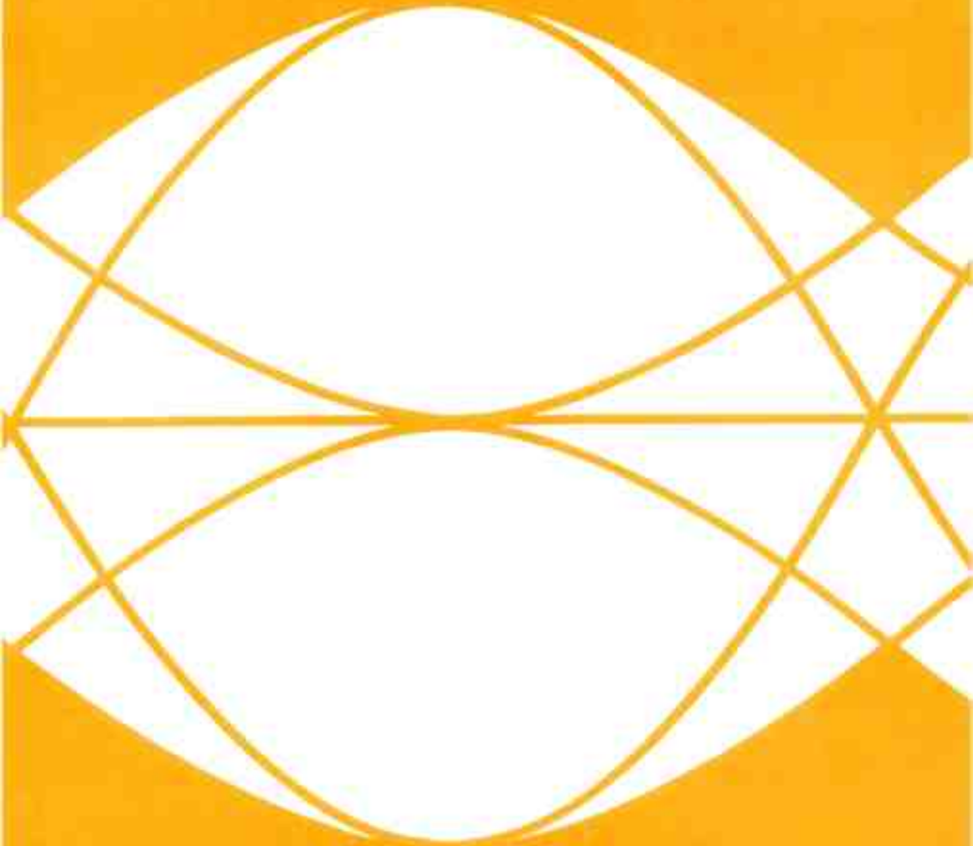
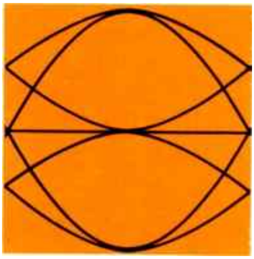
GTE LENKURT

DEMODULATOR

JUNE 1973



PCM Cable Considerations



Pulse Code Modulation is finding greater usage in today's modern communications systems, and promises to be one of the major forms of telecommunications in the future. Yet, the equipment that makes PCM a reality, is greatly dependent on the cable used for transmission.

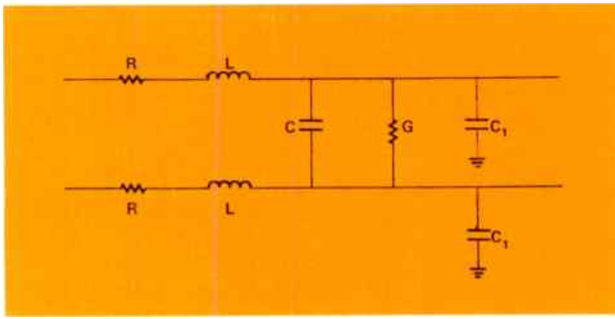
Cable pairs that are to be used for PCM, should be checked for suitability prior to installation of the carrier and repeater equipment. The usual method of testing cables for PCM is with a frequency selective VTVM (vacuum tube voltmeter) and a signal generator or oscillator tuned to 772 kHz, which is the equivalent fundamental frequency of a T1-type PCM pulse train. With the signal generator transmitting at 772 kHz at one end of the cable pair, the amount of signal attenuation can be ascertained by the VTVM at the other end of the line. This method has considerable limitations in that it tests cable performance at only one frequency – 772 kHz. Theoretically, a cable pair *could* be suitably checked with a signal generator if all frequencies from zero to approximately 2.5 MHz were transmitted individually down the cable pair, but this would indeed be a tedious procedure. The cable is also checked for correct loop resistance, insulation, capacitance and dc continuity. (See previous *Demodulator* issues for descriptions of general PCM operation.)

