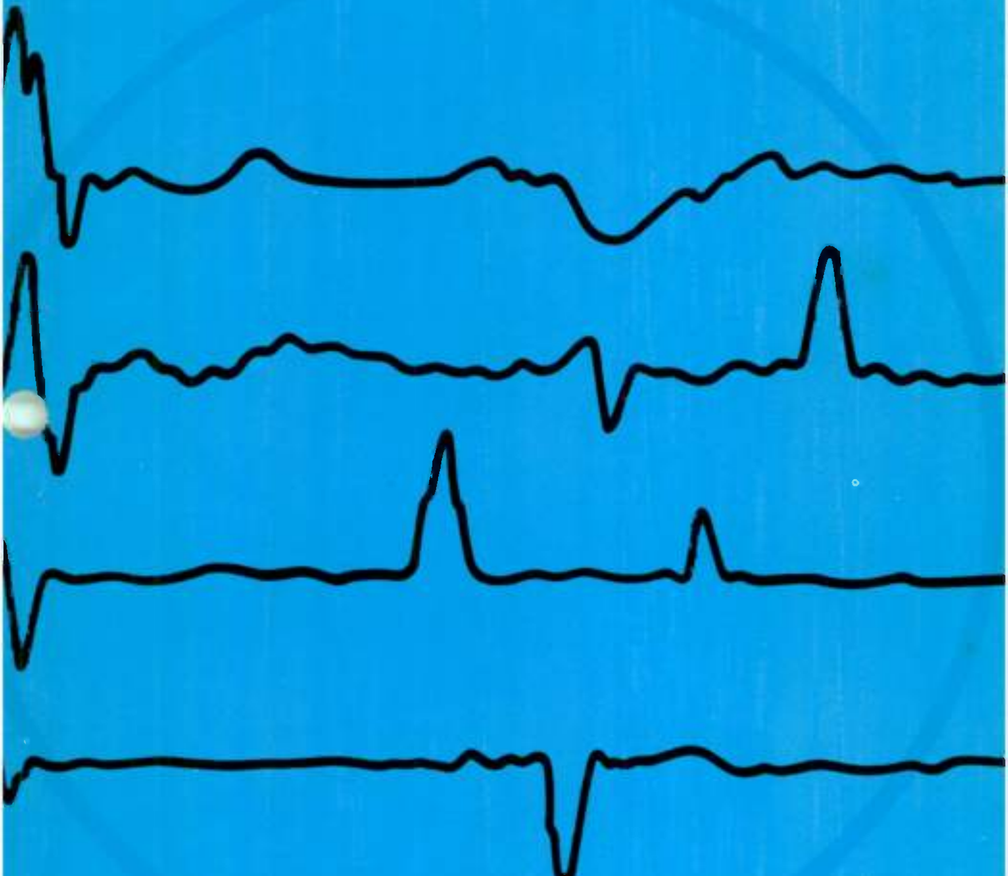
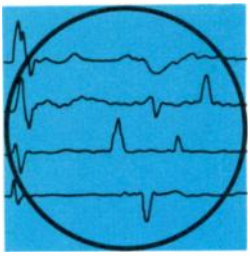
GTE LENKURT

DEMODULATOR

DECEMBER 1971



CABLE TESTS AND MEASUREMENTS FOR PCM



For the user of communications equipment who is contemplating connecting new equipment to cable that has already had considerable service, it is wise to be sure that existing lines are in acceptable condition.

New equipment has on many occasions been connected to older cable resulting in an unsatisfactory system. In a situation such as this, if only part of the total number of channels function properly – what is at fault, the cable or the equipment? Because it is difficult to reliably estimate the overall condition of older cable without testing, this question can only be answered after a complete series of tests and measurements have been performed on the cable.

Because of its period of usage, deterioration of older cable may result in such faults as shorted cable pairs or moisture within the sheath. To detect faults such as these, measurement of each cable pair is still the ideal method of operation. Although the measurements discussed here tend to favor testing for PCM, they are suited for all types of carrier operation.

The use of 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, bridged taps, and cable terminals bridged across pairs (when subscriber cable is used). Should a bridged tap, loading coil, or building-out network scheduled for removal be overlooked when reading a cable location map, subsequent visual observations may completely fail to detect it. For this reason, pulse reflection tests using a radar test set are recommended when the presence of any of these external additions is suspected. Additional tests which help to evaluate the overall condition of a cable include:

(1) DC loop resistance and conductor resistance balance test using a Wheatstone bridge.

