

WESTERN ELECTRIC'S

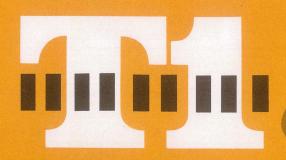
carrier

AN INEXPENSIVE NEW-TECHNIQUE CARRIER SYSTEM FOR SHORT HAUL APPLICATIONS



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WESTERN ELECTRIC introduces a new-technique carrier system for use by the BELL TELEPHONE COMPANIES

carrier

J98710-J98711

...designed by

BELL TELEPHONE LABORATORIES

The first Pulse Code Modulation carrier system for commercial telephony in this country, Western Electric's new T1 Carrier is the most economical system yet devised to multiplex existing short-haul cable facilities. T1 Carrier is designed for use on 10 to 25-mile routes, and can prove in over even shorter distances.

Pulse Code Modulation transmission does not require the well equalized and well regulated broadband transmission media usually needed with frequency-modulation carrier techniques—the T1 Carrier system provides 24 telephone and data channels on two voice-grade cable pairs.

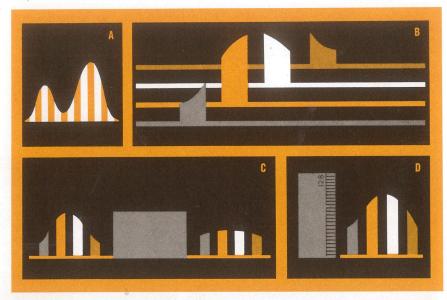
With its short-haul economy and its ability to operate over voice-grade cable pairs, T1 Carrier is an ideal way to meet the expanding communications requirements of metropolitan areas.

Advanced design and manufacturing techniques arising from computer technology have been fully utilized by Bell Telephone Laboratories and Western Electric in producing the T1 Carrier system. Solid state circuitry and highly-efficient new ferrite components help achieve high equipment reliability, excellent transmission characteristics, economies of space and power.

Western Electric's new T1 Carrier helps the Bell System make efficient use of its existing outside cable in exchange areas. Another contribution to the long time drive against plowing money into the ground in the form of new cable lines.

(On the front cover: T1 Carrier terminal equipment to transmit and receive 72 channels mounted on 11' 6" central office bay.)

A. Samples of each voice signal form analog pulse train by Pulse Amplitude Modulation. B. Voice samples are interleaved in time; 12 PAM signals are combined into one analog pulse train.



- C. A compressor circuit amplifies low-level PAM samples to maintain high transmission quality.
 D. PAM samples are measured against reference voltage levels. Height of each sample is described
- D. PAM samples are measured against reference voltage levels. Height of each sample is described by code "word."

how pulse code modulation works

The Pulse Code Modulation (PCM) technique used by T1 Carrier permits 24 telephone conversations to be transmitted as a train of pulses, at the rate of 1.5 million pulses per second. A seven-bit binary pulse code "word" is the basic information-carrying unit of the transmitted pulse train.

T1's 1.5 mc pulse rate appears to be ideally suited for future development as a high-speed data transmission medium. For the present, its chief value to the Bell System is in making carrier techniques economically feasible over short hauls using voice-grade cable.

PREPARING THE VOICE FOR CODING

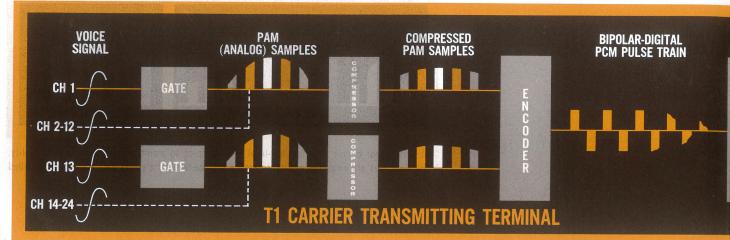
Twenty-four voice signals are multiplexed at the T1 Carrier terminal. Each signal enters the terminal through a gate circuit, where it is sampled at the rate of 8,000 samples per second. At the output of each gate circuit, these samples form a train of analog (amplitude-modulated) pulses—the height of each pulse representing the amplitude of the voice signal when the sample was taken. This stage of T1 terminal operation is called Pulse Amplitude Modulation, or PAM.

