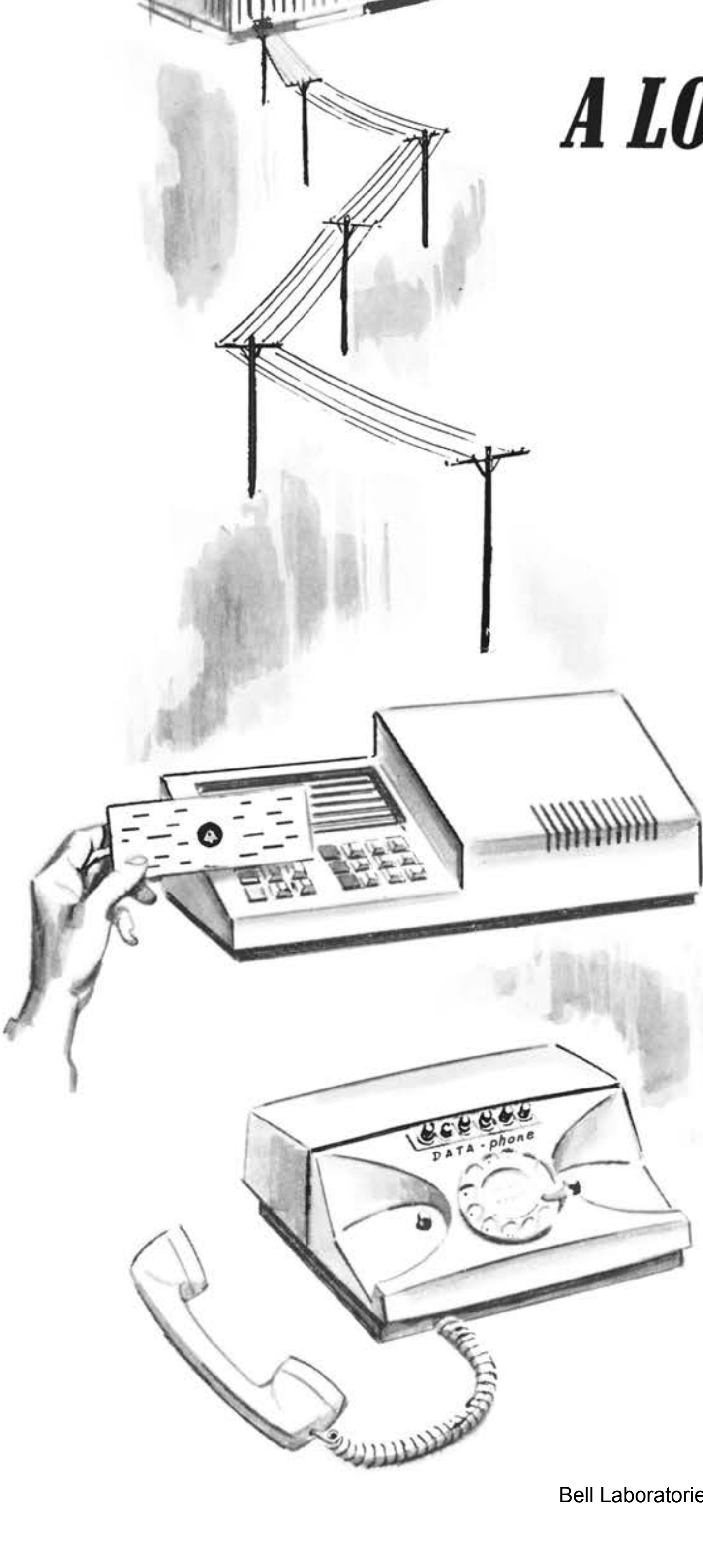
A LOW-SPEED DATA SET FOR



R. Sokoler

One of the frontiers of communication is the transfer of symbolic language or code through the voice telephone network. Such information transfer is made possible by the Bell System's DATA-PHONE service which incorporates a variety of data-transmission systems. Some of these systems carry information between business machines in digital form, such as coded alphabetic or numeric characters. Other systems handle information in continuous, or analog, form. Most of the data sets may be used as ordinary telephones when they are not handling data. Transmission speeds vary from more than 2000 bits (binary digits) per second to less than 100 bits per second.

