GTE LENKURT

DEMODULATOR

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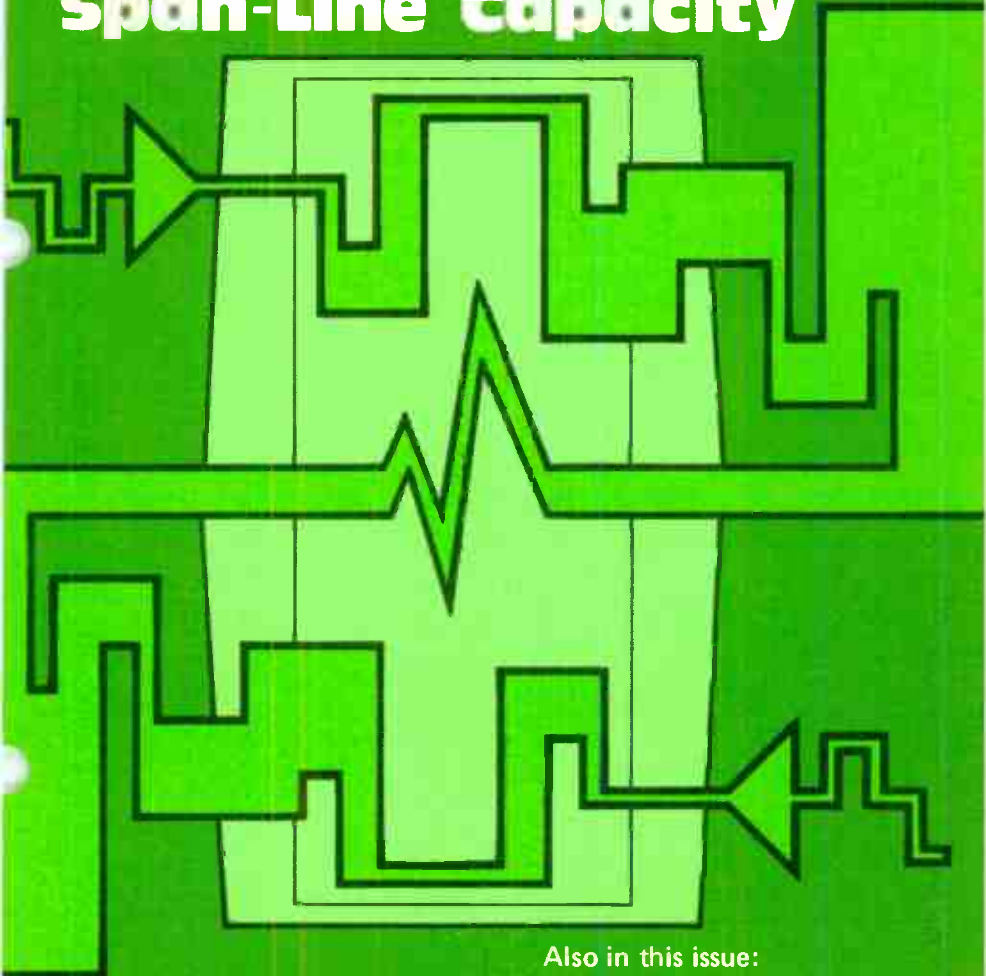
Increasing PCM Span-Line Capacity



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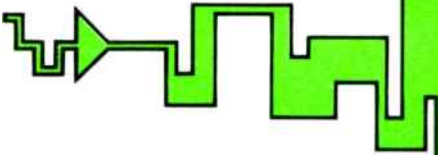
RF REPEATERS



The channel capacity of new PCM cable carrier systems is markedly greater than that of older systems. A new development at GTE Lenkurt, however, allows expanded capacity to be achieved using existing facilities.

The first commercial cable transmission system to use pulse code modulation (PCM) techniques was Western Electric's T1 cable carrier system, which was introduced in 1962. Soon after its appearance, independent manufacturers began producing similar T1-type equipment of their own. In all of these systems, analog information contained in as many as 24 voice-frequency (vf) channels is encoded and combined into a single digital transmission signal.

Basically, T1-type systems consist of terminal equipment, normally located in a central office, and a "repeatered" or "span" line (see Figure 1).

The heart of the terminal equipment is the channel bank, which performs the actual conversion from analog to digital form. One fully equipped channel bank contains 24 channel units, each of which accommodates an individual channel carrying, for example, a telephone conversation. In transmission, a channel unit samples its associated information 8000 times a second, producing an amplitude pulse sample every 125 microseconds (μs). A transmit common equipment unit in turn sequentially samples the pulse amplitude modulated (PAM) outputs of the channel units so that every 125 μs a complete "frame" of 24 pulse samples is transferred into the transmit common equipment. The amplitude of each pulse is encoded as an eight-bit binary number, or word, in which logic ones and zeros are represented by discrete voltage levels. Each frame therefore contains 192 bits of information derived from vf channels; to this is added an extra "framing" bit for identification purposes. Because the sequential sampling occurs 8000 times a second, information in a T1-type system is transmitted at 1.544 million bits per second. This single 1.544-megabit (Mb/s) digital stream – a multiplexed PCM signal – is passed through a converter that inverts alternate pulses to produce a bipolar digital format that can be transmitted over one pair of wires to a channel bank in another central office.

