in ac operation, the receivers and transmitters are all in parallel, bridged across the green and red line conductors. From this it is seen that every receiver experiences the same ac signal produced by the transmitters so that the circuit is sidetone neutral -- a good performance characteristic.

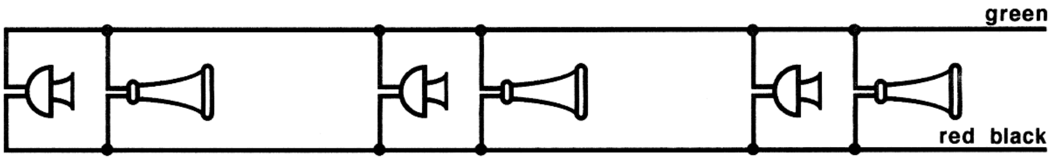

Fig. 22-17. Alternating current (ac) equivalent of the 3-wire intercom circuit showing effective parallel connection of receivers and transmitters

Conventional telephone cable with four conductors (black, green, red, and yellow) is ideal for hooking up this intercom circuit, and the extra conductor (yellow) can be used for signaling. If 6-volt buzzers or bells are used, the 6-volt battery (a lantern battery is convenient) that powers the intercom can also provide power for signaling; magnetos and ringers could, of course, be used instead. Any of the desk stands or space savers described in Chapters 10 and 11 can be connected directly with this circuit, and their hook switches can be arranged to connect and disconnect the battery (polarity is unimportant). Several different arrangements for signaling and switching are possible, and a convenient configuration can be chosen as desired. Handsets alone can also be used with this circuit, making it very easy to establish good-quality local communications with a minimum of equipment.

Federal Regulations and Industry Standards

After making several decisions regarding the connection of non-Bell equipment to the public switched telephone network, the Federal Communications Commission initiated a registration program in 1975 permitting customer-provided terminal equipment (facsimile equipment, answering machines, telephones, etc.) to be directly connected to the network. Regulations governing such connections were given in Title 47 of the Code of Federal Regulations under Part 68, Connection of Terminal Equipment to the Telephone Network. In 2001, a major revision was made in Part 68 to replace the FCC registration process with an industry certification process and to streamline other parts of the regulation.[5] Technical requirements for connecting terminal equipment to the telephone network are now given in an industry standard, TIA-968-A.[6]

Several selected paragraphs from those regulations and the standard are reproduced below to point out that there are restrictions on telephones that may be connected to the public telephone network. The selected paragraphs do not constitute all of the regulations or standards that might apply, and the reader should not rely on the material presented here for legal advice.

The purpose of these regulations is stated in the opening paragraph of Part 68.

> **68.1 Purpose.**
> The purpose of the rules and regulations in this part is to provide for uniform standards for the protection of the telephone network from harms caused by the connection of terminal equipment and associated wiring thereto, and for the compatibility of hearing aids and telephones so as to ensure that persons with hearing aids have reasonable access to the telephone network.

Terminal equipment may be directly connected to the public telephone network in accordance with certain rules, one of which involves certification or an equivalent process.

> **68.102 Terminal Equipment Approval Requirement.**
> Terminal equipment must be approved in accordance with the rules and regulations in subpart C of this part, or connected through protective circuitry that is approved in accordance with the rules and regulations in subpart C.

Subpart C of Part 68 provides a detailed description of approval procedures. Protective circuitry is available in the form of plug-in modules and circuit boards for incorporation in products, such as facsimile machines and modems.

Some consideration was given to grandfathering of older equipment in the original Part 68. That consideration was carried over to Annex A of the new industry standard and subsequently modified.[7]

> **A.2 Grandfathered Terminal Equipment (other than PBX and key telephone systems) and Protective Circuitry.**
> a) All terminal equipment (other than PBX and key telephone systems) and protective circuitry of a type directly connected to the public switched telephone network and services identified in 1.1(b) as of October 17, 1977, may remain connected for life, without approval, unless subsequently modified.

Although this is the main section that deals with plain old telephones, there are other sections of Annex A that deal with telephones connected between October 17, 1977, and July 1, 1979, as well as sections that

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[5] Code of Federal Regulations, Title 47 (Telecommunication), Part 68, October 1, 2001, edition.

[6] The Telecommunications Industry Association's (TIA) standard was adopted on June 27, 2001, by the Administrative Council for Terminal Attachments (ACTA). The ACTA was established by Federal Communications Commission order, FCC 00-400, to publish technical criteria to prevent harms to the telephone network. The ACTA web site is at www.part68.org.

[7] The modification was made in September 2003 as the result of a suggestion from this author to TIA's Technical Subcommittee TR-41.9. The suggestion was based on information in this book that demonstrates compatibility from the earliest phones with the booster circuit to registered phones with the standard network circuit.

deal with PBXs, key telephone systems, data channels, etc. More importantly, the recent modification of Annex A clearly defines the language in these sections.

> In this Annex, the phrase "may remain connected for life" means that grandfathered [terminal equipment] may remain connected, or be moved or reconnected at the same or different premises, for the life of the equipment. The phrase "unless subsequently modified" is not intended to limit routine repairs that restore [terminal equipment] to the same functional operation and specifications it had prior to the failure that resulted in the repair operation. Instead, the phrase "unless subsequently modified" is intended to cause grandfathered status to be lost if:
>
> - Components are replaced during a repair operation with components that are not comparable to the original ones;
> - Changes are made to the equipment that affect the characteristics of that equipment at the network interface;
> - Modifications significantly change the function(s) of the original equipment.

The original FCC list of grandfathered equipment was considerable and included: Western Electric 200-series desk stands with anti-sidetone subsets, and 300-type and 500-type telephones; Automatic Electric types 34, 35, 40, 50, 80, and 90 telephones; Kellogg 900, 1000, K500, and 500-type telephones; and Stromberg-Carlson 1243, 1543, and 500-type telephones. Telephones that continued to be manufactured after the registration program began were then registered, and telephones that are manufactured now are certified.

On-hook impedance limitations are defined in Section 4.7 of the industry standard, and they are unchanged from the old Part 68. Those limitations address the properties of a ringer and its associated condenser, because a ringer and condenser are always connected to the line even when the receiver is on the switch hook. For the standard ring frequency of 20 cycles per second, Table 4.12 in this part of the standard specifies that the impedance between the tip and ring sides of the line should not be less than 1,400 ohms. A ringer equivalence number (REN) is defined as 5 times this minimum value of 1,400 ohms (i.e., 7,000 ohms) divided by the measured impedance between the tip and ring terminals of a phone.

$$\text{REN} = 7{,}000 \text{ ohms} / (\text{impedance of ringer and condenser})$$

Measured REN values for a number of telephones that predate the FCC registration requirement are given in Table 22-1. Ringer coil resistance and condenser capacitance have been shown to identify the particular ringer and condenser combination that was measured, because a variety of coils and condensers were used in some of these phones. Additional information on ringer design is given in Chapter 6.

Notice that the measured REN for a Western Electric 500-type phone is listed as 0.9. This is the average of measurements that ranged from 0.78 to 0.95 for 15 different phones. To account for such a range of manufacturing variances, one would round this number up to 1.0 to capture the phones with smaller impedances. In fact, this phone continued to be manufactured after registration requirements became effective and the manufacturer’s label shows a ringer equivalence of 1.0A on later production runs. The letter “A,” which follows the REN on a registration or certification label, indicates the ringing type (in this case 20 ± 3 cycles per second) that is found in Row A of the table in the new standard or the old regulation. More recent Western Electric 2554, Princess, and Trimline phones with M-type and P-type ringers also have registered RENs of 1.0A.