The 401 data set described here transmits data at relatively low speeds—about 80 bits per second. Why not a high-speed data set for high-speed business? In designing any equipment, there must be a middle ground between features such as high speed and economy. The data sets in the 401 family are designed primarily for those businesses and industries which originate relatively short messages at outlying stations and collect data at a centralized receiver. Because many business machines deliver their information in parallel form, direct transmission by parallel

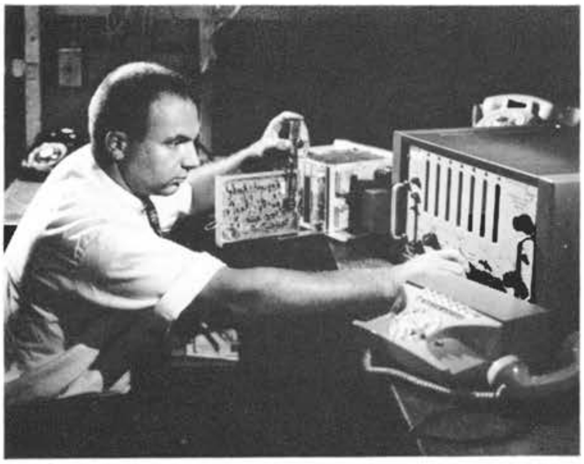
HIGH-SPEED BUSINESS

If clarity, accuracy, and speed are criteria for effective communication, the output of a machine has an advantage over the human voice. Recent developments in data systems may make the language of machines commonplace in American business and industry.

techniques affords greater simplicity and economy. With a 401 data set transmitter, a customer can send information from his business machine, one character at a time by transmitting several frequencies simultaneously. With these data sets, all organizations large and small can transmit information to any point in the United States.

The use of the existing voice telephone network eliminates the necessity of leasing private lines and makes the system economically attractive and highly flexible. To set up a data connection, a customer dials a number just as for a regular telephone call. The receiving terminal, unlike a standard telephone, may not ring, but may answer the call automatically and transfer the line to the data portion of the receiver. The customer's equipment, sends a go-ahead signal to the calling party indicating that transmission may begin. During the data call, an attendant at either the transmitter or receiver can transfer from data to voice. He can return to the data mode by operating a data key. The data transmitter may be activated by a combination of contact closures delivered from a variety of business machines, such as simple paper-tape reader or a punched card reader.

Let's take a hypothetical example of how the system might function. Consider a business whose major income is from catalogue sales. The present ordering procedure might be something like this: After making his choice of items from the catalogue, a customer calls the sales office. The salesman answering the call writes down the customer's account number and the items he wishes to purchase. After he hangs up, and when time permits, the order is transcribed for transmission to the central warehouse. In all, an order may be handled three or four times by various



Author R. Sokoler adjusts frequencies on the answer-back oscillator in the 401 data receiver.

people. At the warehouse, if the item is temporarily out of stock, the customer may get a substitute product of "comparable" value or nothing but a note to the effect that the item the customer wants is out of stock.

Now let's examine the procedure using a data transmission system: The sales force has punched cards on file that cover each item in the catalogue. When a call comes in, a customer asks for the particular items he wants and gives his account number. A salesman takes the associated cards from the file and a data call is placed to the warehouse on another line. At the warehouse, the call is automatically answered and a go-ahead signal sent back to the sales office. The salesman inserts the punched cards for each item into a card reader, one at a time, and the information they contain is transmitted. The quantity of each item may be manually transmitted after each card by pushbuttons on the card reader. After each item is transmitted, information is immediately returned to the sales office as to whether or not that item is available. If everything is satisfactory, the customer's account number is manually transmitted, and the order is processed and billed by automatic equipment at the warehouse, with verification on each item—before the customer hangs up his phone.