In reception, a receive common equipment unit accepts PCM signals and decodes them into 24 PAM signals for application to the channel units. The channel units then reconstruct the analog vf information.

A T1-type system requires a four-wire transmission path – one pair of wires for each direction of transmission — between channel banks. The path provided is referred to as a repeatered, or span, line; the aggregate of all span lines between locations is collectively referred to as the span.

Span Lines

As in any transmission medium, the PCM pulses generated by the terminating equipment are susceptible to distortion by the attenuation and phase characteristics of the cable, so regenerating repeaters are placed at intervals on the transmission path, and are thus considered as part of the line.

A repeater "looks at" each bit time slot in the PCM signal carried in its associated pair of wires, and determines whether or not a pulse is present. If the repeater logic decides that there is a pulse, it generates a new pulse free of the noise, distortion and interference contributed by the preceding line section. These factors, however, can produce erroneous pulse detection; for example, the repeater may identify a noise spike as a pulse. The ratio of incorrectly identified bits to total number of transmitted bits in a given time interval is the "error rate." The desired error rate in T1-type systems is no more than one error in 10^6 bits. It has been found that this standard can best be maintained with a repeater spacing of approximately 32 dB at 772 kHz. For example, when the span line is a pair of 22-gauge, paper-insulated wires, it is necessary to install repeaters about 6000 feet apart because at that distance the signal level at 772 kHz is 32 dB below the output of the terminating equipment or the preceding repeater; any further loss would allow noise and other types of interference to produce an unacceptable number of errors.

The repeaters associated with span lines are of two basic types: office terminating and line. Each is divided into two sections. The office repeater, which functions as an interface between the span line and terminating equipment, typically has passive transmit and regenerating receive sections. Line repeaters are equipped with regenerators in both sections and can operate in either a bidirectional or unidirectional mode. Along the length of the path, protective housings are provided for groups of repeater units, generally ranging from three to twenty-five units per group.

When a system is designed for one-cable operation, both directions of transmission share the same cable and line repeater housings (see Figure 2A). The line repeaters are bidirectional: that is, their regenerators operate in opposite directions. In this type of design, low-level inputs and high-level outputs appear at the same point in the cable. Because of this appearance, near-end crosstalk (NEXT) — coupling of energy from the high-level to the low-level line — is a limiting factor. The number of PCM systems that can be accommodated by a single cable is thus mainly controlled by the physical separation of the pairs in the two directions of transmission.

In two-cable operation (see Figure 2B), separate cables and line repeater housings are used for each direction of transmission. The line repeaters are unidirectional (both regenerators operate in the same direction), and NEXT is therefore not a major limiting factor. This design, however, requires that duplicate transmission facilities be provided, which can represent a considerable outside plant investment for a telephone company.

An alternate system design makes use of shielded cable, which has an insulated metallic screen separating cable pairs allotted for the two directions of transmission. This greatly re-

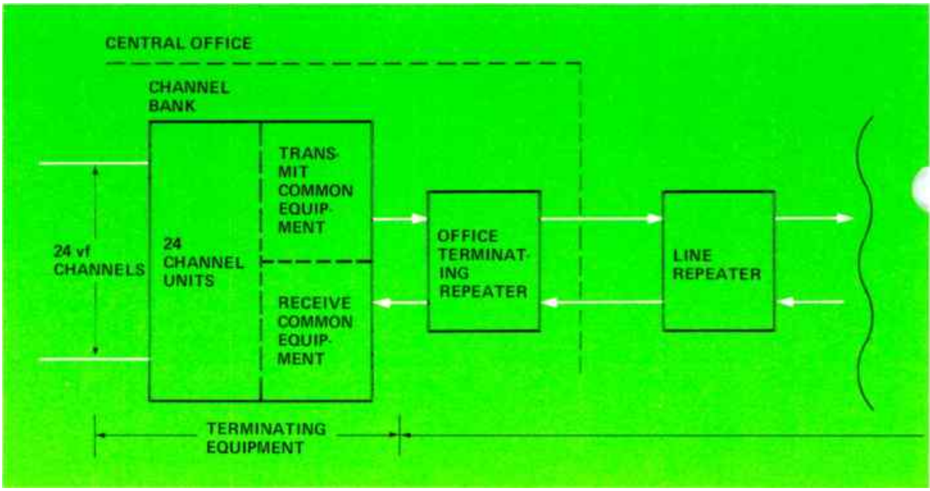


Figure 1. A typical 24-channel, T1-type PCM cable carrier system is composed of terminating equipment, in the form of channel banks, in two central offices linked by a span, or repeatered, line.