The 24 gate circuits are timed to open in sequence—each of the voice signals is sampled, in order, before the first voice signal is sampled a second time. PAM samples of each voice are thus interleaved in time, and outputs from several gate circuits can be combined. Combining is called Time Division Multiplex (TDM). In practice, the PAM samples are combined into two analog pulse trains, each of which contains samples from 12 of the total 24 incoming voice signals. Samples of a given voice signal, then, appear at twelve-pulse intervals in one of the two analog pulse trains.

Each analog pulse train arrives at the encoder by passing through one of two instantaneous compressors. The compressor is a non-linear amplifier which has the effect of amplifying low-level PAM samples. Actually, the amplification factor in the compressor circuit is a logarithmic function, high for low-level samples, and approximately equal to 1 for high-level samples. The compressor thus reduces the ratios between high and low-level pulses in the analog pulse train. This compression is necessary to maintain high transmission quality.



Regenerative repeater examines distorted pulse train,



CODING THE VOICE FOR TRANSMISSION

The two combined analog pulse trains are again interleaved at the encoder. Two 12 channel PAM pulse trains are first encoded and then combined to make up 24 channel PCM pulse trains. On this basis, the PAM samples are coded for transmission over the line.

In the coding process, the heights of the PAM samples are compared to a set of reference voltage levels. The encoder can describe each of these voltage levels with a different pulse code "word"—the height of each PAM sample is measured to the nearest reference voltage level, and the appropriate code word is assigned.

The code words are made up of digital pulses (pulses of equal size). Each word contains seven time slots, each of which may or may not contain a pulse. Information is carried by the presence or absence of pulses in the seven time slots.

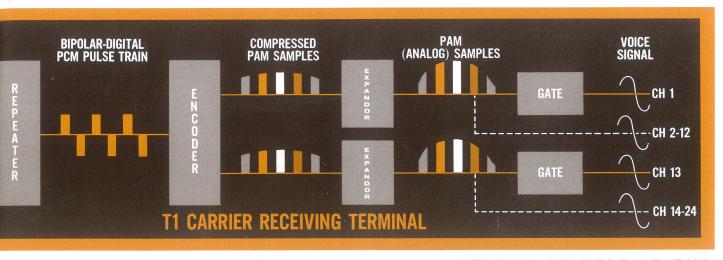
This is a binary code—a code made up of two numbers, "one" and "zero," where 1 is represented by a pulse, and 0 is represented by a no-pulse condition. Code words are formed (1 1 1 1 1 1;

0 1 1 1 1 1; 0 0 1 1 1 1 1; etc.) by arranging seven "ones" and "zeros" (pulses and no-pulses) in various permutations.

The use of seven time slots theoretically allows 128 pulse code words to be formed. One of these, however, is the word made up of no pulses—or seven "zeros." This word is not used for transmission purposes—in practice, 127 code words are used.

The encoder can therefore describe 127 reference voltage levels. The height of a given PAM sample will rarely be exactly equal to one of these reference levels, so a certain amount of "quantizing noise" is introduced during coding by approximating each PAM sample with the nearest reference level. Low-level PAM samples, however, have been amplified by the compressor before arriving at the encoder—this reduces the signal-to-quantizing noise ratio to a point where it has little or no effect on transmission quality.





AFTER THE VOICE IS CODED

After coding, an eighth time slot is added to each seven-place binary code word. Absence or presence of a pulse in the eighth slot carries signaling information compatible with dial pulsing, revertive, E&M, or multi-frequency central office signaling equipment.

To every 24th code word, still another time slot is added. A pulse or no-pulse condition in this time slot carries timing or "framing" information to the receiving terminal equipment.

Immediately before transmission over the line, the digital pulse train of code words is converted to a "bipolar" state. As used in the T1 system, the term "bipolar" refers to a pulse train where pulses appear alternately positive and negative. Bipolar transmission is used to eliminate the DC component inherent in a unipolar digital pulse train, and to shift inherent high-frequency components to lower frequencies. Another advantage gained from bipolar transmission is in error detection—two consecutive pulses of like polarity indicate malfunctioning carrier equipment.

