GTE LENKURT

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PCM Repeatered Lines

The PCM repeatered line is a system of physical wire lines with repeaters situated at specific locations along the way. It is responsible for accurately reproducing the digital signals that are transmitted between two PCM terminals.

Legend has it that in the early days of telephony, the original repeaters had human form. It seems that before electronic repeaters were developed to amplify voice signals along a telephone line, a human being (called a repeater) would periodically relay information along the line, from the caller to another repeater, or to the final listener. Later, vacuum tube amplifiers replaced the human repeater and adopted his name. Then, solid-state repeaters, were developed to amplify voice frequencies along a line. With the emergence of PCM (pulse code modulation), a totally different type of repeater was developed to accommodate the totally different PCM transmission medium.

PCM Channel Banks

PCM terminals (channel banks) originate and receive the digital information which is conveyed along the PCM repeatered line. There are two types of terminals which are in general use — the D1- and the D2-type. Both D1- and D2-type channel banks can function over the T1-type repeatered line (which is the subject of this discussion), and both sample each voice channel 8000 times per second. Each can handle 24 voice channels over two pairs of cable (one pair for each direction of transmission). One of the major differences between these two terminals is that the D1-type has 127 discrete voltage levels available for quantization, while the D2-type has 255 available levels. The greater number of available levels of the D2-type terminal results in a more accurate representation of the original voice signal at the distant terminal. (See the August, 1971 and January, 1972 issues of the Demodulator for a discussion on D1- and D2-type PCM channel banks.) The digital pulse train generated by the PCM terminal and processed by the repeater is in bipolar form. This means that each pulse (or binary "one") is directly opposite in polarity to the previous binary "one," even if there is a string of zeros in between (see Figure 1).

PCM Repeaters

The purpose of a PCM repeater is to construct an accurate reproduction of the original digital pulse train as it originated at the PCM terminal. The three major functions involved in this process are reshaping, regeneration, and retiming.

The original design of PCM repeaters had to take into consideration existing cable parameters, since economics dictated that existing cable plant be used. In voice frequency transmission systems, loading coils are installed along the line according to a predetermined loading plan, to increase line inductance and thereby improve transmission characteristics. For example, an H88 loading plan requires that 88-millihenry coils be placed at 6,000-foot intervals (except at end sections where spacing is 3,000 feet). Also, if a loading coil cannot be installed at the predetermined 6,000-foot interval, line-building-out networks must be installed to make up the distance required by the loading plan. Both loading coils and line-

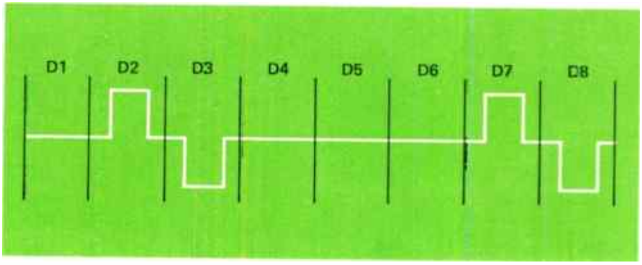


Figure 1. In bipolar format, each pulse is of opposite polarity from the preceding one, even if there is a string of zeros in between.

building-out networks must be removed from existing voice-frequency cable plant if it is to be used for any carrier systems above 4 kHz.

Taking into consideration the 6,000-foot intervals of loading coils, PCM repeaters were designed to faithfully reproduce digital pulses at distances of 6,000 feet or less. This is true for 22-gauge, paper insulated, 0.083 μf cable. The repeater itself was designed to reproduce pulses which have a maximum attenuation of approximately 35 dB at 772 kHz. With these transmission design characteristics, repeaters could be placed at the same location previously occupied by the loading coils. This means that a repeater is necessary for every 6,000 feet (approximately 1 mile) of 22 gauge cable. However, depending on the gauge and capacity of a cable, repeaters may be spaced at up to 2-mile intervals. The advantage of a PCM system, as well as other types of cable-carrier systems, is that for each two cable pairs which previously accommodated two telephone channels, 24 two-way voice channels can now be accommodated.

Reshaping (Equalization)

Reshaping of incoming pulses is the first of three major functions that take place in the repeater. A pulse at a point 6,000 feet from a terminal or repeater will be distorted and may appear as shown in Figure 2. Since the pulse is spread out in time, it is the task of the repeater equalizer to restore the pulse to its original width. It should be noted that it is not necessary or even desirable to restore the pulse to a perfectly rectangular configuration. Hence, the restoration results in a limiting of the frequency band and the production of a rounded pulse at the output of the equalizer. A reshaped pulse might appear as shown in Figure 3.