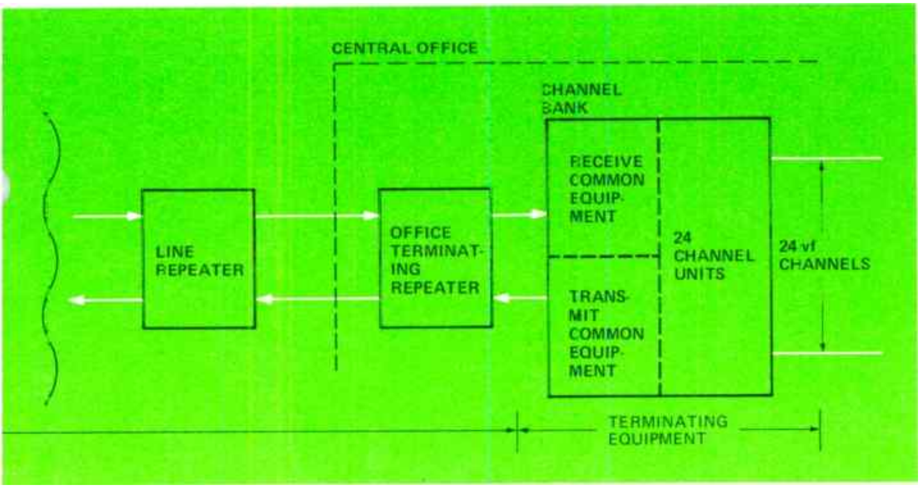
duces NEXT and can allow one-cable operation with a 100-percent dedication to PCM. Such cable, however, is more expensive than the unscreened type.

In most non-screened, one-cable operations, only a limited number of pairs can be devoted to PCM traffic because of the separation requirement. In a 900-pair cable, for example, NEXT might restrict PCM use to only 400 pairs in two non-adjacent groups of wire. These pairs could serve up to 200 T1-type systems, each consisting of two terminating equipment groups and connecting span lines. When fully equipped, 4800 channels could be carried on the PCM lines. The remaining 500 cable pairs would convey one analog channel each, with some being devoted to fault isolation and order wire functions.

Increased Capacity

The application of T1-type carrier to a cable is a relatively permanent undertaking. Cables, once installed, are expected to remain in place for as long as 20 years, and rearrangement of and work on cables placed in service for PCM carrier is difficult and undesirable from the standpoint of service reliability. Until recently, then, the only practical way in which a telephone company could increase its total channel capacity to meet growing service demands has been to add more 24-channel T1-type systems, with all of the attendant equipment and cable costs.

New PCM systems are now available that can carry up to 48 channels, instead of 24, on one span line. GTE Lenkurt's 9102A and Western Electric's T1C are examples. As shown in Figure 3, a digital multiplexer is added to the central office terminating equipment to combine the outputs of two channel banks into one 3.152-Mb/s digital signal, and 48-channel repeaters are placed along the span line. The repeaters have the latest thick-film



hybrid and custom integrated circuit technology incorporated into them to enable processing of the doubled bit rate, but the basic transmission process is the same as that of the lower-capacity equipment.

Ideally, it would be possible to double the capacity of a 24-channel system simply by adding the multiplexer and replacing existing repeaters with the new ones. The repeater spacing requirement for a 48-channel span line is, in fact, the same as that of a T1-type route. Practically, however, the over-all engineering rules are sufficiently different to make one-for-one retrofit highly impractical.

For example, most of the energy in a bipolar signal is concentrated near frequencies of about half the pulse repetition rate. Maximum power in a 1.544-Mb/s signal therefore appears at about 772 kHz, while in a 3.152-Mb/s transmission it is present at around 1.576 MHz, or about twice the frequency of a 24-channel transmission. Loss within a cable varies as the square root of frequency, so loss in a 48-channel system is greater than that in a 24-channel system by a factor of $\sqrt{2}$. This requires a higher-gain regenerator and a more sensitive receive section in the repeaters. These factors make NEXT much more of a problem, and cable pair separation at repeater points more crucial. No 24-channel line repeater housings provide the physical separation needed, so new ones have had to be developed and must be installed when 48-channel equipment is used. Furthermore, suppliers of this equipment specify that either screened or two-cable facilities be provided, or that at least a 900-pair cable be used for single-cable operation. The difficulty and expense of changing such hardware in working systems effectively precludes retrofit, and thus limits 48-channel capacity to new installations only.

A recent development at GTE Lenkurt overcomes such difficulties. The 9148A Modified Duobinary Repeatered Line, as it is called, enables retrofit of 24-channel systems to achieve 48-channel capacity without massive replacement of housings or disruption of service. Any existing system that has been properly designed and is operating according to