The actual transmission of the information occurs as the holes in the punched cards are read by the card reader. These holes are converted to contact closures in the reader and cause voice frequencies to be generated in the data transmitter. As the holes are read in sequence, on-off bursts of coded signal frequencies are transmitted over the telephone voice channel as any voice message might be. Each burst represents one character. Because of this on-off method of transmission, neither the speed at which the characters are sent nor their timing is critical, since the start of a character is recognized by the start of the signal burst, and the end of that character by the end of that burst. This asynchronous operation permits transmission at any speed up to 20 characters per second.

Data signals do not possess the redundancy inherent in the spoken word. Therefore, in designing a data-transmission system which uses the regular telephone network (rather than private lines tailored to the system), the network characteristics and limitations must be kept in mind constantly to insure optimum system performance. Since this data system uses multifrequency signaling as its method of transmission, such considerations as limited bandwidth, frequency shift, echo, noise, net loss, and coding played important roles in the system's final design.

The voice channels in today's telephone system pass voice frequencies from a few hundred cycles per second to about 3000 cps. Of course, there are variations in these cutoff frequencies. To afford sufficient reliability to the system, the designers selected frequencies from 600 to 2350 cps which conform to this voice-frequency band limitation but still allow some guard space at the edges of the band.

Transmission frequency shift is another important factor in any multifrequency signaling system. If the transmitting and receiving carriers of a telephone transmission system differ in frequency by some number of cycles, then each frequency component of the received signal will suffer a frequency shift of that many cycles. Although there are shifts in frequency up to 20 cps on a few carrier systems still in use, these shifts are unnoticed by the human ear. They are, however, substantial by multifrequency data standards. To allow for a maximum 20-cps shift, the system designers allotted a band of frequencies over which each data frequency would be clearly recognized. This "recognition band" for each data frequency is 65 to 80 cps wide.

The low-speed parallel data system provides a reverse transmission signal to permit the receiving party to acknowledge a message. The data receiver returns "answer-back" tones to the transmitting station to indicate either satisfactory or unsatisfactory reception. To avoid interfering with these answer-back signals, the transmitter does not send continuous carrier when it is not transmitting data. If it did, echo suppressors on long circuits might be held in one transmitting direction, prohibiting reverse transmission. This consideration suggests the use of amplitude modulation or "on-off" keying. However, echoes on lines of intermediate length make AM undesirable, and for this reason, the system designers chose a modified FM transmission method.

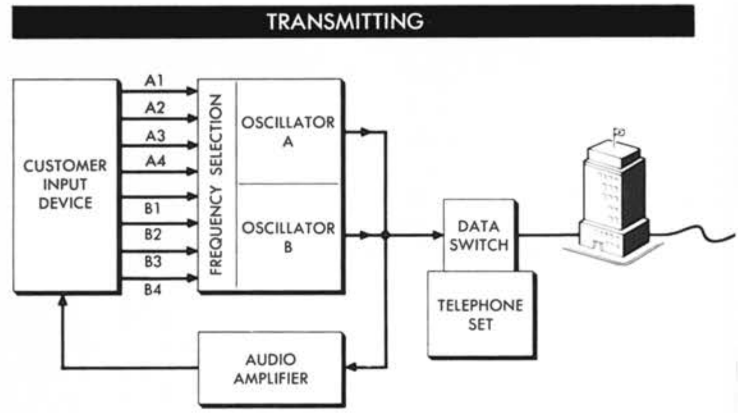
Carrier at a rest frequency in each group is turned on at the start of transmission. The data message controls the shift to data frequencies. After each character is transmitted, the rest frequencies are restored. At the end of transmission, the carrier goes off after an 80-millisecond delay. This 80-millisecond rest tone signal following each character eliminates undesirable effects of line echoes. If the transmission rate is greater than about six characters per second, a continuous signal is transmitted.