THE REPEATERED LINE

At 6,000′ intervals, a miniature solid-state repeater regenerates the pulse train, which has become distorted during transmission over the line. The regeneration is done on a pulse-by-pulse basis—the repeater examines each time slot, determines whether a pulse is present or absent, then replaces each distorted pulse with a new pulse for transmission to the next repeater, or to the receiving terminal.

AT THE RECEIVING TERMINAL

At the receiving terminal, the transmitted pulse train is decoded, producing replicas of the original PAM samples. The PAM samples pass through an expandor, where the original ratios between high-and low-level pulses are restored. Gate circuits sort the expanded samples into 24 separate channels—the sorting is synchronized by the framing pulse from the transmitting terminal.

The 24 PAM pulse trains are than passed through low-pass filters, which "blur" the samples for each channel together in such a way that the original voice signal is faithfully reproduced.



THE T1 CARRIER SYSTEM:

terminal equipment

The basic unit of the T1 Carrier terminal is the "D1 Channel Bank." This unit mounts on 23″-wide bulb-angle bay, and houses the multiplexing equipment to transmit and receive 24 telephone channels on two cable pairs.

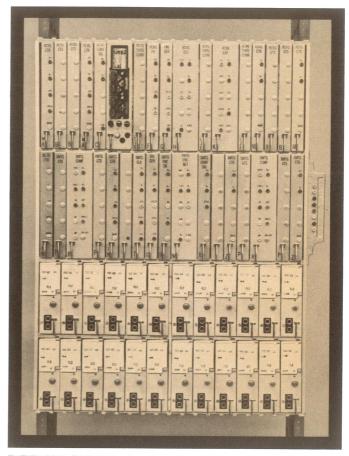
Two D1 Channel Banks, providing 48 channels, can be mounted on a 9-foot central office bay. An 11' 6" bay accommodates three D1 Channel Banks, providing 72 channels. In both mounting arrangements, space is left at the top of the bay for plug-in power converters, fuses, and alarm circuits.

D1 Channel Bank power equipment is plug-in. This is one of the first uses of plug-in power equipment in Western Electric carrier equipment. Plug-in equipment simplifies maintenance, and makes equipment more flexible—an important office engineering advantage is that only necessary power circuitry need be installed.

Simplifying office engineering, T1 terminal bays are shop-wired, Plug-ins for D1 Channel Banks and associated Power Units can be individually installed in step with expanding carrier requirements. Another advantage of shop-wired bays, and plug-in modular design: modules can be manufactured on an assembly line basis and stocked for easier ordering, exact testing and Quality Control procedures can be carried out at the Western Electric manufacturing location instead of in the field.

In the D1 Channel Bank are four rows of plug-in equipment modules. Two of these contain 24 Channel Units—one for each telephone channel to be multiplexed.

Channel Units are available to transmit dial pulsing, revertive pulsing, E&M, and multi-frequency signaling via PCM. The Channel Units are plug-in modules, and can be installed in any combination in



TWENTY FOUR CHANNELS—A D-1 Channel Bank (D stands for digital) holds all the T-1 Carrier terminal equipment necessary to send and receive 24 voice channels. The two rows of plug-in modules on the top are common equipment and the two rows on the bottom are channel units.

the T1 terminal—any combination of these signaling techniques can be handled in the 24-channel circuit provided by the D1 Channel Bank.

The remaining two rows of plug-in equipment in the Channel Bank are common to 6 or more multiplexed channels. Among these equipment units are the compressors, expandor, encoder, and decoder.

HOW PCM PAYS OFF AT THE T1 TERMINAL

Common equipment is the big advantage of PCM in the T1 terminal. More than half of the equipment in the D1 bank is common to all 24 telephone channels. Two-wire T1 channels do not include individual channel amplification; all of the required gain is obtained in common amplifiers. Also, only two instantaneous compressors, each serving 12 channels, and a single expandor for all 24 channels are needed.