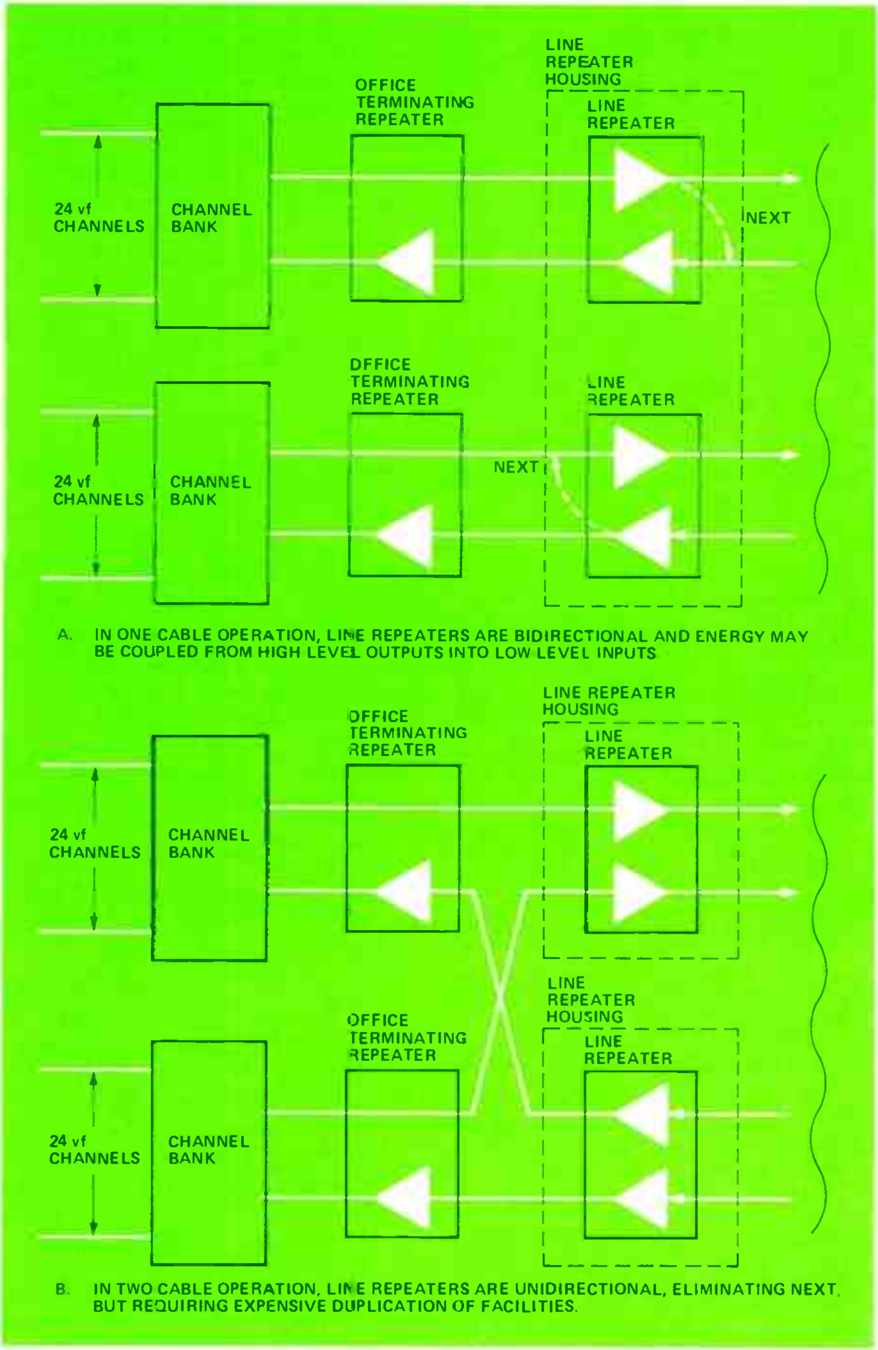


Figure 2. Line repeaters can be made bidirectional or unidirectional by proper orientation of their regenerator sections.

T1-type rules is a candidate for expansion to 48 channels by the simple expedient of adding a digital multiplexer and replacing the office terminating and line repeaters.

Margin

Margin is a measure, in dB, of the amount that noise can be increased before a system exceeds a given bit error rate; as has been indicated, the maximum acceptable rate in PCM cable carrier systems is one error in 10^6 bits. Some of the factors making margin an important engineering consideration are variations in repeater clock recovery circuits and in cable performance characteristics, proximity of cable pairs and the presence of crosstalk at repeater sites, and tolerances allowed in the equipment manufacturing process. All of these elements introduce noise into, and interfere with, the transmitted information, and their effects must be accounted for in designing a cable transmission network.

In most instances, the engineering rules for 1.544-Mb/s systems include a 12-dB margin (a 6-dB allowance is made for the span line, with the other 6 dB assumed to be designed into the repeaters); that is, the signal is maintained at a level which – even after the 32-dB attenuation of a typical span line – can tolerate as much as 12 dB more noise before excessive errors occur. Although the duobinary repeaters do have a noise penalty imposed on them by their unique process, it is substantially less than that imposed by other multilevel techniques. The repeaters are thus generally able to operate over lines in which sufficient margin was originally provided.

Duobinary Technique

The basic duobinary technique of encoding pulse signals was introduced by GTE Lenkurt in 1962 as a means of transmitting more information over a given facility than is possible with binary methods, and do so without the susceptibility to interference of other multilevel techniques. Since then, it has been successfully utilized in high-speed digital data transmission sets operating over voice-quality telephone circuits.