The maximum net loss is less than 30 db on most lines. The intensity of the signal is limited principally by potential crosstalk; a maximum level of about −6 dbm is considered satisfactory. Line noise and signal echo problems, however, restrict the maximum receiver sensitivity to some reasonable value consistent with system requirements to keep a minimum error rate. For example, a 401 transmitter that delivers −11 dbm per frequency to the line requires a receiver with a minimum sensitivity set to a few db below −41 dbm to adequately detect the weakest incoming signals in the presence of noise.

The frequencies used in this system—ranging from 600 to 2350 cps—are divided into three channels. Each channel contains four data frequencies. A single character is represented by

Miss Sue Ehlers demonstrates data set in Laboratories computer center. Note receiver on rear table.

Block diagram of the numeric 401 data transmitter and receiver. The transmitter, controlled by the customer's business machine, sends parallel multifrequency signals over a telephone line to a receiver. At that point, the data signals are decoded and presented to an associated business machine in the form of simple contact closures.



one frequency from each channel. This arrangement provides a maximum of 64 frequency combinations — 26 codes for alphabetic characters, 10 for numerics and 28 for use as special symbols or functions. This form of coding provides inherent error-detection because the receiving business-machine equipment immediately detects any signal combination that contains either more or less than one frequency from each channel.

Although the low-speed parallel system can transmit alpha-numeric data, the present trend indicates a large demand for a purely numerical system which uses only two of the three channels. Such an arrangement provides 16 two-frequency combinations—10 codes for numerical digits and six for other functions.

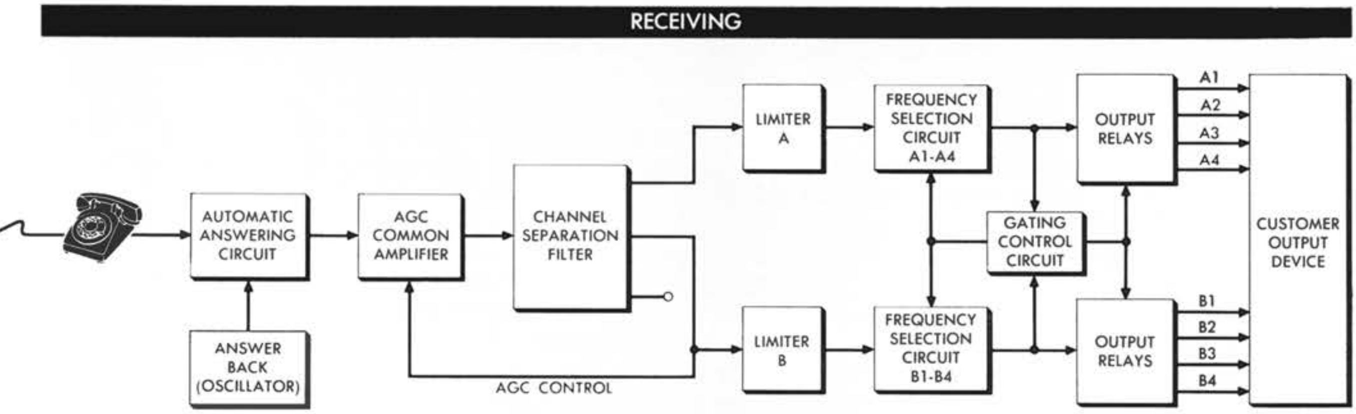
The Data Transmitter

The transmitting terminal that generates the multifrequency signals for the purely numerical system is shown in block form above. It consists of two transistor oscillators operated in parallel. Each oscillator can produce a rest frequency or one of four higher data frequencies, depending on the input data leads chosen. In addition to the oscillators, the transmitter contains a two-stage amplifier which receives the answer-back signals from the data receiver. This amplifier drives an external speaker that produces an audible answer-back tone as well as side-tone that allows a customer to hear the data signals being transmitted. The transmitter is powered directly from the telephone line using a polarity guard bridge network at its input to insure the proper polarity of dc potential. As an optional feature, the transmitter may also be equipped with a slightly more elaborate answer-back amplifier that will produce either of two relay contact closures in response to one of two acknowledgment signals.