Differences in Transmission

It is impractical to assume that a cable that is known to operate satisfactorily in the voice frequency band will necessarily accept PCM signals. The fault in this assumption is that there are more critical transmission requirements for the high bit rates associated with PCM. A cable pair acts as a low-pass filter to transmitted signals. It has a tendency to pass the lower frequencies quite easily, but rejects the higher-frequency components. In rough figures, the loss per mile at voice frequencies (0 – 4 kHz) is about 1 dB, but about 31 dB per mile at 772 kHz.

Although simple in appearance, a cable pair has complex electrical properties which must be taken into consideration when designing a transmission system, since they determine the transmission characteristics of the cable pair. Figure 1 shows a simplified equivalent circuit of a cable pair. The series resistance (R) is the simple ohmic resistance of the conductors. The series inductance (L) is the self inductance of each conductor, plus the mutual inductance between the individual conductors. Shunt conductance (G) is the total conductance of the current leakage paths between the conductors, and shunt capacitance (C) is the electrical capacitance between conductors. C_1 is the capacitance between the conductors and ground. These parameters define the attenuation characteristics of the cable, which can be represented as an attenuation-

Figure 1. The electrical properties which determine a cable pair's suitability for PCM are distributed along the entire length of the cable.



versus-frequency curve. The particular values of these parameters depend on the physical configuration of the cable, the material of which it is constructed, the frequencies involved, and the ambient temperature. The simplified equivalent circuit shown in Figure 1 shows the cable parameters as lumped constants, but in reality, they exist uniformly along its length, and are considered to be distributed rather than lumped. The inductance in a cable tends to act as an open circuit at high frequencies, and the capacitance approaches a short circuit at high frequencies. As frequency increases, the more loss there will be in the cable.

Because of the frequency difference between the voice band and the spectrum used for transmission of PCM pulses, acceptable voice frequency pairs may not be good PCM pairs. Voice usage only requires that a cable pair have consistent properties out to about 4 kHz. PCM requires that the cable perform as predicted out to about 2.5 MHz. Added to this requirement of a very wide bandwidth are other potential problems such as crosstalk and impulse noise which become more critical at the higher frequencies. It is important for a user who is contemplating a PCM-system installation to know if his existing cable meets the necessary requirements. A simple solution to accurate determination of cable suitability for PCM is to simulate an actual PCM pulse train on the line before installation of carrier equipment. This can be done quickly and inexpensively by using one of the PCM cable test sets recently introduced in the telecommunications industry.

PCM Cable Test Sets

One such test set is the GTE Lenkurt 91100 PCM Cable Test Set, which consists of a two-section unit that can transmit or receive a bipolar, T1-type PCM pulse train at 1.544 megabits per second. Two test sets are necessary for PCM cable section testing. The pulse train from the test set is "pseudo random." It is random in that any combination of ones and zeros may appear on the line, but pseudo random in that the pattern repeats itself after a set number of transmitted bits. The receiving section of the set evaluates the incoming pulses, and displays on a meter and dial, the cable's suitability to accept PCM signals. Figure 2 shows a block diagram of the PCM cable test set.

In the laboratory, it is possible to see the way in which the test set evaluates a cable pair by observing the eye pattern produced when an oscillo-