Table 22-1. Measured ringer equivalence number (REN) for some telephones that predate FCC registration requirements

Telephone	Ringer	Coil ohms (dc)	Condenser[a] microfarads	REN
Western Electric No. 317[b]	38A	1,000[c]	1	1.4
Western Electric No. 534A and 634A subsets	8A	1,400[c]	1	1.6
Western Electric No. 584A and 684A subsets	78A	1,500[c]	1	1.6
Western Electric No. 417[b]	53B	2,500[c]	1	0.9
Western Electric 300 type and "...B" subsets	B-type	4,500[c]	0.5	0.8
Western Electric 500, 554, 1500, and 2500	C-type	3,650	0.5	0.9
Automatic Electric Types 34, 35, 40, and 50	AS-80	1,400[c]	1	1.5
Automatic Electric Types 80 and 90	ASL	4,000[c]	0.4	0.7
Kellogg No. 1000	BA	4,000[c]	0.5	0.8
	(alternate hookup, 1-microfarad condenser, REN=1.3)			
Stromberg-Carlson No. 1222 and 1243	61-A	2,000[c,d]	1	1.4

[a] All measurements were made with a standard 1.00, 0.40, or 0.50 microfarad condenser.

[b] Local-battery phone with ringer condenser for connecting to common-battery line.

[c] Ringer has two coils, each with half of this resistance (often marked on coil wrapper).

[d] Measured value. Listed in catalogs as 1,800 ohm. All other measurements agree with listings.

The standard, and the old regulation, also say that the sum of all such ringer equivalences on a line shall not exceed 5 (hence, total impedance not less than 1,400 ohms), but it goes on to say that a system with a total ringer equivalence of 5 may not be usable on a given telephone line or loop.

Each piece of registered or certified equipment is required to carry a label. On earlier registered equipment, the label includes a line that says, for example, Ringer Equivalence 1.0A or Ringer Equivalence 0.8A. On newer certified equipment, the label includes a product identifier in the format of US:AAAEQ##TXXXX, where ##T are the ringer equivalence numbers (without a decimal point) and the ringing type letter designator. For example, a ringer equivalence of 1.0A would be shown in this code as 10A, and a ringer equivalence of 0.8A would be shown as 08A.

Recent revisions of Part 68 include a new paragraph on customer premises wiring for telephone installations.

> **68.213(c) Material Requirements.** (1) For new installations and modifications to existing installations, copper conductors shall be, at a minimum, solid, 24 gauge or larger, twisted pairs that comply with the electrical specifications for Category 3, as defined in the ANSI EIA/ITA Building Wiring Standards.

Category 3 cable consists of twisted pairs (usually 4 pairs) of insulated solid copper wire with 3 twists per foot.[8] This is an interesting change inasmuch as the use of non-twisted pairs, such as found in cables commonly sold in hardware stores, results in considerable cross-talk between lines. This cross-talk is especially noticeable when a computer is being used on one line.

Paragraph 68.216 of the old regulation described restrictions on who could repair registered equipment. That paragraph has been removed from the current regulation and was not transferred to the new standard.

Finally, paragraph 68.213 (b) of the revised regulation states that “All plugs and jacks used in connection with inside wiring shall conform to the published criteria of the Administrative Council for Terminal Attachments.” Section 6 of the new standard contains detailed drawings and electrical configurations for standard modular connectors like the RJ11 line-cord connector used on typical modern telephones. These specifications were previously in Part 68 of the old regulation.

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[8] Category 5 and 5E, with at least 8 twists per foot, has even better performance and has become the recognized standard for broadband services.

Appendix
Fundamentals and Conventions

A few fundamental principles of physics are utilized in the text, and certain conventional symbols and names are employed in the descriptions and illustrations. These fundamentals and conventions are summarized here for easy reference.

Conventions

Figure A-1 identifies the symbols used in the circuit diagrams. To the extent practical, early American Standard basic graphical symbols have been used.[1]

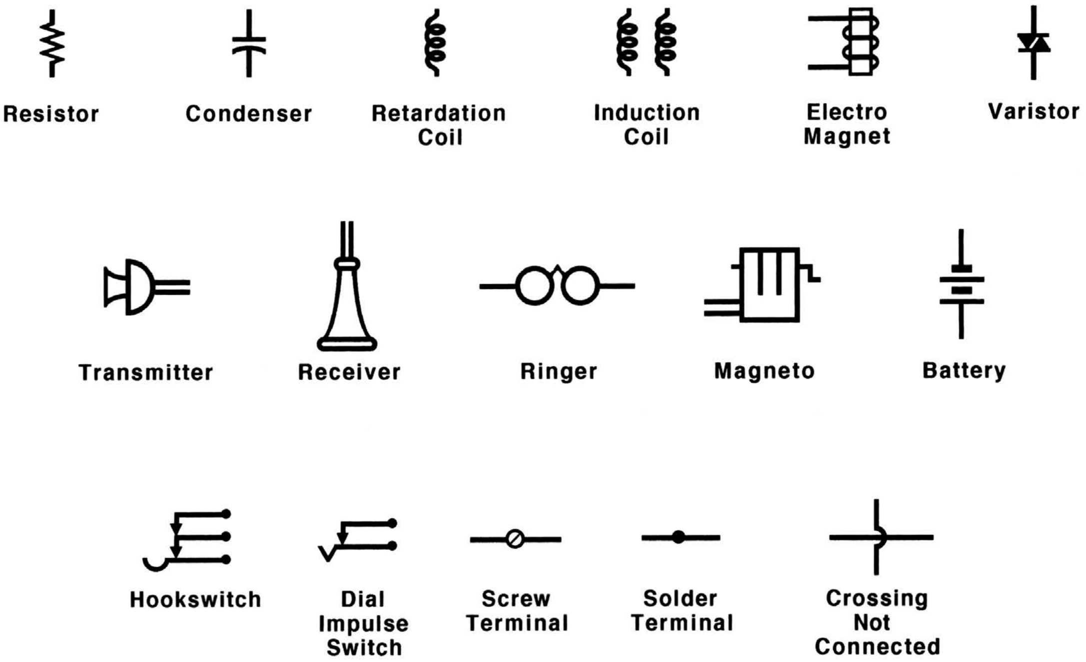

Fig. A-1. Graphical symbols used in circuit diagrams and illustrations.

Figure A-2 shows several of the wiring conventions and names that have come into common usage in the telephone business.[2] It is interesting to note that the tip side and the ring side of the line are named after features on the cord plug of a switchboard; the term ring has nothing to do with a ringer.

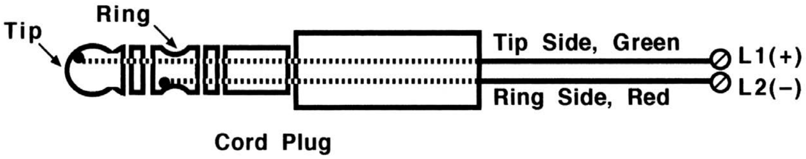

Fig. A-2. Wiring conventions showing nomenclature for a 2-wire line.

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[1] ASA Standard Z32.12, 1947.

[2] In telephone cables with two pairs (four wires) for two lines, the colors are usually green (tip), red (ring), black (tip), and yellow (ring). In cables with three or more pairs, each pair has one solid color wire and one white wire with a narrow band of the matching color. The first pair is blue and white with a blue band. The first four colors are blue, orange, green, and brown, in that order. In all pairs, the white lead with the colored band is the tip side of the line and the solid color is the ring side of the line.

Electric Current

All material is composed of atoms, and every atom contains electrons and other particles. Electrons are real things that weigh something and have an electric charge. When electrons with their electric charge move, their movement is an electric current. Electrons can move through metals easily. Nevertheless, even in metals, each atom needs to keep its assigned number of electrons nearby (29 for copper). Therefore, to get an electron out of one end of a metal wire, you have to put an electron into the other end of the wire. For this reason, electrons flow in loops or circuits to produce an electric current.

Figure A-3 illustrates a simple circuit. Here a loop of metal wire is connected to an electron pump. The pump could be a battery, a magneto, or some other generator, but it's important to realize that the pump doesn't create any electrons or destroy any electrons. It merely pulls them out of one end of the wire and pushes them into the other.

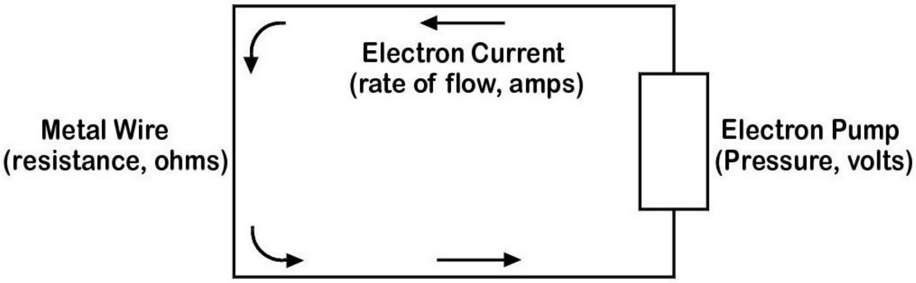

Fig. A-3. Diagram showing electrons being pushed through a loop of wire thus creating an electric current.