This technique is based on the idea of permitting a controlled amount of intersymbol interference (distortion caused by the edges of preceding and succeeding pulses intruding into the time slot of the pulse currently being transmitted) to occur, rather than seeking to eliminate it. To accomplish this, a binary input signal is passed through a filtering process that delays it by one time interval and adds it to itself; the mathematical bases of the filtering process involve addition in the algebraic and modulo 2 realms, and are thus outside the scope of this discussion. The result of the process is transformation of the two-level input into a three-level signal in which the central level represents a binary zero, and both extremes correspond to a binary one (that is, a pulse on either side of the central level is interpreted as a binary one). The information transmission rate of a duobinary signal is effectively twice that of the original binary format.

In the waveform produced by the basic duobinary technique, a direct transition between two successive extreme levels is not possible, which considerably reduces unwanted intersymbol interference. Also, the number of bits at the center level between successive extremes determines the polarity of the successive levels: if the number of bits is even, the level polarities are identical; otherwise, they are opposite. In this way, a predetermined pattern is established that can

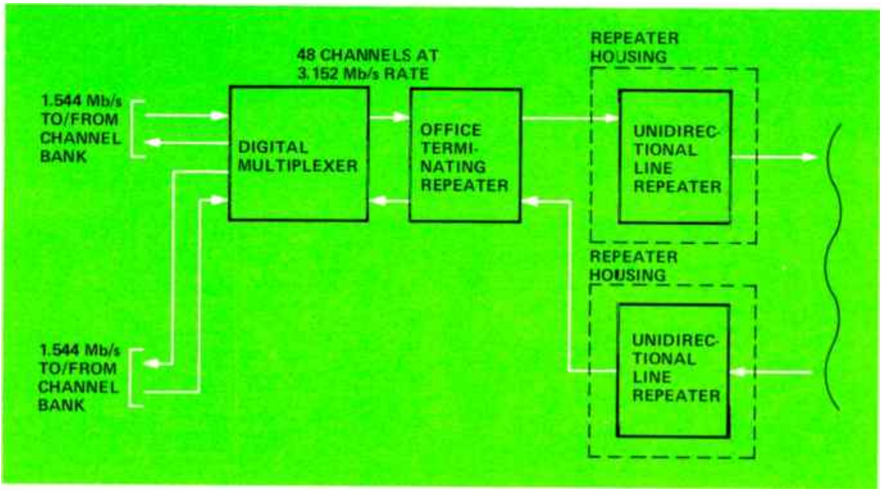


Figure 3. A typical 48-channel PCM cable carrier system requires a digital multiplexer to combine two 24-channel signals. It also requires new repeaters and repeater housings, and is thus generally used only in new installations.

be readily decoded to recover the original binary information.

A somewhat different three-level signal derived from a binary waveform can be obtained by doubling the delay factor and utilizing algebraic subtraction rather than addition at the output. Unlike basic duobinary, which has an energy content down to the dc level, this "modified duobinary" process, as it is properly called, produces a waveform having no dc component, and is thus easily adaptable to the single-sideband modulation commonly used in telecommunications. It is also possible for a transition to occur between any two levels. This process is used in GTE Lenkurt's duobinary products, although the term "modified" is generally dropped for the sake of convenience.

The duobinary encoding process provides a two-to-one bandwidth compression relative to binary signaling; that is, it affords twice the transmission speed in bits per second as a binary signal of the same fixed bandwidth. This is one of the keys to the duobinary repeater's ability to operate within the same facilities as T1-type units.

Duobinary Repeater

The number of channels that can be combined using PCM techniques depends upon the duration of the time slot assigned to each sample pulse; the shorter the pulse, the greater the number of channels. The digital multiplexer in a 48-channel PCM system accepts two inputs, each containing 1.544 million time slots every second, and combines them so as to produce 3.152 million time slots per second (a 3.152-MHz transmission frequency); the presence of a pulse within a slot determines its logic state. To accomplish this combining, the multiplexer shortens the duration of each slot. It also reduces the duration of the pulses within them to maintain the 50-percent duty cycle (ratio of pulse