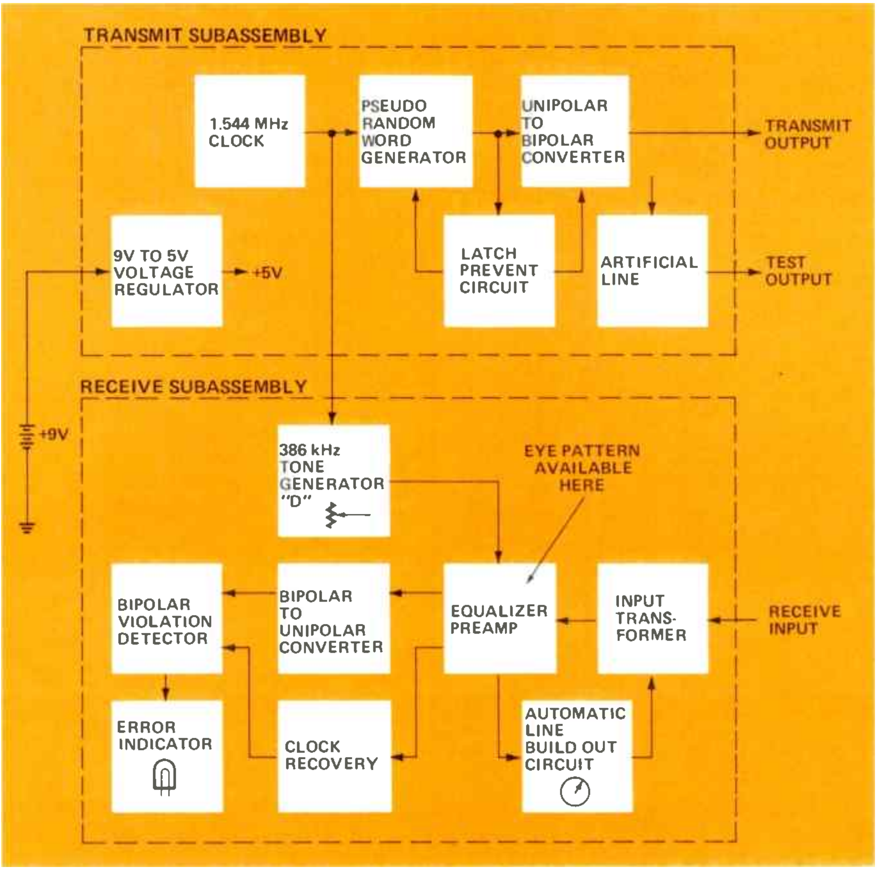


Figure 2. Block diagram of a PCM cable test set.

scope is connected to the preamplifier of the set. The oscilloscope displays all the incoming bipolar pulses superimposed on one another. Figure 3 shows an example of an ideal eye pattern. The threshold detector in the test set is set at the center of the eye, where there is maximum probability of detecting a one or a zero. Any signal that goes above the threshold is a one, and any signal that falls below, is a zero. The eye pattern is a composite of all the incoming pulses and the distortion associated with them. It makes visible to the observer, the condition of the incoming digital bit stream by displaying an open, partially-open, or closed eye. Figure 4 gives an example of an open eye and a partially-open eye under actual transmission conditions. The amount of closure is determined by the amount of distortion in the cable.

Noise Margin

The noise margin of the cable determines how much more noise a cable can tolerate before it is no longer suitable for PCM transmission. Figure 5 shows how the test set may be

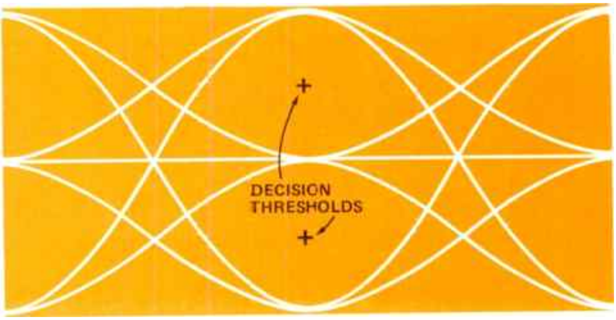
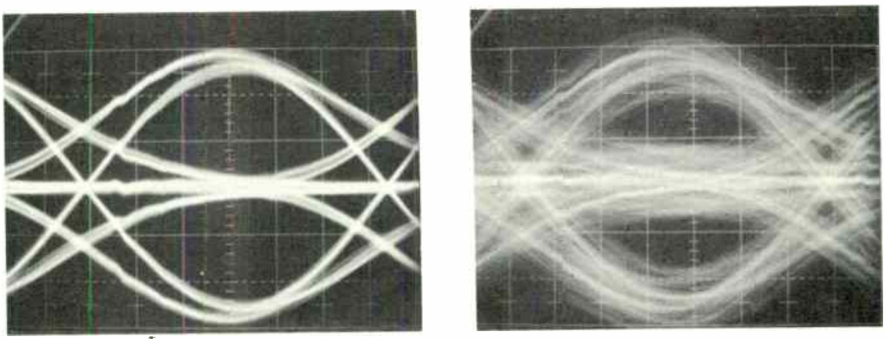


Figure 3. An ideal eye pattern which would be observed with a perfectly noise-free signal.

utilized to check cable sections between repeaters and complete span lines between terminals. If the test set at A transmits a pseudo-random pulse train which is received at test set B, the meter at B records the amount of attenuation in dB that the signal has undergone in traveling from A to B. If, for example, a 6,000-foot section of 22-gauge, .083-μf/mile cable were under test, and the attenuation was 27 dB, this would be an acceptable loss for that length of cable. However, a much higher dB reading would indicate a bad cable or the presence of some obstruction such as a loading coil or building-out network. The use of existing cable pairs for PCM or any other type of carrier service requires that they be free of loading coils, building-out networks, crosses, splits, high-resistance splices, grounds, moisture, and bridged taps.

If the amount of attenuation is acceptable, the operator at the receive end begins to apply an interfering tone to the incoming signal, by turning a D-factor potentiometer. The D-factor corresponds to a mathematical relationship between the ideal eye and the eye of the cable under test. The D-factor potentiometer indicates the amount of *degradation* imposed on the incoming signal by the test set. The amplitude of the interfering tone is increased until the test set begins to make errors. Visually, this would create a closed eye pattern, and would



OPEN EYE PARTIALLY-OPEN EYE

Figure 4. The greater the eye opening, the better the possibility that the cable is suitable for PCM.