(2) Insulation resistance measurement using a megger test set.

(3) Frequency response test to 1 MHz using an oscillator and frequency selective voltmeter.

Radar Cable Test Set

The radar cable test set is an invaluable tool in detection of cable discrepancies and attached networks. The test set, as its name implies, operates on the simple principle of pulse reflection. The nature of the return pulse reveals the type of discontinuity present in a cable. For example, a positive (upward) deflection on the test set oscilloscope trace indicates an open circuit or high impedance mismatch while a negative deflection indicates a short circuit or low impedance mismatch. A shorted pair returns a strong negative pip at the point of short circuit since almost all energy is returned from the fault. A good cable pair will show either no reflection or an open (positive pulse) providing the end of the cable is within the range of the radar test set. In addition to

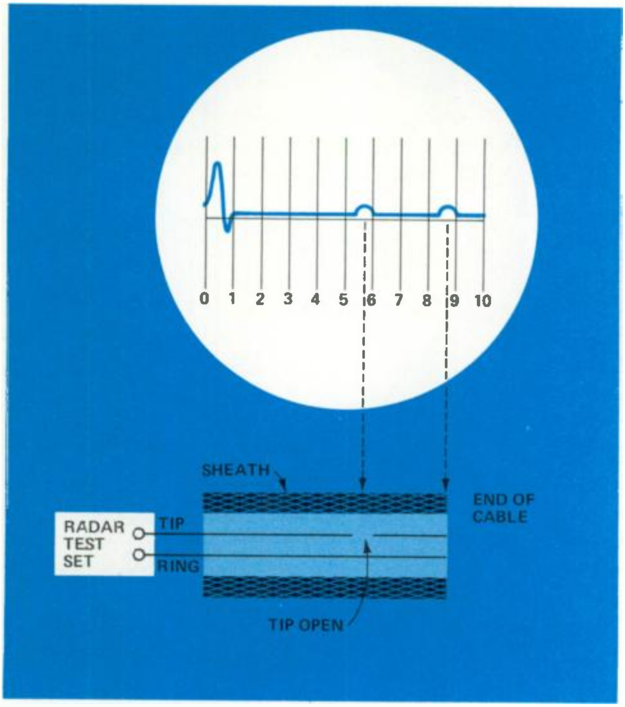


Figure 1A. A pair with one conductor open will show a positive return pulse.

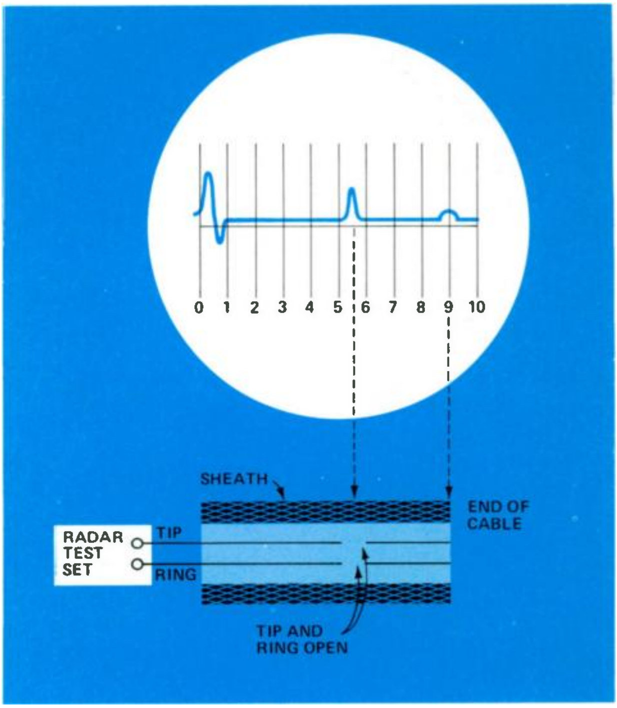
revealing the nature of the discrepancy in a cable, the radar test set can also show the actual distance to the point of fault.

Although the operation of a radar test set is relatively simple, some experience is necessary on the part of the operator in the interpretation of the return signals. For example, a negative return pulse displayed on the oscilloscope of the radar test set for two separate cable pairs does not necessarily mean that the cable pairs have similar discrepancies. The method of detection in this case would be to notice the amplitude of the return pulse since different amplitudes indicate different cable faults.