When electrons move in a circuit like this, their rate of flow, or current, is measured in amperes. The electron pump has a pressure, or voltage, which is measured in volts. And while electrons can move easily in metals, they can't move freely. The metal wire will offer some resistance to their movement, and this resistance is measured in ohms. Resistors are discussed below.

If the pump is a battery, the electrons will move steadily in one direction. This steady flow of electrons is called direct current (dc). If the pump is a magneto, the electrons will flow first in one direction and then go back in the other direction – repeating this cycle many times per second. This back-and-forth flow of electrons is called alternating current (ac). Of course you can have a current that always flows in one direction, but its rate of flow increases and decreases many times per second. Bell called this an undulating current. This term is not used anymore because it is easy to see that an undulating current is just a combination of a direct current and an alternating current. Suppose the undulating current went from 1 amp up to 1.1 amp, then down to 0.9 amp and back up to 1 amp – and it repeated this cycle many times per second. This undulating current is just the sum of a 1-amp direct current and an alternating current that goes from zero to +0.1 amp to -0.1 amp and back to zero many times per second.

In understanding how currents behave in telephone circuits, we can usually consider the direct currents and the alternating currents separately – almost as if the other didn't exist – because the net result is that these currents simply add together (i.e., the ac is superimposed on the dc). This separation will simplify the understanding of the telephone circuits.

Measuring Voltage and Current

A direct current, like the steady flow of water in a pipe, and a dc voltage, like water pressure, are easy to measure with an ordinary multimeter. The values recorded on the meter are simply those steady values of voltage and current.

The situation is quite different, though, for alternating current and ac voltage because those values vary up and down with time. The recorded values on the ac scales of a standard multimeter are averaged values of ac voltage and current. By using a special method of averaging, the recorded values of ac voltage and current obey many of the electrical laws, such as Ohm's law, that apply to dc voltages and currents. This special method of averaging, called the root-mean-square or rms method, is used on all standard multimeters, and special attention to this important detail is usually not needed.[3] For example, the measured household voltage of 120 volts ac is, in fact, an rms value; and a 20-ampere household fuse limits the current to 20 amperes rms.

There is, however, one commonly encountered situation where the casual use of rms values is not adequate. This situation arises when adding together individually measured ac voltages (see Adding Voltages below). Nevertheless, all of the ac voltages and currents mentioned throughout this book are assumed to be rms values, and would therefore be the same as the values measured with a meter.

Resistor

Copper is a good electrical conductor, but long lengths of thin copper wire offer substantial resistance to current flow. Other conductors, such as German silver or carbon, present higher resistances, even for shorter conducting pathways. Most components in a telephone have significant electrical resistance, and occasionally a carbon or wire resistor is intentionally put in a circuit for a particular purpose. The resistance (R) to current flow in a resistor is measured in ohms (Ω) and is the same for direct current or alternating current. A more general term for the impeding effects of any component is impedance, denoted as Z. So, for a resistor, it can be said that the impedance is a constant called the resistance,

$$Z = R \tag{1}$$

The relationship between the current (I in amperes) passing through a resistance (R in ohms) and the voltage (V in volts) developed across the resistance is known as Ohm's law. It is given by:

$$V = ZI = RI \tag{2}$$

Currents in telephone circuits are usually in the range of a few thousandths of an ampere (i.e., milliamperes or mA); ac voltages are in the range of a few thousandths of a volt (millivolts or mV), and dc voltages are usually in the range of a few volts (V).

Condenser

Condensers (also called capacitors) for telephones were made from two strips of metal foil separated by a strip of paper -- all of which was folded up and put in a can for protection. Although an electrical current cannot actually go through a condenser, the foil strips (or plates, as they are called) have the capacity to store electrical charge when a voltage is applied to them. Thus, when a voltage is applied, a momentary current will flow to the condenser plates while they are accumulating their electric charge; and when the voltage is removed or reversed, a momentary current will flow in the other direction. Although no current flows across the gap from one plate to the other, this back-

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[3] For a pure sine wave voltage or current, the rms value is simply ½ the peak-to-peak value divided by 1.414 (the square root of 2).

and-forth charging-and-discharging current is in all respects equivalent to an alternating current. Hence, a condenser can be used to conduct ac, but it will not conduct dc. Current flows more easily through a condenser at high frequencies than at low frequencies -- and not at all at zero frequency, i.e., dc.

The impedance to current flow in an ideal condenser (one with zero resistance in the metal foil) is given by:[4]

$$Z = 1/(2\pi fC) \tag{3}$$

where Z is again in ohms, $\pi = 3.14$, f is the frequency (cycles per second), and C is the capacitance (in farads or F). This inverse relationship between impedance and frequency describes an impedance that is large at low frequencies and gets smaller at higher frequencies. And, as seen from Equation 3, the impedance of a condenser of any size to direct current ($f = 0$) is infinite;

$$Z = 1 \div (2 \times 3.14 \times 0 \times C) = 1 \div 0 = \infty$$

Condensers are therefore frequently used in telephone circuits to block the flow of dc, while passing the flow of an ac signal. A typical telephone condenser used for this purpose has a capacitance of one millionth of a farad (microfarad or μF). Again using Equation 3, the impedance of a 1-microfarad ideal condenser at 1,000 cycles per second (a typical voice frequency) is:

$$Z = 1 \div (2 \times 3.14 \times 1{,}000 \times 0.000001) = 159 \text{ ohms}$$

This is a relatively low impedance that quite readily passes ac voice signals. A 1-microfarad condenser is also often used in the ringer circuit, so its impedance at 20 cycles per second (typical ring frequency) is of interest. For this case, Equation 3 gives:

$$Z = 1 \div (2 \times 3.14 \times 20 \times 0.000001) = 7{,}960 \text{ ohms}$$

This value is used in Chapter 6, where the significance of pairing a 1-microfarad condenser with a typical ringer is discussed. The metal foil in a real condenser contributes an additional resistive impedance to the total impedance of a condenser. This resistive impedance, which is frequency dependent, is on the order of ⅓ of the ideal impedance (Equation 3), but the resistive impedance does not add that much to the total because of phase relationships.

Ohm's law relating the voltage across an ideal condenser to the current in it is thus:

$$V = ZI$$

or

$$V = I/(2\pi fC) \tag{4}$$

where V and I are rms values.

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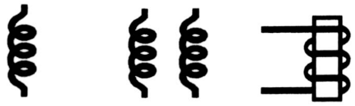
[4] In the following equations we will interchangeably use the symbols / or ÷ for division, and either indicate multiplication by putting the two quantities side-by-side, such as ZI, or writing Z x I.

Coil

A tightly wound coil of wire impedes the flow of alternating current far more than does the dc resistance of the wire with which the coil is wound. This happens because the varying magnetic field produced by the alternating current induces opposing voltages in all the coil windings that feel the magnetic field, including the winding that is producing the magnetic field.

Three types of coils are used in telephone circuits. The first type has a single winding around a core of iron wires, strips, or laminated plates -- this type is used as a retardation coil. The second type has two or more such windings and is used as an induction coil or a repeating coil (these coils are actually transformers). The third type has a single winding around a solid iron core, and is used as an electromagnet in telephone receivers and ringers.