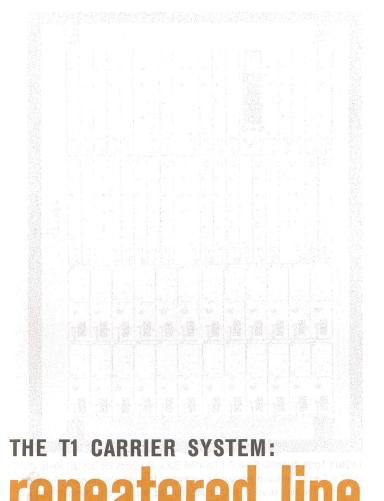
Conventional frequency-division carrier systems would use a separate compandor for each channel.

Signaling arrangements can be economically built into a PCM terminal which is already handling large volumes of digital data.

Low cost per channel for terminal equipment is achieved because only simple individual channel equipment is required. The terminal equipment price per channel includes the inexpensive individual channel equipment and only 1/24 of the common equipment.

The compact T1 terminal saves valuable central office space. Space economies achieved through the use of common equipment are enhanced by solid state devices and highly efficient new ferrite filter components, used exclusively in the T1 equipment design. This design feature also contributes to low system cost and simple maintenance procedures.





Solid state T1 repeaters are required about every 6,000 feet along the transmission line and 3,000 feet from the central office. Twenty-five of these repeat-

ers mount in a cylindrical Apparatus Case measuring 10" in diameter and 28" long.

The T1 system is designed to operate on existing cable plant. Because of T1's expected application in metropolitan areas, the repeater Mounting Cases are designed for installation in manholes. The cases may be mounted on cable racks as are splice cases, or attached to the manhole wall, and come equipped with a 10', 15', or 20' stub containing separate units for in and out pairs.

The T1 system operates on non-loaded cable pairs. Since the T1 repeater spacing on 22 gauge cable matches the spacing of H load coil spacing, cable pairs can often be unloaded and repeater cases installed in one splicing operation. Plug-in load coils are available for temporarily reloading pairs in the

Apparatus Case if they are not used for T1 immediately.

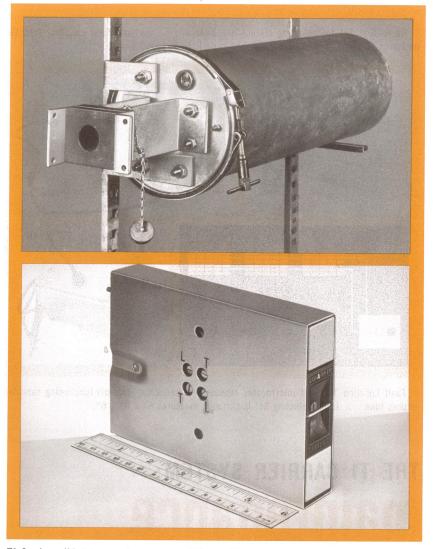
When repeater locations do not coincide with loading, "through connectors" may be placed in the cases and the pairs loaded elsewhere or used as non-loaded facilities. Thus, pairs appearing in a repeater case may be operated on either a voice-frequency or carrier basis.

There is a repeater installation test set for measuring the required line build-out networks. Thus each repeater can be easily matched for proper electrical length of line before being placed in the apparatus case.

The T1 repeater is a two-way device, containing two separate regenerators and a common power circuit. Twenty-five two-way systems can be handled by repeaters in a single Apparatus Case, and transmitted through non-adjacent cable pairs in a single cable sheath.

For large installations, the two directions of trans-

T1 Repeater Apparatus Case, 10" in diameter and 28" long, houses 25 repeaters.



T1 Carrier solid-state repeater measures $4\frac{3}{16}$ " x $1\frac{1}{8}$ " x 6", exclusive of guide pins.

mission should be segregated into separate cable sheaths. Systems are then treated in pairs, and each repeater handles two systems, or 48 channels, in one direction. The repeaters in a single Mounting Case then handle, in effect, 50 one-way systems.

HOW PCM PAYS OFF ON THE REPEATERED LINE

Regeneration is the key to PCM transmission. Noise and interference do not accumulate from repeater section to repeater section. Each repeater section is essentially an independent transmission problem. While the line signal occupies a large bandwidth, the transmission media does not need to be well equalized or well regulated. Therefore, cables originally designed for voice transmission can be used.