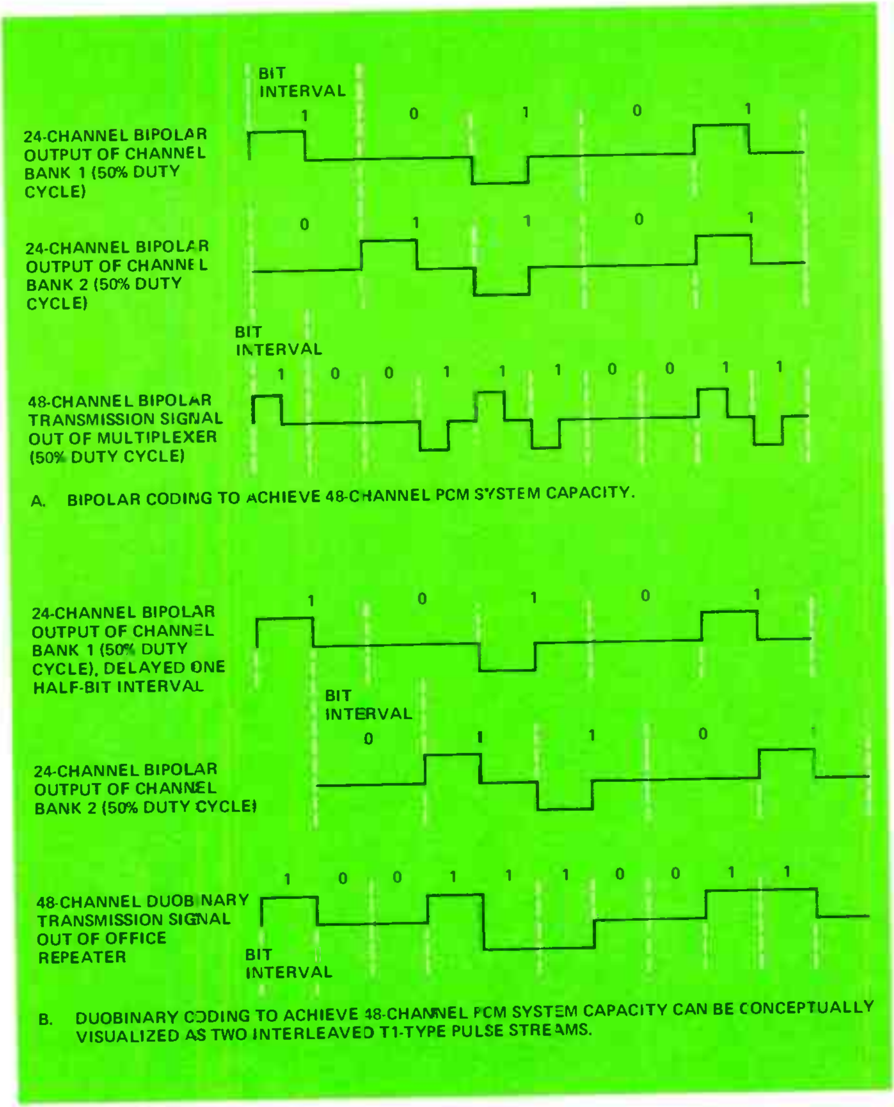


Figure 4. Combination of two 24-channel PCM signals into a single 48-channel transmission is accomplished with encoding techniques.

duration to pulse repetition frequency) used in the 24-channel inputs, as shown in Figure 4A. As has been indicated, this results in a redistribution of power across the frequency spectrum.

In a PCM system that has been equipped with duobinary repeaters to carry 48 vf channels, the duration of the time slots is also shortened, but each pulse is allowed to utilize the entire slot interval. A convenient way

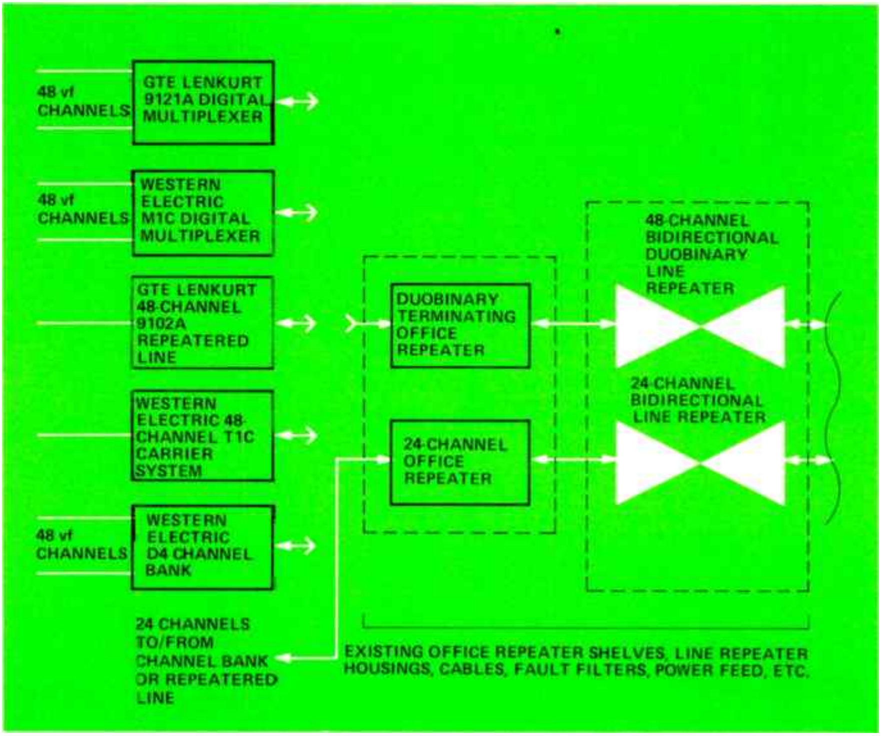


Figure 5. The duobinary repeatered line can accept its 3.152-Mb/s input from many sources, and can operate in the same cable as 24-channel systems.

to visualize this is to consider the duobinary signal as two T1-type pulse streams, one of which is delayed by a half-bit interval with reference to the other, interleaved to produce a 100-percent duty cycle output at twice the speed of the inputs (see Figure 4B). Duobinary coding doubles a system's transmission rate – and channel capacity – while maintaining exactly the same energy distribution curve shape. Not only does this allow expansion of a transmission system's capacity without requiring massive rearrangement of cables and replacement of housings, but it also means that 24- and 48-channel systems can operate within the same facilities without reconditioning the span.