All of these coils have an impedance to ac current flow that is larger at high frequencies than at low frequencies. The impedance of an ideal coil (one with zero resistance in the coil wire) is given by:

$$Z = 2\pi fL \qquad (5)$$

where L is the inductance (in henrys or H), $\pi = 3.14$, and f is the frequency (cycles per second) as before. It can be seen from the following equation that an ideal coil will offer no impedance to the flow of direct current ($f = 0$);

$$Z = 2 \times 3.14 \times 0 \times L = 0$$

Coils, therefore, can be used to block ac signals while passing dc. This property is opposite that of a condenser.[5]

The relation between the voltage across an ideal coil and the current through it is again given by Ohm's law,

$$V = ZI$$

or

$$V = 2\pi fLI \qquad (6)$$

In reality, coils are made of long lengths of fine wire so the impedance of a real coil is a combination of its inductive impedance (Equation 6) and its resistive impedance. The impedance at 1,000 cycles per second of typical coils used in telephones varies from low values around 200 ohms for coils in receivers to over 100,000 ohms for ringer coils.

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[5] The symmetry of these three basic electrical components is worth noting. One (the resistor) has an impedance that is constant, independent of frequency, and will thus affect ac and dc alike. One (the condenser) has an impedance that is inversely proportional to frequency and can be used to block dc while passing ac. And one (the coil) has an impedance that is directly proportional to frequency and can be used to block ac while passing dc. These unique properties form the basis of much ac circuit design.

Varistor

Semiconducting materials (such as copper oxide and silicon carbide) have a variable resistance, unlike the constant resistance of a metal or carbon. Varistors are variable resistors made from these semiconductors, and their electrical properties are determined by the relationship between voltage and current (Bennett 1953; Dienel 1956). Figure A-4 shows voltage versus current for a frequently used Western Electric No. 312D varistor and, for comparison, a common 300-ohm resistor.[6]

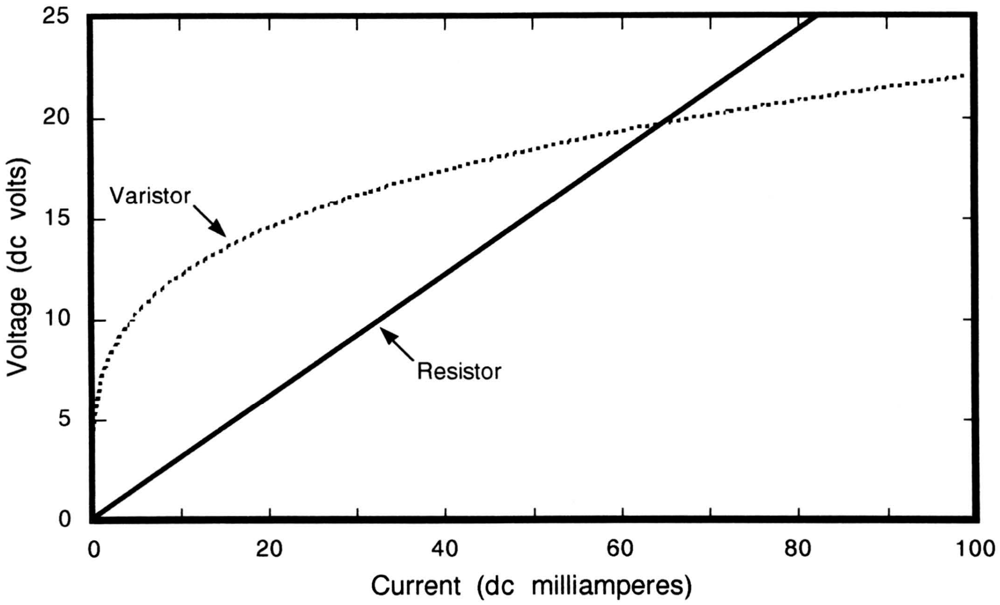

Fig. A-4. Voltage as a function of current through a typical varistor (Western Electric No. 312D) and a typical resistor (300 ohms).

Using Ohm's law, the resistance of either the varistor or the resistor can be calculated from such a figure:

$$R = V/I$$

The varistor is seen to have a high resistance at low voltage and low current, whereas its resistance decreases to a low value at high voltage and high current.[7] The resistor, on the other hand, is seen to have the same resistance for all voltages and currents.

One use of varistors in telephone circuits is to control a small ac current that is superimposed on a large dc current. In those applications, the resistance seen by the small ac current is the extra voltage divided by the extra current relative to the dc voltage established by the direct current. In other words, the ac resistance in this application is the slope of the voltage-versus-current curve at the point on that curve established by the direct current. Suppose, for example, that the dc current through the varistor were about 63 millamperes, where the two curves cross in Fig. A-4. You can see that the slope of the dashed curve (the ac resistance) at that point is less than the ratio of voltage to current (the dc resistance) at that point. More importantly,

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[6] Figures A-4 and A-5 are based on data from Bennett (1953) for the 312D and 312E varistors, and the data are in agreement with the author's measurements. Figure A-6 for the 44A and 104A varistors is based on the author's measurements.

[7] This symmetric behavior -- independent of polarity -- is like that of two diodes, of opposite polarity, connected in parallel, and the graphical symbol for a varistor has that appearance (see Fig. A-1).

however, this ac resistance can be controlled by adjusting the dc voltage across the varistor, and this gives the circuit designer important new flexibility.

The ac resistance versus dc voltage is shown in Fig. A-5 for two commonly used Western Electric silicon carbide telephone varistors. In the 425B network circuit (and all later circuits) described in Chapter 19, the No. 312E varistor operates in the range of about 3 to 8 volts whereas the No. 312D varistor operates in the range of approximately 5 to 15 volts. These two varistors are similar in outward appearance, having the shape of a wafer, and are about ¾ inch in diameter.

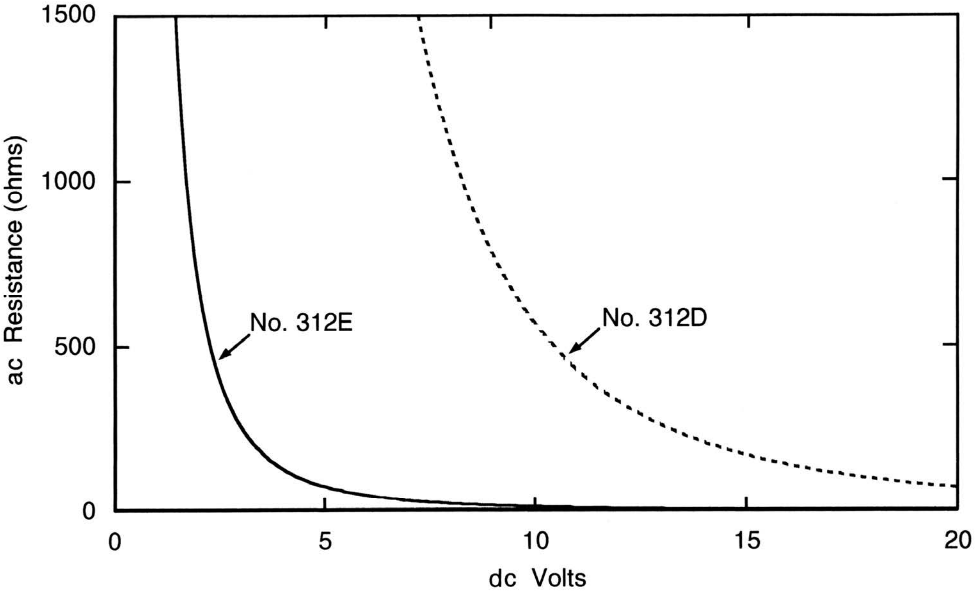

Fig. A-5. Resistance (ac) as a function of voltage (dc) for the Western Electric varistors in the standard network circuit.

A second important use of varistors in telephone applications is to shunt high-voltage noise pulses (e.g., hook switch clicks) around the receiver. In this application, no direct current flows through the varistor, so its ac and dc resistances are the same. Figure A-6 shows the resistance versus voltage for the early low-voltage Western Electric No. 44A copper oxide varistor and a later No. 104A germanium varistor used for this purpose. Normal signal levels at the receiver are on the order of 50 to 100 millivolts (0.05 to 0.1 volts). At those levels, the varistor's resistance is much higher than the impedance of the receiver (145 ohms at 1,000 cycles per second for the U1 receiver), forcing nearly all of the signal to go through the receiver. For noise pulses greater than 300 to 400 millivolts (0.3 to 0.4 volts), however, the varistor's resistance is lower than the receiver's, providing an effective shunt around it. The No. 44A varistor is in a metal pill-box enclosure about ⅝ inch in diameter and ¼ inch in thickness.