Regeneration

After the reshaping function, the pulse train is amplified to a predetermined value before proceeding to the regeneration function. The pulse train then enters a voltage-comparator circuit which has a threshold such that if any incoming pulse does not exceed 50% of the nominal pulse height, there

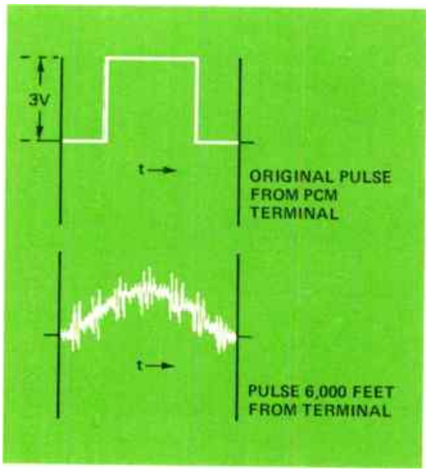


Figure 2. The original pulse is distorted in shape, amplitude, and time, as it travels along the line.

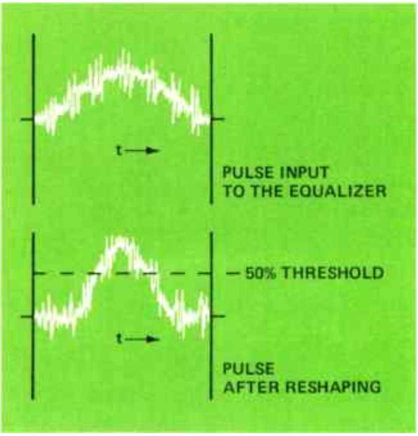


Figure 3. The reshaping function restores the correct pulse width to the incoming pulse.

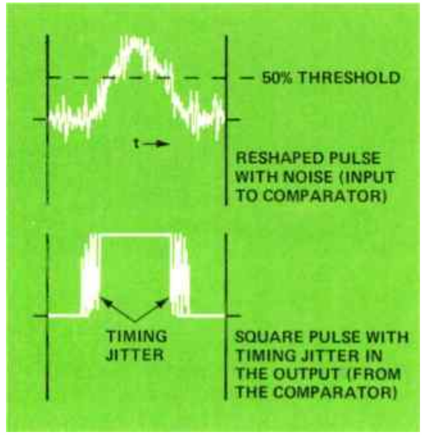


Figure 4. The voltage comparator circuit detects the presence or absence of pulses.

will be no change in the output state from the comparator, for that pulse. Essentially, this circuit is used to detect whether there is a pulse present. If there is no output change from the comparator, a zero (no pulse) condition is assumed. A pulse train may have frequency distortion, amplitude distortion, or timing distortion. All these forms of distortion must be minimized by the repeater functions. In the comparator, the level of the incoming pulse plus the noise riding on the pulse must add up to more than the comparator threshold if there is to be a one (pulse) output. An output pulse from the comparator is a square wave with timing jitter, and might appear as shown in Figure 4.

Retiming

The digital pulse train of a PCM system carries its own timing information. The beginning of the timing process takes place after the pulse has been equalized in the reshaping circuit, amplified, and brought to the correct level in the regeneration circuit. The signal path is then split in two directions — one direction goes into the regeneration circuit, and the other into a full-wave rectifier (see Figure 5). The rectifier transforms the bipolar pulse train into a unipolar pulse train so that each pulse has the same polarity. This unipolar pulse contains the timing wave or clock which must be extracted to provide the repeater timing. Extraction is accomplished by passing the unipolar pulse train through a bandpass filter (LC tank circuit), to produce a 1.544-MHz sine wave. The output from the bandpass filter is fed to an amplitude limiter whose output will be a constant-amplitude square wave. This square wave is differentiated, and produces the appropriate timing spikes, which are fed to the timing circuit to provide the correct timing information for the repeater.

The clock (LC tank circuit) must be triggered at least two out of every 16 pulse periods (approximately 10 μs) to maintain oscillation. To accommodate this, the channel bank suppresses any all-zero codes, thus insuring a minimum of one pulse every word time (approximately 5 μs).