Net loss regulation of the over-all channels depends

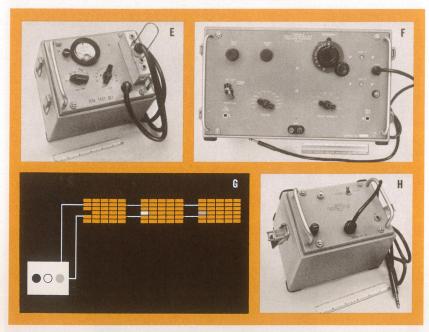
only on the terminal equipment. If the code words representing each PAM sample are passed from the transmitting terminal to the receiving terminal without error, the channel net loss is independent of variations in the line loss.

Essentially independent repeater sections simplify engineering of repeatered lines through the multimesh cable network that exists in our large metropolitan areas. Only the types of cables, splicing arrangements, noise and crosstalk exposures within each repeater section need be considered when laying out the line. Minor cumulative effects (except for timing jitter which cumulates with number of repeaters) may be ignored.

Standard levels exist at repeater outputs—the output of any repeater may be connected to the input to any repeater section without adjustment. Therefore, repeatered lines between central office repeaters may be cross-connected together in any combination to form the repeatered line for a system.



E. Cable Test Set for selecting correct line build-out. **F.** Portable Fault Location Test Set measures 10" x 17" x 9"; can be mounted in partially-equipped bay.



G. Fault Location Test Set interrogates repeaters in sequence; properly-functioning repeater returns tone. H. Error Detecting Set is portable, measures 6" x 8" x 6".

THE T1 CARRIER SYSTEM:

maintenance

A special repeater test set is available for use in testing T1 repeaters before installation. This test set will normally be used in the central office. The set is portable, contained in an aluminum box 9"x 13"x 9".

After installation, repeaters on a faulty repeatered line can be tested from the central office by means of the T1 Fault Location Test Set. This test set sends an interrogating tone to each repeater in sequence. A properly-functioning repeater passes the tone, which is returned to the central office through a selective filter in the repeater Apparatus Case. Failure to get a returned tone at the central office indicates the repeater being interrogated is faulty.

Terminals: Simple maintenance procedures using a minimum of test equipment have been worked out for the terminal equipment. Arrangements for sectionalizing system troubles to the repeatered line, to the transmitting common equipment or to the receiving common equipment at either end are built into the system. Maintenance access to many com-

mon equipment functions and to 4-wire voice-frequency test jacks is provided. Access to the common equipment is obtained by removing a connector board and inserting one of four special test boards. These test boards are very similar to regular common equipment packages except that switches and jacks are provided on the front. Standard voice frequency detectors are used to measure the outputs of the boards. Much of the terminal logic is used in its own test procedure rather than have a test set which duplicates it; therefore, the terminal test equipment is simple and low in cost.

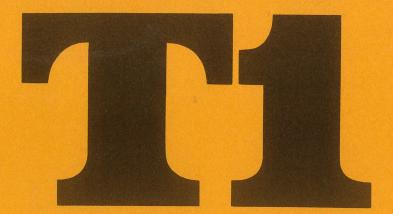
For T1 system repeatered line testing, an Error Detecting Set checks the bipolar pulse train for "violations"—a violation consists of two consecutive pulses of like polarity. Violations are indicated by a lamp on the front of the test set and gives an indication of the performance of the repeatered line.

T1 Carrier maintenance is simplified by the long life of solid state components used exclusively in T1 design.

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For additional information refer to:

Bell System Practices (BSP) J98710 (Section AA388.123) Bell System Practices (BSP) J98711 (Section AA388.124)



a new-technique carrier system

Western Electric's T1 Carrier system is a new approach to carrier telephony. It is the first Pulse Code Modulation carrier system for commercial telephone use in this country. It uses solid state devices and ferrite filter components. Offering economies of space and power at a low initial investment, T1 Carrier is the least expensive way yet devised to use existing facilities for carrier transmission.

T1 Carrier transmits and receives 24 telephone channels over two non-loaded voice-grade cable pairs. It is especially well suited for use in large metropolitan areas; operates in the 10- to 25-mile range, and proves in on routes shorter than 10 miles in special cases.

T1 Carrier, designed by Bell Telephone Laboratories and manufactured for the Bell System by Western Electric, is a new way to provide high-quality carrier service on an economical basis, helping meet the increasing need for communications services.

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