Unfortunately for Western Electric, the No. 44A varistor could only be successfully made with copper oxide from a mine in the Chilean Andes, and that ore was being rapidly depleted (Michal 1960). Consequently, the Bell Laboratories developed a low-voltage varistor out of silicon. In the early 1960s, the copper oxide varistor was replaced with the No. 100A silicon varistor. In the late 1960s, this was replaced by the No. 104A germanium varistor, whose properties are shown in Fig. A-6. This new varistor was not only cheaper to manufacture, but it also had better performance than the No. 44A, with its lower voltage cutoff. The 100A and 104A varistors were encapsulated in a phenolic resin and look about like a low-wattage resistor (plain green or black with no color bands).

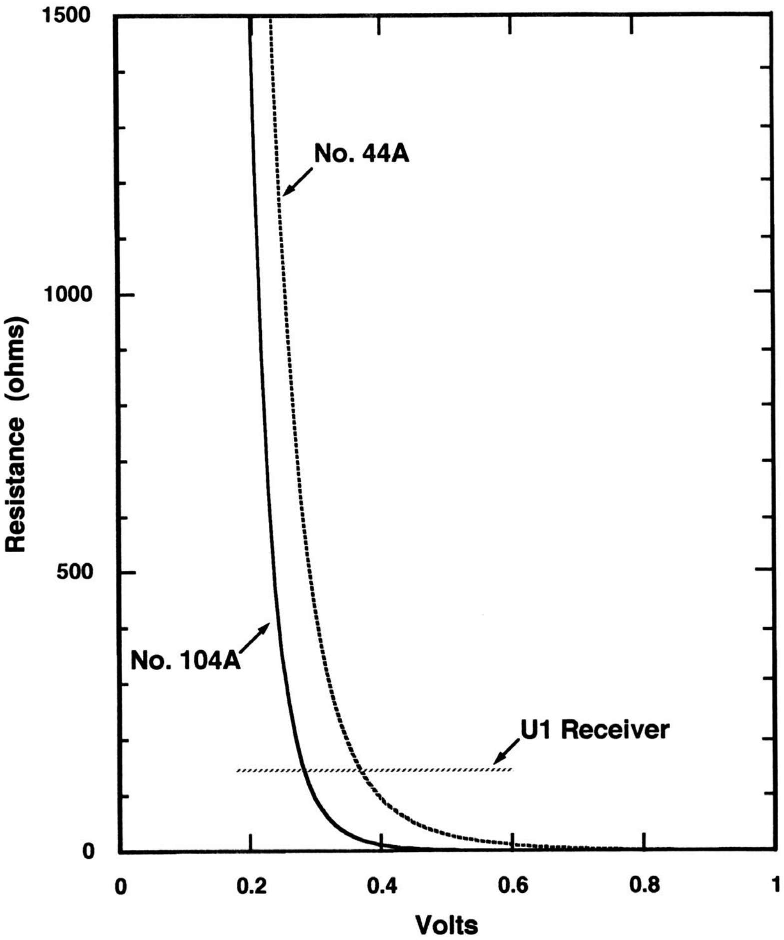

Fig. A-6. Resistance as a function of voltage for the Western Electric No. 44A and 104A varistors used to shunt noise pulses around the receiver.

Subsequently, a whole family of 100-type varistors was produced with different cutoff voltages. The 100D (yellow band) and 100E (green band) varistors used in touchtone oscillators are nearly identical and have resistance-versus-voltage curves similar to the 104A shown in Fig. A-6, except that the curves are shifted about 0.4 volts to the right (cutoff around 0.6 volts). The 100-type varistor used as a shunt around light-emitting diodes (LEDs) has properties similar to the No. 312E (cutoff around 2½ volts).

Transformer

Two or more coils of wire wound on the same core will act as a transformer. An alternating current passing through one coil will induce an ac voltage in the others, whereas a direct current passing through one coil will not induce any voltages in the other coils. Each coil of a transformer will have an inductance and impedance. However, as long as the impedances are quite large (and this is the way transformers are designed), the actual values of the inductance and impedance do not enter into the important properties of a transformer.

Because the magnetic fields that couple together the coils of a transformer depend largely on coil geometry, the transformer properties of most interest turn out to depend only on the number of turns of wire in each coil winding. Thus, for a typical two-winding transformer,

$$V_1/V_2 = N_1/N_2$$

where V_1 and V_2 are the voltages across windings 1 and 2, respectively, and N_1 and N_2 are the number of turns of wire in windings 1 and 2. Alternatively, this can be written as:

$$V_1 = (N_1/N_2)V_2 \tag{7}$$

Hence, if winding 1 has 10 times as many turns of wire as winding 2 ($N_1/N_2 = 10$), and winding 1 is hooked up to a 120-volt household circuit, then:

$$120 = 10 \text{ x } V_2$$

or

$$V_2 = 12 \text{ volts}$$

This, of course, would describe a common doorbell transformer.

Similarly, the currents in windings 1 and 2 are inversely related to the turns ratio,

$$I_1/I_2 = N_2/N_1$$

or

$$I_1 = (N_2/N_1)I_2 \tag{8}$$

Thus, in the doorbell transformer example above, the current in winding 2 would be 10 times greater than the current in winding 1. Although the transformer has stepped down the voltage, it has stepped up the current.[8]

Next consider the circuit in Fig. A-7, where a resistor (R_2) has been connected across winding 2 of a transformer. It is now possible to get an equation that describes the equivalent resistance of the transformer and R_2 taken together as a single unit. Using Ohm's law ($V_2 = R_2I_2$) and Equations 7 and 8 (for V_2 and I_2), it is found that:

$$V_1 = (N_1/N_2)^2R_2I_1$$

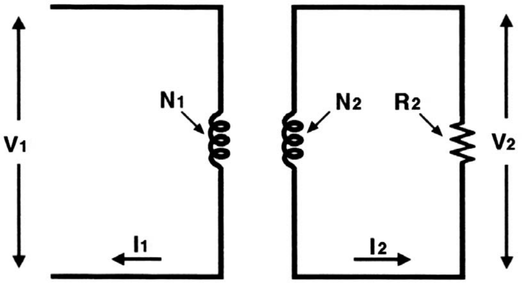

Fig. A-7. Transformer with a voltage imposed across winding No. 1 and a resistor connected across winding No. 2 to demonstrate the effect of turns ratio on apparent resistance.

Comparing this directly with Ohm's law ($V_1 = R_1I_1$), it is apparent that:

$$R_1 = (N_1/N_2)^2R_2 \tag{9}$$

That is, the transformer and resistor R_2 together are behaving as if they were a resistor of resistance R_1 connected directly where winding 1 is connected.

The significance of Equation 9 can be illustrated as follows. Suppose that the transformer in Fig. A-7 is an induction coil of a local-battery circuit with a turns ratio of 4 (see Table 15-1). Also suppose that R_2 has a resistance of 800 ohms, which is roughly the impedance of a medium-loaded local-battery line

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[8] Notice that the power (in watts), which is given by multiplying the voltage times the current, is the same in winding 1 and winding 2: $V_1I_1 = V_2(N_1/N_2)I_2(N_2/N_1) = V_2I_2$ This result, which is obtained with the aid of Equations 7 and 8, is expected on the basis of conservation of energy.

with talking between two phones.[9] Then the apparent impedance of the line, as seen by the transmitter of the transmitting phone, would be:

$$R_1 = (1 \div 4)^2 \text{ x } 800 = 50 \text{ ohms}$$

This value is equal to the impedance of a typical early transmitter, and the impedances are said to be matched. Thus, the transformer (induction coil) is also used to match impedances, the importance of which is described in the following section.

Matching Impedances

To demonstrate the advantage of matching the impedance of a transmitter with that of its load, three cases are considered to determine the amount of power delivered to the load, for this will determine how effective the circuit is. The load (i.e., the receiver in the transmitting phone plus the line and the phones on the line) in these examples is replaced by a resistor to make the calculations easier, and the resistor is given a different value in each case to illustrate the point.