The retiming function must correct the presence of timing jitter in the

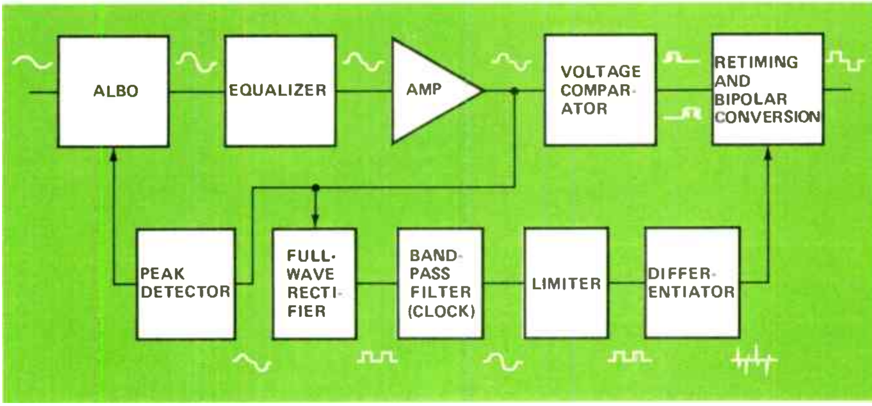


Figure 5. The digital pulse train supplies its own timing information.

pulses coming from the comparator. To do this, the retiming circuit is designed to produce a sample pulse which must be lined up with the nominal center of the pulse coming from the comparator, to minimize the effects of timing jitter present at the pulse edges. A logic function "looks" at the nominal center, and detects if a pulse is present. If a pulse is present, a new pulse is started in the pulse output circuit. The clock also generates a turn-off command which terminates the new pulse (see Figure 6). The only condition that must be met to generate a pulse is to have a "one" output from the comparator when the sample pulse occurs.

One of the problems in the reshaping function is to assure that the pulse, which has widened in time, does not overlap into the next time frame and interfere with the detection of a no-pulse condition. So, one of the functions of pulse reshaping is to make sure that the reshaped pulse dies out by the time the next point in time appears when a measurement (sample) must be taken.

In the regeneration circuit it is important that the threshold be accurately established. And, in the retiming function, it is important that the timing take place in exactly the correct region, since a pulse carrying enough noise to tax the limits of the repeater will have considerable jitter at the output of the regenerator (comparator), as in a worse-case condition. There will be a very narrow region in time where a certain output dictates a pulse condition, but once this condition is detected, a new, noise-free pulse is produced by the repeater.

Repeater Limitations

In theory, an indefinite number of repeaters can be placed in a PCM

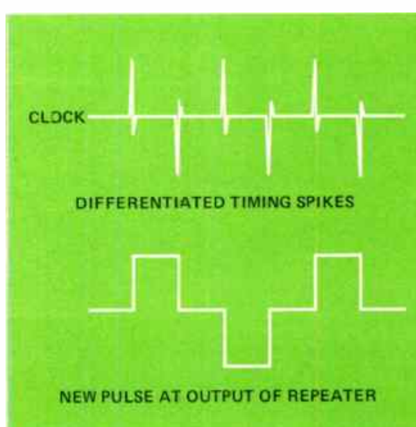
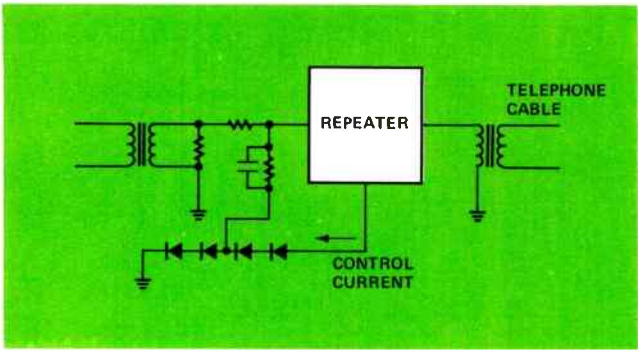


Figure 6. The timing spikes begin and terminate the new pulse.