Open Conductors

An open in either conductor will result in a positive pulse on the oscilloscope screen although of lesser amplitude than if both conductors were open. Figures 1A and 1B show the oscilloscope display as it would appear with one and two conductors open. Also shown are the corresponding cable pair and sheath with the appropriate conductor designations. The reflection from the end of a cable may sometimes be observed in spite of an open in one of the conductors, but this depends upon the closeness of the fault to the end of the cable and upon the size of conductor used. Telephone communications lines generally use cable which ranges from 16 to 26 gauge; the attenuation of the cable increases in direct proportion to the gauge number. The return pulses in 26-gauge cable are the weakest since this gauge has the greatest attenuation due to its higher resistance. Testing

Figure 1B. When both conductors are open the return pulse will be of greater amplitude than that for one conductor open.



a 26-gauge conductor, the maximum fault location distance is about 4000 feet. For greater distances (8000 to 10,000 feet) a special pulse amplifier must be used to see the return signal.

Historically, the tip (T) and ring (R) designations were so called because they corresponded to the contacting part at the tip and ring of the phone plug used to make circuit connections in a manual switchboard. Today, the designations tip (T) and ring (R) are used to identify the two conductors of a cable pair. The sleeve of the plug is used for certain control functions, not directly associated with the cable pair.

Loading Coils and Building-out Networks

The function of a loading coil is to increase line inductance and thereby improve transmission characteristics. As shown in Figure 2, the tip and ring conductors connect to separate windings on the donut-shaped core. The two coils are wound in a direction that produces an aiding magnetic field. A cable which runs between two points is engineered according to a predetermined loading plan. For example, an H88 loading plan requires 88-millihenry coils to be placed at 6,000-foot intervals along the cable.

If for some reason, be it geographical obstruction or inconvenient location, a loading coil cannot be placed in the designated area, a building-out network is used to artificially make up the required distance (6000 feet in the case of H88 loading). The building-out network consists of resistors and capacitors connected in such a way that electrically, the distance between loading coils conforms to the required loading plan. That is, the building-out network contains the resistance and capacity inherent in the length of cable necessary to conform to the loading plan. Loading coils and building-out networks must be removed from the cable before it can be correctly evaluated for use.

Open Sheath Detection

A high-frequency pulse such as is emitted from the radar test set will usually be prevented from passing through a loading coil by the choking effect of inductance on high frequencies. However, using a certain hookup procedure, the radar test set may be made to measure beyond loading coil points.

Individually, the tip and ring windings of the loading coil will have a nullifying effect on a high frequency pulse, but when the pair conductors are connected together, this effect is counteracted to some extent.

To detect an open sheath, one or more cable pairs which have been tested and found to be serviceable must be connected in parallel to one terminal of the radar test set; the other terminal is connected to the cable sheath. In this way the effect of the loading coils is cancelled and the test pulses can pass beyond the attenuating inductance. Figure 3 shows the radar test set hookup and corresponding oscilloscope display for open sheath detection.

Grounded Sheath On Buried Cable

When cable is buried by means of a cable plow, the surrounding earth will remain loose, thus creating a void around the cable. With the passage of time a gradual repacking takes place and the void is eliminated. Should a grounded sheath exist during a void environment. detection of the fault is possible provided the void is filled with water such as occurs in an area with a high water table or after a rainfall which has heavily wetted the ground.

Plowed cable normally disturbs the surrounding earth to such an extent that the sheath-to-ground capacitance is non-uniform. This causes sufficient variation in capacitance to make propagation of the radar pulses difficult. However, when the void is filled with