Each oscillator uses a three-winding ferrite transformer to generate feedback and control frequency of oscillation. Tight coupling and large feedback are provided to insure fast oscillator start up. The lowest frequency in each group is the rest tone generated by a fixed polystyrene capacitor across a portion of the tuning winding of the transformer. The remaining frequencies are obtained by shunting the main tuning winding at appropriate taps by a second inductor. The transformers and inductors are wound on similar ferrite structures and the inductance of each can be adjusted with a center slug.

The keying of the transmitter is controlled by business-machine equipment, which makes parallel contact closures to select one data frequency in each channel. Immediately following this selection, a third contact closure (the keying contact) applies power to the oscillators, and only then are the data signals transmitted. The data receiver tolerates only a fixed amount of time separation, or skew, between the two data frequencies. For this reason, the order in which the data-keying functions are performed is necessary to eliminate any excessive skew that may be inherent in the data contacts of the controlling business machine. That is, if the data frequencies were transmitted at the time each frequency selecting contact was closed, excessive delays of one frequency relative to the other might destroy transmission of data. If however, this skew, or time separation, between the start of the frequencies is less than about 6 milliseconds, the order in which these operations are performed is unimportant.

As mentioned earlier, in addition to the four



data frequencies, there is one rest frequency in each channel which suppresses any echo signal in the data receiver. To provide a rest tone of the desired duration following each data frequency, a series resistance-capacitance arm is connected across the keying contact terminals that supply power for the oscillators. The network is adjusted so the charging line current sustains these rest tone oscillations for the required time. As the capacitor charges, the current available to the oscillator diminishes, and after about 80 milliseconds this current is insufficient to allow continued oscillations. This is why rest tones follow data tones for the prescribed duration.

If the character repetition rate is greater than about six to eight characters per second, the transmission is continuous FM; that is, the normal off periods between data tones will be completely occupied by the rest tones with no interruption of signal on the line. The transmission of a character before the rest tones have subsided simply generates frequency-shift signals. For rates less than about six characters per second, the "hangover tones" (that is, the 80 milliseconds that include both rest frequencies) do not completely fill the interval and periods of no signal will be present. Regardless of the character rate, however, there will always be a return to quiescent condition following the opening of the keying contact after the last character of the sequence is transmitted. This permits the receiving terminal to acknowledge or deny satisfactory reception of the data message. The normal quiescent conditions recognized at the data receiver are either all rest tones or the absence of all data frequencies.

The two-stage receiving amplifier in the transmitting terminal produces the necessary audio power to drive a small speaker for the audible answer-back tone. Most of the current from the telephone line passes through a choke coil and a string of six silicon alloy diodes. The nearly constant voltage drop across these diodes is the power source for the amplifier, which delivers between 1 and 2 volts rms to its speaker when receiving answer-back signals over transmission paths having loss as great as 30 db.

The Data Receiver

The current numeric data receiver, shown in block form above receives data signals from both channels over telephone circuits with as much as 30-db net loss. The receiver output to the customer's business machine consists of a pair of contact closures (one contact out of four in each channel), which correspond to the closures at the transmitting terminal.

When a call is received, answering circuits in the data receiver automatically answer the call and transfer the line to the data circuits. (The answering circuit may be disabled for customers who do not desire automatic answering.) If power is not applied to the receiver, or if the business machine is not in the data mode, the telephone rings in the normal manner (regardless of the receiver's answering option) and some manual action is necessary.