Figure 7. The automatic line-building-out network maintains a constant electrical length on a section of line.



system; in actual practice this is not the case. Economic limitations prohibit electronic perfection in each of the repeater functions. A slight amount of deterioration is allowed in each repeater, mostly in the form of timing jitter. This means that the pulse train leaving a repeater is not perfectly retimed. The accumulation of timing jitter as the pulse train progresses from one repeater to another slowly reduces the margin-to-noise ratio. Also, the pulse train may be disturbed by crosstalk from other systems or by impulse noise in the cable which comes from relay systems that might be switching in the same cable. These forms of interference influence the clock to a certain extent and result in timing jitter. Because the timing is recovered from the incoming pulse train itself, signals carrying jitter from a previous repeater arithmetically transfer their jitter to the next repeater. It is possible to eliminate most of this accumulated jitter by periodically inserting a special dejittering device, but this would require a very expensive repeater with a highly accurate clock. This might be done in a case where it became necessary to extend the present length of a system.

Automatic Line-Building-Out Network

The major development in PCM repeaters since their original design is the automatic line-building-out network (ALBO). The first designs were such that if the spacing between repeaters wasn't close to 6,000 feet, small artificial lines had to be installed at the input of the repeater. Variations in repeater spacing are now controlled by an automatic circuit. The peak of an incoming pulse is detected by a peak detector which then feeds a control signal into a control element so that the same peak value is maintained at all times, regardless of cable length, as long as the length is less than 6,000 feet. As the cable length varies, the ALBO readjusts to maintain what appears to be a constant length going into the equalizer of the repeater.

The operation of the ALBO is relatively simple. The device, appears schematically as shown in Figure 7. Part of the ALBO is a variable resistance which is realized by varying the current in silicon diodes. This control comes from the repeater, and is proportional to the peak of the input signal. If a cable pair is very short, the signal-input to the repeater will be strong. The peak detector senses the strong signal and puts out a large current which makes the diode resistance very low, thus producing a large shunting affect on the signal. If the diode resistance is low, there is an increase of attenuation to the network. In this way the level of the signal at the input to the repeater always has the same value. Two cable pairs are required for two-way PCM telephone communication. Each repeater, then, has two separate devices within, each capable of handling the digital bit stream in one direction. And, each device is independent of the other except for a common power supply.

Cable

Although there have been some improvements in voice frequency cable that yield better transmission characteristics, no significant changes have been made. Some recent efforts have also been made to place two sets of groups of pairs within the same cable sheath, separated by a shield, to eliminate near-end crosstalk problems. There is work going on now to develop cables with internal shielding for T2-type repeatered lines which must operate at more than four times the speed of the T1-type. Another alternative is to use separate cables for each direction of transmission. This would yield better transmission characteristics but would be the more expensive alternative. The T2-type repeatered line will have a capacity of 96 voice channels on two cable pair, and, if special low-capacity cable is used, spacing between repeaters will be around 12,000 feet — twice as long as for T1 line.

Cable Testing

As mentioned earlier, the bulk of PCM systems being installed today are taking advantage of existing voice-frequency cable. There is, however, a significant difference between the transmission of a square, digital pulse and the transmission of a sinusoidal voice frequency. A cable pair, for example, may work perfectly for voice frequencies, but be completely inoperative when PCM information is placed on it. This has to do, in part, with the frequency band over which the equipment is operating. The square wave has an infinite number of frequencies in the form of odd harmonics in its composition, while with a sinusoidal voice frequency, only the fundamental frequency must be transmitted down the line. It is therefore important for a user of telecommunications equipment to be able to determine which of his existing cables are suitable for PCM transmission.

There are several ways of testing voice-frequency cable for PCM; one of the simplest involves the use of a test set recently developed by GTE Lenkurt. This test set, called the GTE Lenkurt 91100 PCM Cable Pair Test Set, can make three major evaluations, each of which involves the transmission of a *true* PCM signal from the test set. The test set can measure the approximate attenuation of a PCM signal in dB, on any cable pair between repeaters. It can also measure the margin of degradation in a cable pair. This measurement not only tells the user if he has a cable pair suitable for PCM, but also tells him how much more interference a cable pair can tolerate before it can no longer be used for PCM. The third use for the test set is to check a PCM system from end-to-end. This measurement is used when it is uncertain if a transmission problem lies in the terminals or in the repeatered line.

The move toward PCM systems has been gaining momentum for some years. It is one of the major transmission mediums of the future. Already plans are being conceived which make almost exclusive use of PCM transmission. PCM over microwave is also now out of the experimental stage so that in the future, PCM signals will not only travel through cable, but also through space.

GTE LENKURT
1105 COUNTY ROAD
SAN CARLOS, CALIFORNIA 94070

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