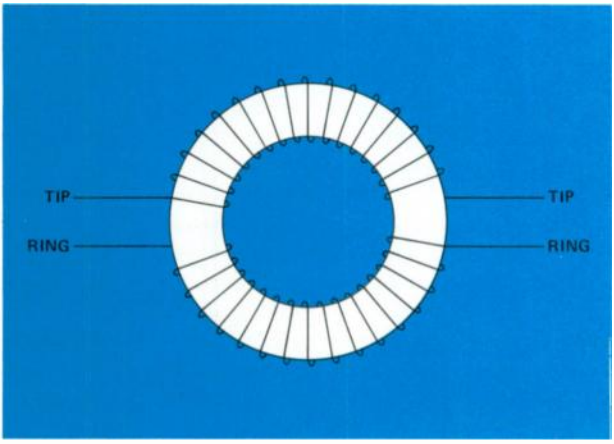
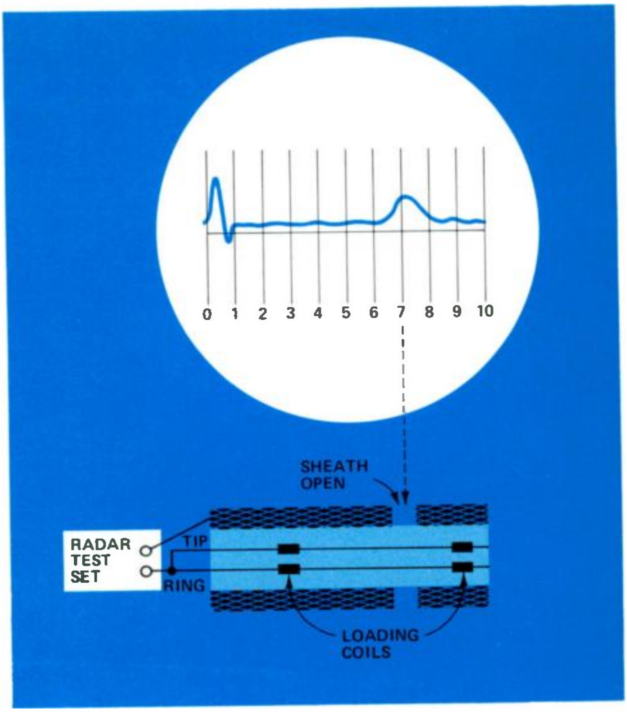


Figure 2. Loading coil with corresponding tip and ring connections.

Figure 3. Display and hookup for open sheath detection.



water, or earth conductivity is low (40 to 50 ohms), the capacitance tends to become more constant, and a pulse may be returned with sufficient strength to be visible. Figure 4 shows the grounded sheath oscilloscope display with the corresponding test set connections.

Cable Splices

Due to the change in relationship between cable pairs and the sheath, a splice represents a decrease in capacitance, and will appear as a small rounded positive pip (radar return pulse) followed by a small negative pip on the oscilloscope trace. At times, the negative pip may not appear. A known splice may be used as a reference point for calibration when performing measurements in a cable of unknown dielectric constant.

Crosses

Metallic crosses (short circuits) between pairs present somewhat the same indication as a short to the sheath. Since a metallic cross is usually a solid connection it may seem that the easiest way to find the other pair or conductor involved is by performing a standard battery and earphone test. However, since the radar test set indicates the distance to the trouble, once the sheath is opened the trouble can be found visually.

Crosses due to moisture in the cable appear as an extremely noisy trace with a vertical displacement of the entire trace throughout the wet section, as shown in Figure 5. Any reference points, such as splices within the wet area will appear farther apart than normal. Ranges in the wet area will appear approximately 60% greater

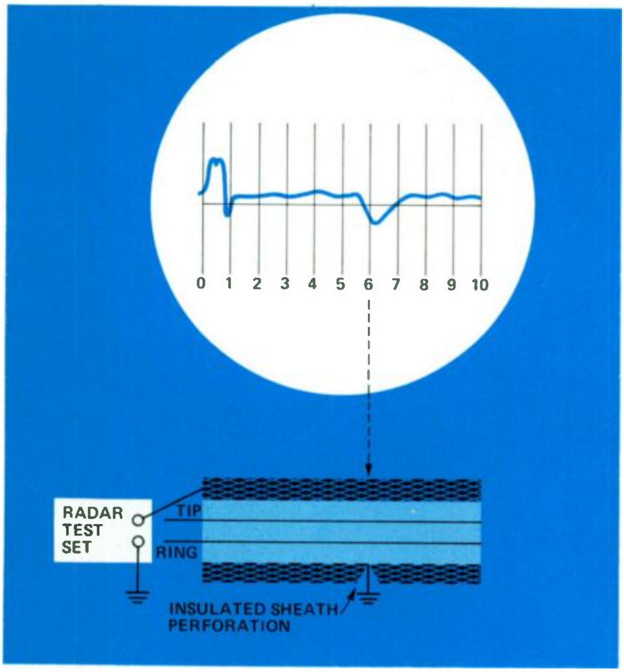


Figure 4. Grounded sheath on buried cable.