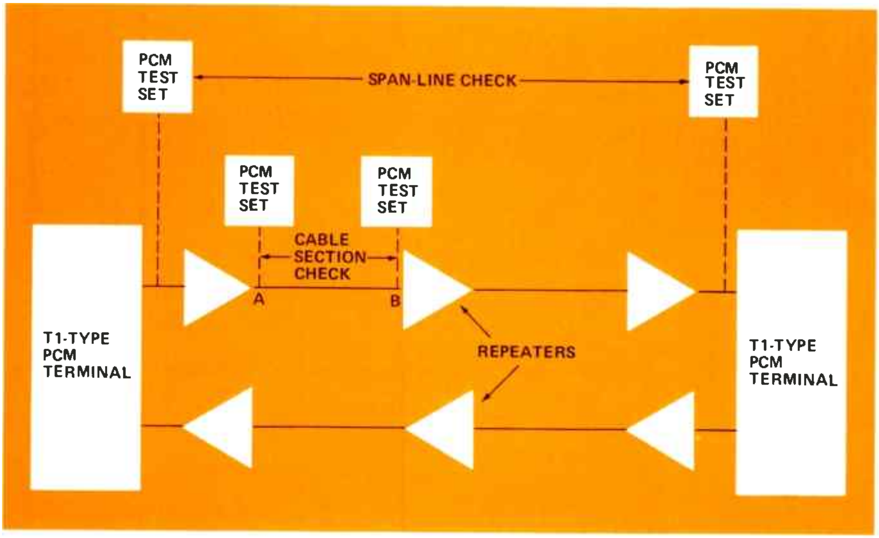


Figure 5. A PCM test set can be used to check cable pairs between repeaters, and entire repeatered lines.

correspond to a situation where the threshold detector of a repeater, or in this case, of the test set, could no longer distinguish between a one and a zero. The reading on the D-factor dial is numbered from 0 to 1.0 in 0.1 steps, with the lower numbers indicating the best conditions. Figure 6 shows the D-factor readings and the corresponding loss in margin-to-noise (system degradation). In practice, desired D-factors for normal cable sections will be between 0.1 and 0.3. Cables with D-factors between 0.3 and 0.5 are still acceptable, but as shown in Figure 6, the margin is reduced 6 dB at 0.5 compared with 3 dB at 0.3. Cable sections with D-factors over 0.5 are not suitable for PCM transmission.

Tests In Both Directions

It is important to test the cable in both directions, since a faulty cable may check good in one direction, but bad in the other. If, for example, there is water in the cable between the two test sets, it will appear as capacitance at a localized point. In a 6,000-foot section of cable, if there is water at 1,000 feet from the transmitting test set at point A, most of the energy will be reflected and the receiving test set at point B will detect a fault and give a high D-factor. However, when point B transmits to point A, since the signal has already traveled 5,000 feet before it hits the water, the reflection will be less, and the reading on the D-factor scale may show the cable as acceptable. So, when the reading in one direction is much better than in the other, it is an indication of a fault in the line.

An important application of the test set is in checking the performance of the complete span line, including line and office repeaters. This test will reveal marginally-operating repeaters, since a span line that can handle the pseudo-random signal generated by the

D-FACTOR	LOSS IN MARGIN, dB
0.1	1
0.2	2
0.3	3
0.4	4.5
0.5	6
0.6	8
0.7	10.5
0.8	14
0.9	20
1.0	INFINITE

Figure 6. The lower the D-factor, the better the suitability of a cable pair for PCM.

test set will perform well with the signal of an actual PCM system.

Additional Systems

When adding a PCM system to a route that has been designed for N number of systems, but due to growth, requires another system, it must be assured that the new system will not cause failures in the existing systems. The cable pairs for the new system should be tested by D-factor measurements in each repeater section. At the same time, any adverse effect that the new system might have on working systems in the same cable can be observed. While one test set is transmitting in the forward direction, errors may be checked on working systems at the receive terminal using a test set or built-in error detectors on the office terminating equipment. If errors do not increase, there is added confidence that the new system will not disturb systems already in service. This is especially so since the sustained pseudo-random output of the test set signal will produce more crosstalk than the normal signal of a PCM system.

The usual dc methods of testing cable such as checking loop resistance, insulation of cable, capacitance of cable, and dc tests for continuity still provide valuable information on the condition of the cable, but the use of cable test sets that send a true PCM signal down the line insures that the cable will stand up under actual PCM-transmission conditions, and evaluates how a cable with existing PCM systems will bear additional systems.

GTE LENKURT
1105 COUNTY ROAD
SAN CARLOS, CALIFORNIA 94070

GTE LENKURT

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TRANSMISSION SYSTEMS

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