Special engineering consideration has been given to matching the physical dimensions and power requirements of the duobinary repeaters to T1-type units, and to allowing existing order wire and fault location lines and filters to be used. The duobinary repeater equipment thus provides for both electrical and mechanical retrofit of existing T1-type systems, doubling channel capacity without demanding total reconditioning (see Figure 5). As such, it includes both office terminating and line repeater units, as well as a unit for use in intermediate offices where interface with a channel bank is not required. All these units are able to operate over both pulp- and polyethylene-insulated cables.

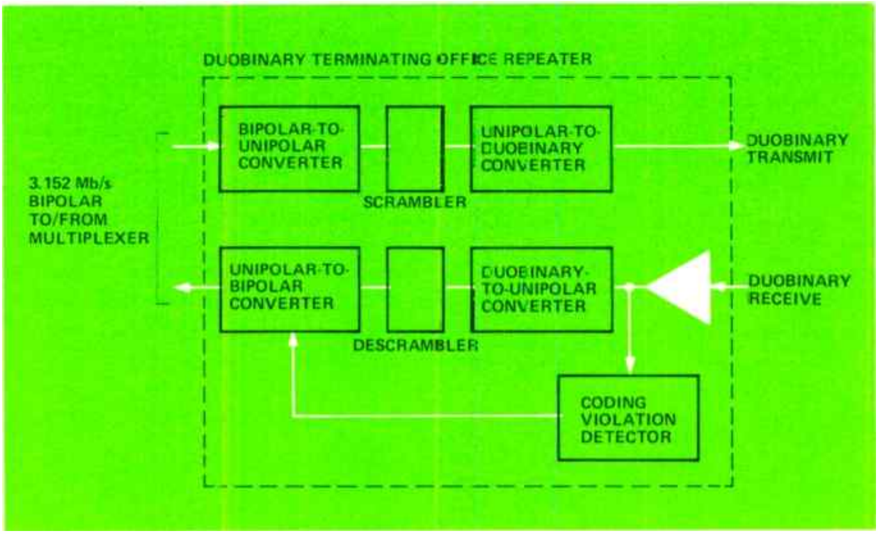


Figure 6. The duobinary end, or terminating, office repeater contains the bipolar-to-duobinary conversion interface that makes possible 48-channel transmission on facilities originally designed for only 24 channels.

The office repeater used at the terminating ends of a span line contains the bipolar-to-duobinary conversion interface (see Figure 6). It accepts the 3.152-Mb/s bipolar output of a digital multiplexer – like GTE Lenkurt's 9121A and Western Electric's M1C – capable of producing such a signal and converts it to a unipolar form. After a scrambling process to eliminate repetitive bit patterns, the unipolar bit pulses are encoded as a duobinary output for transmission over the span line.

In the receive direction, the duobinary input is regenerated, reconverted to unipolar, descrambled, and returned to a bipolar format. In this process, any coding violations introduced during transmission that would indicate defects in the span line tend to be eliminated. Error detector circuitry is therefore provided that detects violations in the incoming signal and inserts them into the output, where they can be identified and action taken to correct the error-producing condition. Along the span, the line and intermediate office repeaters regenerate the signal at the duobinary level, so the only conversion occurs at the end, or terminating, offices.

The demand for service has grown at such a remarkable rate that many telephone companies now find themselves faced with cable facilities operating at maximum capacity sooner than had been expected. Where time and money permit, they can increase their channel capacity by adding more 24-channel systems, or by installing 48-channel systems such as GTE Lenkurt's 9102A or Western Electric's T1C. In most cases, 48-channel systems are selected because they provide greater long-term capacity and thus extend the useful life of such completely new facilities.

Both of these solutions to the filled-cable problem, however, have very much the same shortcomings: they necessitate complete route engineering and installation not only of central office equipment and line repeaters, but also of repeater housings and, usually, cable. Even when existing cable can be used for 48-channel expansion, considerable time and manpower must be committed to resplicing lines into the requisite new housings. Moreover, the entire route is out of service during the changeover.

When conditions preclude such an extensive undertaking, however, expansion of 24-channel systems can still be accomplished using GTE Lenkurt's new 9148A Modified Duobinary Repeatered Line, once it has been determined that sufficient margin was provided in the original route engineering. While there are many instances in which all-new systems can reasonably be justified, there are also many installations that can derive the greatest benefit – both in terms of economics and customer service – from retrofitting existing systems with duobinary repeaters to increase the channel capacity, and thus extend the useful life, of transmission facilities.