In all cases, it is assumed that the transmitter has an average resistance of 50 ohms that varies by ±15 percent because of sound waves (i.e., from 42.5 ohms to 57.5 ohms) and that an average transmitter current of 60 milliamperes is maintained. These are typical values for an early transmitter in a local-battery phone. Increases and decreases in current, which result from the variation in resistance of the transmitter, will be considered to be an alternating current added to a 60-milliampere direct current. The three cases are shown in Fig. A-8. Case A has a resistance of 500 ohms. Case B has a resistance one-tenth of this value (i.e., 50 ohms), which happens to be equal to the resistance of the transmitter. Case C has a resistance of only one-tenth of that value (i.e., 5 ohms). Ohm's law (V = RI) is used repeatedly in these calculations.

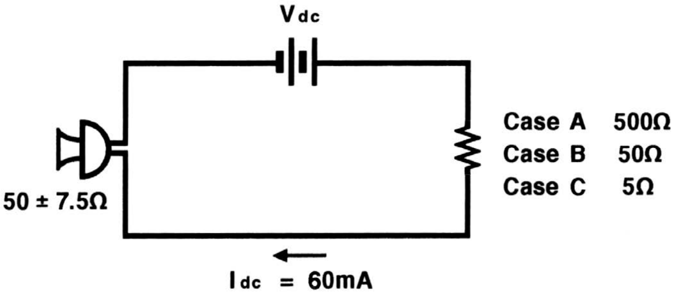

Fig. A-8. Circuit showing three cases that are used to demonstrate the benefit of matching impedances.

<u>Case A (500-ohm resistor)</u>

The dc voltage required to maintain an average 60-milliampere dc current is:

$$V_{dc} = (50 \text{ ohms} + 500 \text{ ohms}) \text{ x } 0.060 \text{ ampere} = 33 \text{ volts}$$

The maximum current occurs when the carbon granules in the transmitter are compressed and the transmitter resistance is lowest;

$$I_{max} = 33 \text{ volts} \div (42.5 \text{ ohms} + 500 \text{ ohms}) = 60.83 \text{ milliamperes}$$

The minimum current occurs when the carbon granules in the transmitter are decompressed and the transmitter resistance is highest;

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[9] Consider a local-battery line with 20 Western Electric No. 317 magneto wall phones and 200 ohms line resistance (a medium-loaded line). The transmitter circuit of the talking phone will see its own receiver, 200 ohms line resistance, the receiver and transmitter circuit of the receiving phone, and 20 ringers in parallel across the line. The combined impedance of this network is approximately 970 ohms with a phase angle of 29 degrees.

$$I_{min} = 33 \text{ volts} \div (57.5 \text{ ohms} + 500 \text{ ohms}) = 59.19 \text{ milliamperes}$$

The peak-to-peak variation of the ac component is then:

$$I_{p\text{-}p} = 60.83 - 59.19 = 1.64 \text{ milliamperes,}$$

and the root-mean-square alternating current is:

$$I_{ac} = \tfrac{1}{2} \times 1.64 \text{ milliamperes} \div 1.414 = 0.58 \text{ milliampere}$$

The rms ac voltage across the 500-ohm resistor is:

$$V_{ac} = 0.58 \text{ milliampere} \times 500 \text{ ohms} = 290 \text{ millivolts}$$

Finally, the ac power delivered to the 500-ohm resistor is:

$$P_{ac} = V_{ac}I_{ac} = 0.290 \text{ volt} \times 0.00058 \text{ ampere} = 0.00017 \text{ watt} = 0.17 \text{ milliwatt}$$

<u>Case B (50-ohm resistor)</u>

$$V_{dc} = (50 + 50) \times 0.060 = 6.0 \text{ volts}$$
$$I_{max} = 6.0 \div (42.5 + 50) = 64.86 \text{ milliamperes}$$
$$I_{min} = 6.0 \div (57.5 + 50) = 55.81 \text{ milliamperes}$$
$$I_{p\text{-}p} = 64.86 - 55.81 = 9.05 \text{ milliamperes}$$
$$I_{ac} = \tfrac{1}{2} \times 9.05 \div 1.414 = 3.20 \text{ milliamperes}$$
$$V_{ac} = 50 \times 3.20 = 160 \text{ millivolts}$$
$$P_{ac} = 0.160 \times 0.00320 = 0.51 \text{ milliwatt}$$

<u>Case C (5-ohm resistor)</u>

$$V_{dc} = (50 + 5) \times 0.060 = 3.3 \text{ volts}$$
$$I_{max} = 3.3 \div (42.5 + 5) = 69.47 \text{ milliamperes}$$
$$I_{min} = 3.3 \div (57.5 + 5) = 52.80 \text{ milliamperes}$$
$$I_{p\text{-}p} = 69.47 - 52.80 = 16.67 \text{ milliamperes}$$
$$I_{ac} = \tfrac{1}{2} \times 16.67 \div 1.414 = 5.89 \text{ milliamperes}$$
$$V_{ac} = 5 \times 5.89 = 29 \text{ millivolts}$$
$$P_{ac} = 0.029 \times 0.00589 = 0.17 \text{ milliwatt}$$

Notice that each time the resistance R was reduced (from 500 to 50 to 5 ohms), the talking current I_{ac} increased (from 0.58 to 3.20 to 5.89 milliamperes), but the voltage V_{ac} decreased (from 290 to 160 to 29 millivolts). However, the power delivered to the load resistor did not continue to increase as the current increased, but it reached a maximum value of 0.51 milliwatt (three times that of the other cases!) when the resistance of the load equaled the resistance of the transmitter (50 ohms). This is an important general result that can be shown mathematically: maximum power is delivered when the impedance of the source and the impedance of the load are matched.

Adding Voltages

There is one significant limitation to interpreting measured ac voltages: the voltages will not appear to add up correctly, as illustrated by the following example. In Fig. A-9, a 100-ohm resistor, a 1-microfarad

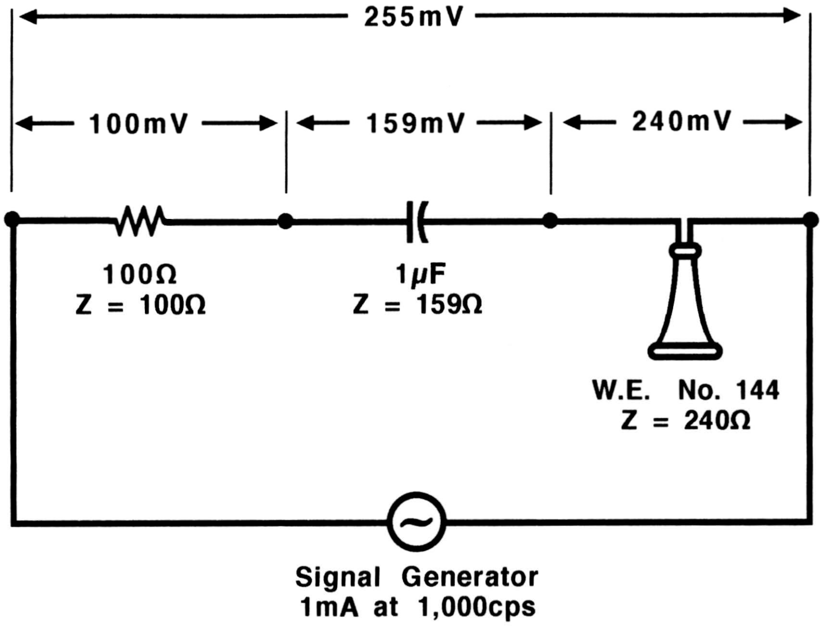

Fig. A-9. Example of measured ac voltages that do not add together to give the measured total.

condenser, and a Western Electric No. 144 receiver have been connected in series and hooked up to a signal generator producing a current of 1 milliampere at 1,000 cycles per second. The impedance of the resistor is, of course, 100 ohms at any frequency. The impedance of a 1-microfarad condenser at 1,000 cycles per second was found from Equation 3 to be 159 ohms. The impedance of the receiver at 1,000 cycles per second is found from Table 3-1 of Chapter 3 to be 240 ohms. Using Ohm's law, V = ZI where I is now 1 milliampere, the voltages across these components separately are 100, 159, and 240 millivolts, respectively; these are the voltages that would be measured with a multimeter. However, the voltage that would be measured across all three of these components together is 255 millivolts, and this value is far less than the sum of the individual values (100 + 159 + 240 = 499).