The received input data signals are in the form of tone bursts. Each burst consist of two data frequencies: one from the first channel and one from the second. Signal power may vary over 30 db depending on the particular transmission circuits, and amplification is sometimes necessary to compensate for such loss. Input signals pass through a common amplifier providing a maximum gain in excess of 40 db. This high gain is required for weakest signals but is quite excessive for the strongest signals received. For this reason, the common amplifier possesses automatic gain control characteristics which substantially reduce the receiver sensitivity for all but the weakest signals. The amplifier delivers output signals which are constant to within a few decibels for input signals with up to 30-db variation in input power. The transmission of the amplifier is sufficiently linear to insure that no errors are caused by harmonic distortion.

After the signals are amplified, a filter separates the data frequencies by groups so that each may drive its respective detection circuit. This separation filter consists of a low-pass filter (which selects frequencies in the first channel), a band-pass filter (which selects frequencies in the second channel), and a high-pass filter (which selects frequencies in the third channel). The inputs of these filters are driven in parallel by the amplified input signals. The single frequency output of each filter drives a single-stage limiter which supplies enough gain to remove the small variations in signal level permitted by the amplifier circuit. The resulting square-wave output maintains the same peak-to-peak value over the entire range of receiver input levels.

Actually there are five frequencies in each channel: Four are for data, and one is the rest tone which lasts approximately 80 ms after each data tone. This fifth frequency is not recognized by the numeric data receiver, and so it does not produce any output; it does, however, play a vital role in suppressing echoes which might otherwise seriously disrupt transmission. Design engineers found these echoes existing on some lines without echo suppressors, with delays as great at 35 ms and levels sometimes only 10 db below the main signal. These echoes arrive at the limiters in the data receiver with energy identical in frequency to the previous data character but delayed up to 35 ms. If both echo frequencies are of sufficient magnitude they may cause a repeated output of that character. If only one echo frequency is strong enough to activate the limiter, only one channel will produce an output closure, and an error may be generated. However, if a rest tone follows each data tone for 80 ms, it will saturate the limiter producing output axis crossings almost purely of the rest tone frequency, suppressing any effects caused by these echoes.

Each channel limiter supplies its signal to four tuned circuits. Each of these circuits responds to one of the four data frequencies in that channel. When the response of one of the tuned circuits exceeds a fixed threshold voltage, the associated detector delivers an output to the gating-control circuit. The gating-control circuit then starts timing. If the signal persists for 10 ms, it is recognized as valid.

The gating-control circuit enables the output amplifiers to permit operation of output relays. It also operates on the detectors to lock in any that are then delivering signals and desensitizes the others so they will not respond to trailing-edge transients. The gating-control circuit remains in this state for 22 ms. At the end of this time output closures are removed even though the input signals persist. The control circuit is reset only when a simultaneous interruption of both data frequencies occurs in excess of 10 ms. The output relay contact closures are delivered to the business machine, and at this point the customer may decide whether he has a valid combination.

Data-System Variations

This system can transmit any one of sixteen different characters by sending two frequencies at one time, with each frequency chosen from a group of four. For this reason, it is often called a two-out-of-eight system. It can handle the ten numeric digits and a few control codes. Acknowledgment, or answer-back, is provided audibly.

When alphabetic and numeric characters are sent, a third oscillator is added to the transmitter and a third group of detectors is provided in the receiver. In this case, the transmitter may be equipped to provide audible answer-back or to respond to either of two acknowledgment frequencies and operate one of two relays. This system is often called three-out-of-twelve.

The three-out-of-twelve systems imposes rather stringent skew tolerance on the timing of contact closures in the transmitting business machine. An alternative system, called three-out-of-fourteen, eliminates this requirement and leaves timing entirely to the machines. This data receiver has no gating. It is, however, arranged to detect rest tones as well as message tones in each group and give indication by contact closures. Thus, there are five detectable frequencies in each of the lower groups. The top group needs only four. This positive detection of rest frequencies provides information to permit use of a stronger error-detection scheme than is possible with the three-out-of-twelve system.

The low-speed parallel data set has been field tested, and is currently available for industrial and private use. Because of its basic simplicity, this system, as part of the general DATA-PHONE service, should become an integral part of American communication facilities.