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RF Repeaters

The basic function of a microwave repeater is to amplify and redirect microwave signals. Passive, baseband and heterodyne repeaters have traditionally been used almost exclusively for this purpose. Until now, rf repeaters have seen such little use in microwave systems that their existence has been mainly academic. A new rf repeater, recently introduced by GTE Lenkurt, provides an economical alternative for some repeater installations.

Microwave repeaters are generally classified as being either active or passive. The most commonly used passive repeater is the "billboard" type of reflector, which simply redirects microwave signals by reflecting them off of its surface. Passive repeaters are generally used on short microwave hops over inaccessible terrain, where a conventional active repeater installation would be too expensive. The principle advantages of the passive repeater are that it requires no power, provides a fixed amount of signal gain, and requires little or no maintenance. The gain of a passive repeater is proportional to its size and operating frequency. For large gains, the beamwidth is quite narrow, making the positioning of the reflector critical. Also, the gain of the passive repeater in the lower microwave frequency bands is low, thus reducing its economic advantages.

Active Repeater Types

The types of active repeaters currently used on microwave paths are generally of either the demodulating-remodulating (baseband) or the IF or rf heterodyne type. In these types of repeaters, the individual information-carrying channels are amplified and otherwise processed at frequencies usually lower than the microwave carrier frequency.

In a baseband repeater, for example, the incoming microwave signal is demodulated down to baseband level, then amplified, remodulated, and transmitted to the following station. In an IF heterodyne-type repeater the incoming radio signal is shifted to a different frequency (usually 70 MHz),

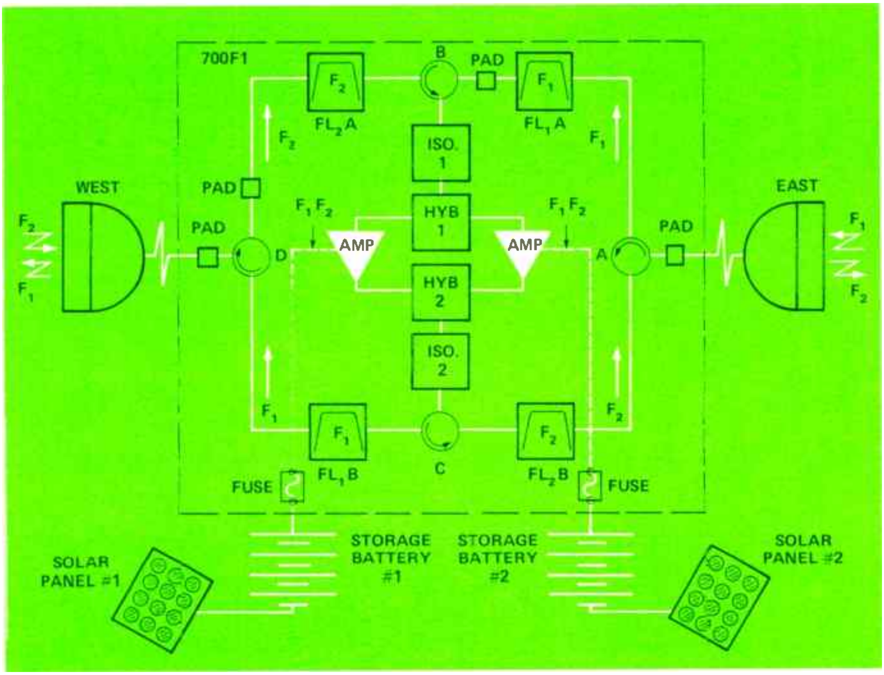

Figure 1. Component diagram of the GTE Lenkurt rf repeater.

which is then amplified and heterodyned back up to the microwave frequency for onward transmission. The rf heterodyne repeater amplifies the incoming microwave signal, then shifts it to a different frequency where it is reamplified and transmitted. The heterodyne-type repeaters do not demodulate the signal to baseband level for the purpose of amplification.

In an rf repeater such as GTE Lenkurt's new 700F1 (patent pending), however, there is no shifting of frequencies before amplification; rather, the entire incoming microwave signal is amplified and transmitted to the following repeater or terminal. The 700F1 is presently licensed by the FCC for use with the GTE Lenkurt 70F1 microwave radio, in the 2-GHz band (1.7-to-2.3 GHz), with a capacity of 36 voice channels. This narrowband rf repeater conserves frequency spectrum, since the band used at the input is the same as that used at the output. Shifting repeaters, such as the rf heterodyne type, have different input and output frequencies.

There is a basic simplicity to the narrowband rf repeater in that there is only one device containing active components, which operate in parallel for increased reliability. There are no frequency generating devices, so complex afc circuitry and periodic frequency checks are unnecessary. Also, the components which are used in the repeater are relatively insensitive to large variations in temperature and humidity, which eliminates any requirements for temperature control, air conditioning, or special enclosures.

Theory of Operation

The operation of the rf repeater can be understood with the help of Figure