The explanation for this apparent discrepancy is that, at any instant of time, the voltage across the condenser might be increasing while the voltage across the receiver is decreasing; they are out of phase. The net result is that portions of these voltages tend to subtract from (cancel) each other, rather than always adding together. Complete analysis of such instantaneous voltages can of course be done, but this requires the use of trigonometry, which will not be called upon here.

Wheatstone Bridge

A clever circuit arrangement that bears the name of Charles Wheatstone is often used in electrical measurement instruments, and it is also used in several important telephone circuits.[10] The typical Wheatstone bridge circuit for measuring an unknown resistance is shown in Fig. A-10. In this circuit, R_1 and R_2 are fixed resistors of known value, R_V is a calibrated variable resistor, and R_X is a resistor of unknown

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[10] This is the same Charles Wheatstone who, along with William Cooke, developed the first practical telegraph. Ironically, Wheatstone who deserves much of the credit for inventing the telegraph -- but did not get it because of history's recognition of Morse -- is remembered for the bridge circuit, which he did not invent nor attempt to claim credit for. The bridge circuit was put forward by a colleague named Christie, and Wheatstone publicized Christie's bridge giving him proper credit. The acknowledgment apparently did not register with the public. See Hubbard (1965, 98).

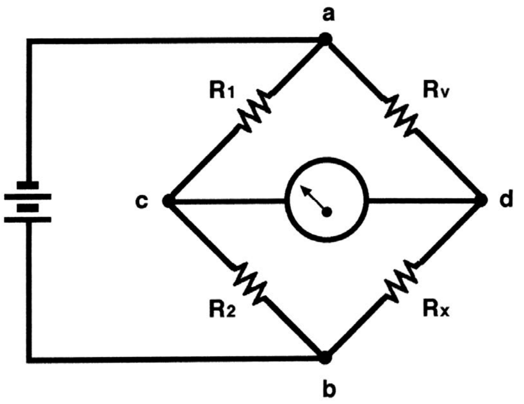

Fig. A-10. Wheatstone bridge circuit for measuring the value of an unknown resistance.

value. If R_V is adjusted until the voltage from c to d is zero (in which case no current flows through the meter), the bridge is said to be balanced. The unknown resistance can then be calculated from the other known resistances using Ohm's law.[11]

The important point for telephone applications is that five components can be arranged in a diamond-shaped pattern like Fig. A-10 such that a current flows from a to b through c, and another current flows from a to b through d, but no current flows from c to d (i.e., the voltage between c and d is zero). The bridge is balanced when $V_{ac} = V_{ad}$ and $V_{cb} = V_{db}$, where V_{ac} is the voltage across R_1, etc. In the telephone circuits of interest, the receiver is connected to c and d (where the meter is located in Fig. A-9), and the other components are coils and resistors.

The usefulness of this bridge circuit in telephone applications is shown in Chapters 16 and 18, where two bridge circuits are described. In both cases, the bridge is balanced under one set of conditions (thus, no current flows through the receiver), whereas under other conditions the bridge is unbalanced and current flows through the receiver, as desired.

Magnetism

All materials are composed of atoms, and every atom behaves like a small permanent magnet with a north pole and a south pole. Most of these atomic magnets are extremely small, but the atomic magnets in iron and some other similar metals are relatively large. If all of these atomic magnets were to line up with each other in a piece of iron, it would be a powerful permanent magnet. But aligned atomic magnets in iron exist in small clusters or domains, which are oriented randomly, so a piece of iron is not a permanent magnet.[12]

However, if a piece of iron is placed near a permanent magnet or an electromagnet, the boundaries between adjacent magnetic domains move such that the domains that are aligned with the magnetic field of the nearby magnet grow and the domains that are not aligned shrink. Thus the piece of iron becomes magnetized with its polarity like that of the nearby magnet. And the stronger the nearby magnet, the more the domain walls will move and increase the strength of magnetism in the piece of iron.

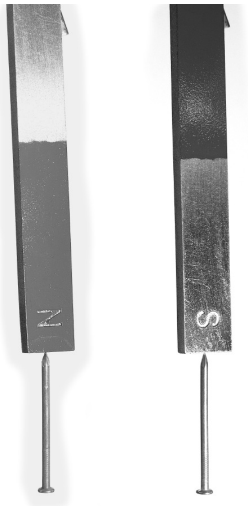

Fig. A-11. An iron nail is attracted to the north pole and to the south pole of a permanent magnet.

Suppose an iron nail is brought close to the north pole of a permanent magnet as shown on the left side of Fig. A-11. The nail becomes magnetized with its south pole up and its north pole down, just like the permanent magnet. Since opposites attract, the south pole of the nail is attracted to the north pole of the permanent magnet. When the permanent magnet is turned around, the domain walls in the iron nail move quickly

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[11] The result is $R_X = R_V(R_2/R_1)$, but this result is incidental to the value of this circuit in telephone applications.

[12] Additional information on magnetism, magnetic domains, and magnetostriction (Page effect mentioned in Chapters 1 and 3) can be found in Wert and Thomson (1964).

to establish a new magnetic field in the nail with its north pole at the top (see the right side of Fig. A-11).

Magnetic domains are large enough to be seen under a microscope, and microscopic precipitates, such as carbon in iron, will impede domain wall motion. Materials that have such precipitates or other defects that impede wall motion are called magnetically hard materials, and the precipitates and defects are the same things that make materials metallurgically hard (e.g., high-carbon tool steel). On the other hand, magnetically soft materials have domain walls that can move rather easily, and these materials are also metallurgically soft (e.g., pure malleable iron).

Some domain wall movement can be forced in magnetically hard material by exposing it to a very strong external magnetic field. When this field is removed, the domain walls cannot move back because of the impediments, and the material becomes a permanent magnet. If a magnetically soft material were exposed to this same external magnetic field, and the field were then removed, the soft material's domain walls would move back to their original position and the material would no longer be magnetized.

The important thing to remember is that magnetically soft material is very compliant; it will obediently become magnetized in the presence of an external magnetic field, and it can quickly change its polarity or become un-magnetized if that's what the external field does. Magnetically soft materials are therefore used for cores of electromagnetic coils and for diaphragms and armatures. Magnetically hard materials, on the other hand, are stubborn; their magnetization can only be changed by very strong external magnetic fields. Magnetically hard materials are used for permanent magnets.

Sound

Sound waves are a series of air-pressure pulses that can push and pull on a person's ear drum or on the diaphragm of a telephone transmitter. These pressure pulses have two important properties. One is amplitude (how high the pressure is in each pulse), which determines loudness. The other is frequency (how rapidly the pulses occur), which determines pitch.

Loudness of a sound wave is actually determined by the amplitude squared or the power, so measurements of loudness are usually related to the power developed by a sound wave.[13] The average power in sound waves from normal talking is about 10 microwatts (0.010 milliwatt) (Albert 1943, 105; Fagen/AT&T 1975, 944). This can be compared with power levels around 0.2 milliwatt developed in a telephone with a carbon transmitter (see the earlier section on Matching Impedances). The limitation of using sound-powered telephones, such as Bell's early inductive devices, can be seen from this comparison. Even if sound-powered transmitters converted all of the power in a sound wave into electrical power with 100% efficiency (which, of course, they cannot do), carbon transmitters can easily generate signals that are 20 times more powerful.

The frequency of a simple sound wave is quite easy to measure, but common spoken sounds or musical notes are composed of sound waves of many different frequencies mixed together. This mixture gives a sound its richness or timbre, as Bell called it. Middle C on a piano, for example, has a fundamental frequency of 256 cycles per second, but many harmonics (multiples of 256) are present in that sound. Pure tones of a single frequency are seldom heard in practice, but pure tones can be generated in some standard touchtone telephones by pressing two buttons simultaneously (see Chapter 21).

The notes on a piano range from 26⅔ cycles per second to 4,096 cycles per second, although higher harmonics are present in the tones (Miller 1930, 121). Most people can perceive frequencies from about 20 cycles per second to 20,000 cycles per second, although young people can often hear frequencies around 30,000 cycles per second. Spoken sounds generally contain larger mixtures of frequencies than do musical

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[13] In practice, measurements of one sound level are made by comparison with some reference sound level using a loudness scale that was named after Alexander Graham Bell. The loudness unit was originally called the bel, but numerical values are large and cumbersome, so a factor of 10 was inserted in the definition. The resulting unit is called the decibel (dB), which is defined as Loudness (dB) = 10 $\log_{10} (P/P_o)$, where P is the power (watts per square centimeter) of the sound wave in question and P_o is the power of the reference sound wave.

notes, but the range of important frequencies is smaller. Figure A-12 shows the relative magnitude of various frequency components present in the spoken letter “a,” pronounced as in tar or car (Albert 1943, 105; Fletcher 1924). Although modern high-fidelity home entertainment equipment generally reproduces frequencies from about 5 to 20,000 cycles per second so that musical sounds are reproduced well, such a wide frequency range is not necessary to transmit intelligible speech, as can be inferred from Fig. A-12. It has been found that excellent commercial telephone service is provided with a frequency range from 250 to 3,000 cycles per second.

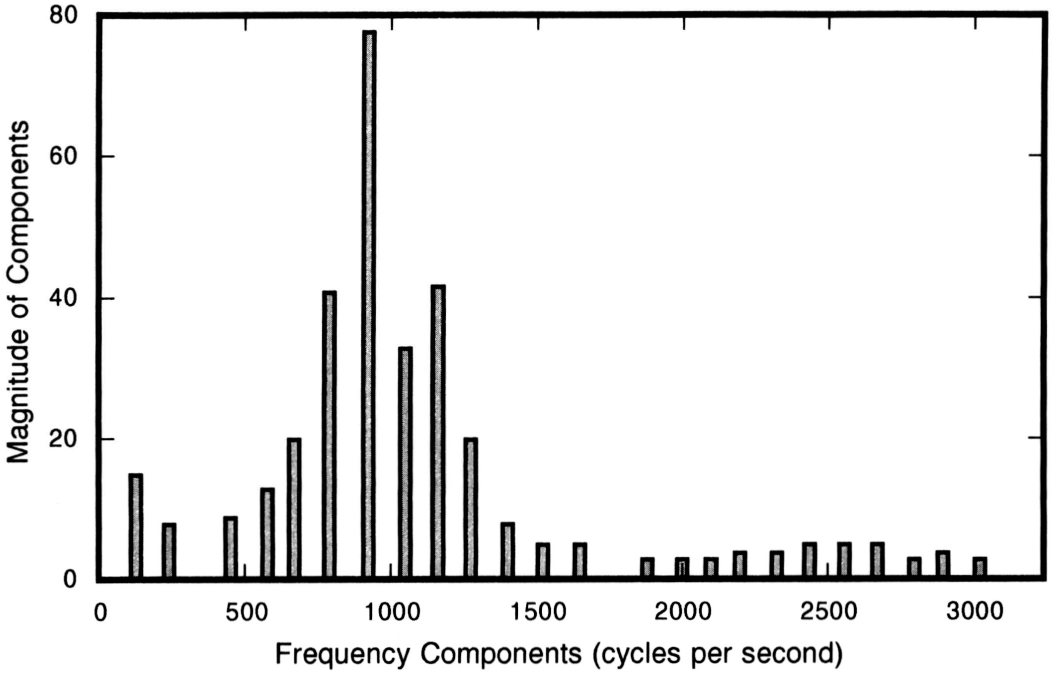

Fig. A-12. Relative magnitude of frequency components in the spoken letter "a" as in tar or car.

As a final note, 1,000 cycles per second is a nice round number that falls near the middle of the voice frequency range. Therefore, it is common practice to make measurements at this frequency when analyzing the operation of telephone components and circuits.

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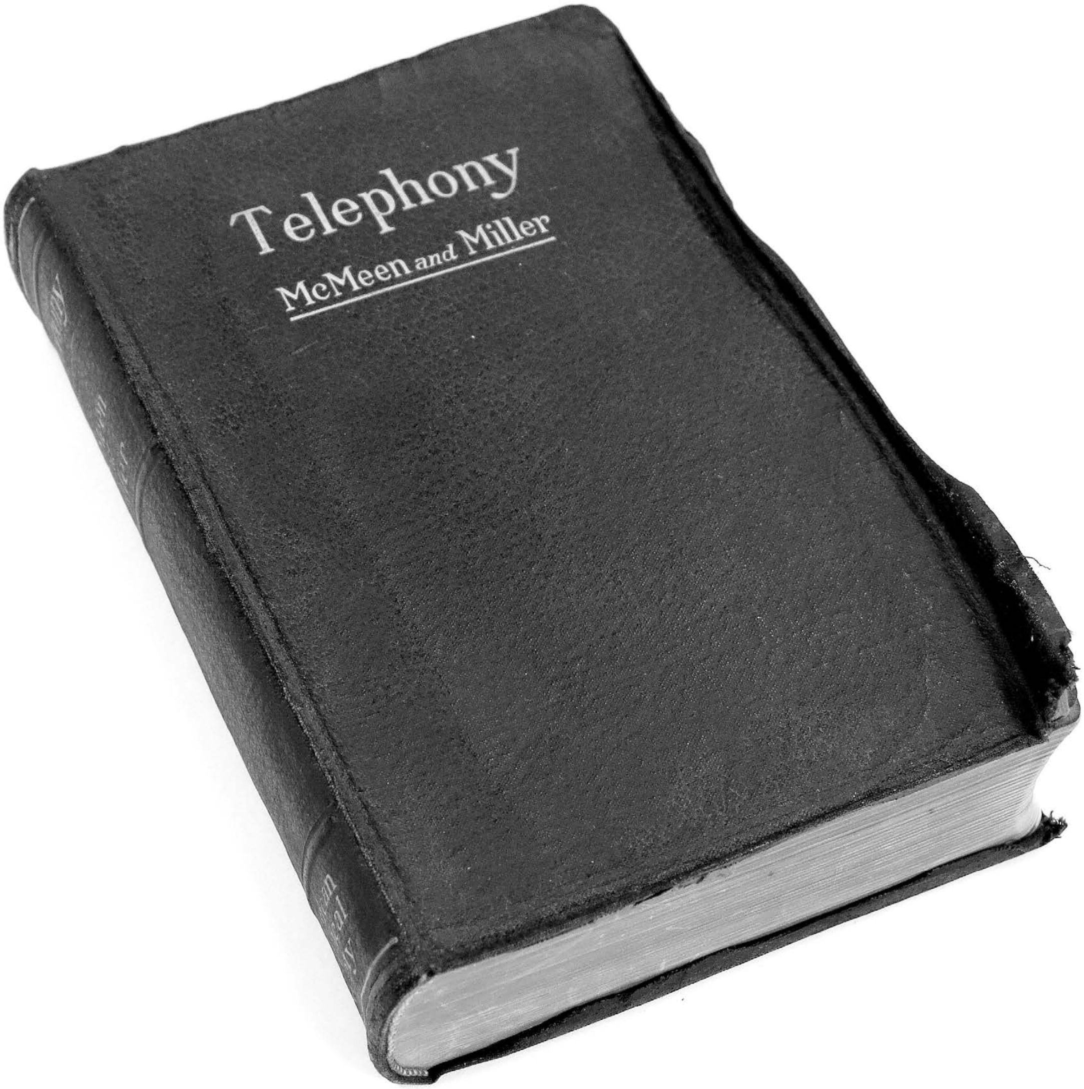

Fig. A-13. The bible of telephony in its time (McMeen and Miller 1912).

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About the Author

Ralph O. Meyer is a Phi Beta Kappa graduate of the University of Kentucky and earned a Ph.D. in physics from the University of North Carolina. He did experimental research at the University of Arizona and Argonne National Laboratory, and his main career was in technical work for the U.S. Nuclear Regulatory Commission. For more than 30 years, he studied and wrote about the history and development of the telephone. He writes a technical column for a newsletter of Telephone Collectors International, and for the past few years he has been working with North Carolina State University on telephone-related design topics. The author is shown on the rear cover with his wife, Sue, in 2014.