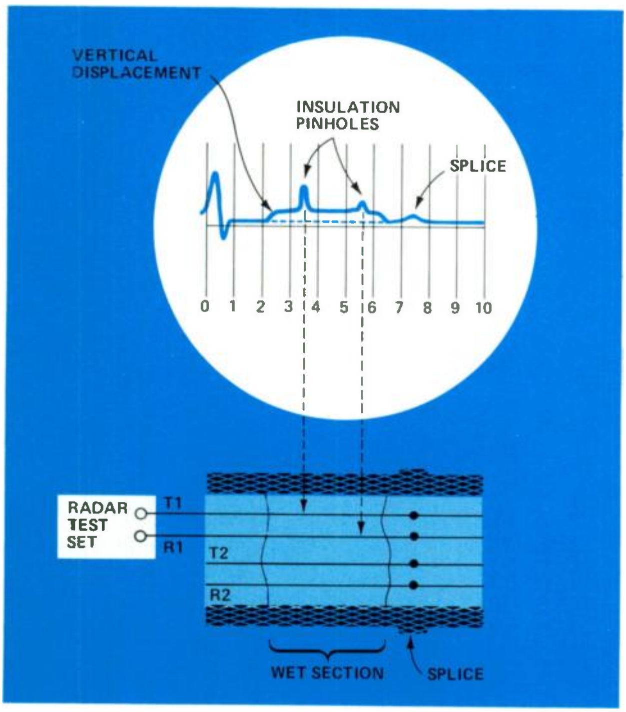
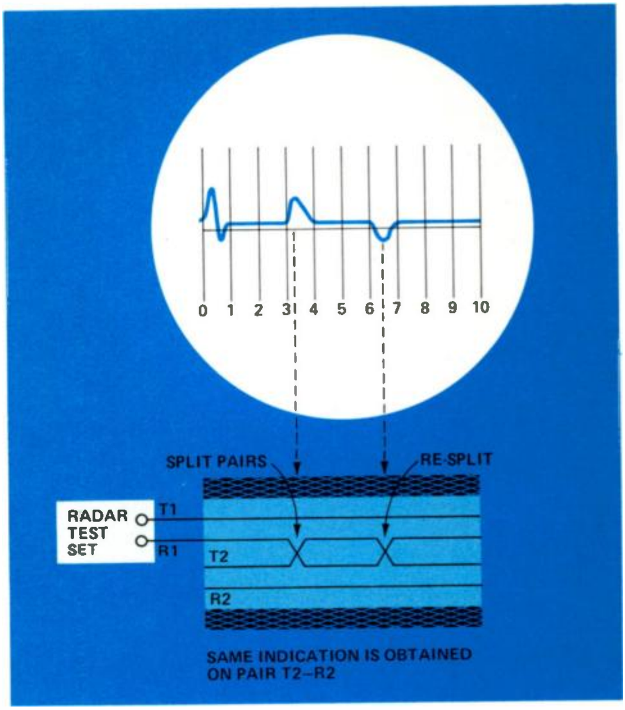


Figure 5. Crosses due to moisture appear as an extremely noisy trace with a vertical shift.

Figure 6. A split pair on a cable causes a decrease in capacitance and a positive pulse on the scope.



than the reference distance if the fixed Polyethelyne Dielectric setting on the radar test set is being used. This setting takes into consideration only dry PIC cable, the PVC (propagation velocity constant) of which is 0.667. This velocity constant means that high-frequency signals in the cable will travel only 66.7% as fast as they would travel in free space. The retardation effect caused by the higher dielectric constant of water decreases the propagation velocity of the pulse, yielding a slower traverse of the pulse through the wet section. To accurately measure the distance within the wet area, the Cable Dielectric Switch on the radar test set may be manually adjusted until a known reference point such as a splice is correctly positioned. The correct distance may now be read in spite of a change in PVC. The propagation velocity constant of wet cable is approximately 0.400.

Split Pairs

A split occurs at a splice when the tip or ring of one cable pair is accidentally spliced to the tip or ring of a different cable pair. Without the radar test set, the location of a split is often very difficult to find, especially on buried cable. The oscilloscope presentation for a split will show a capacitance discontinuity similar in form to that of a splice at the point where the conductors are separated. That is, a decrease in capacitance will be indicated by a positive pip as shown in Figure 6. If a re-split (restoration to normal condition) occurs in a subsequent splice, the pip will appear with the opposite polarity of that shown for the split.

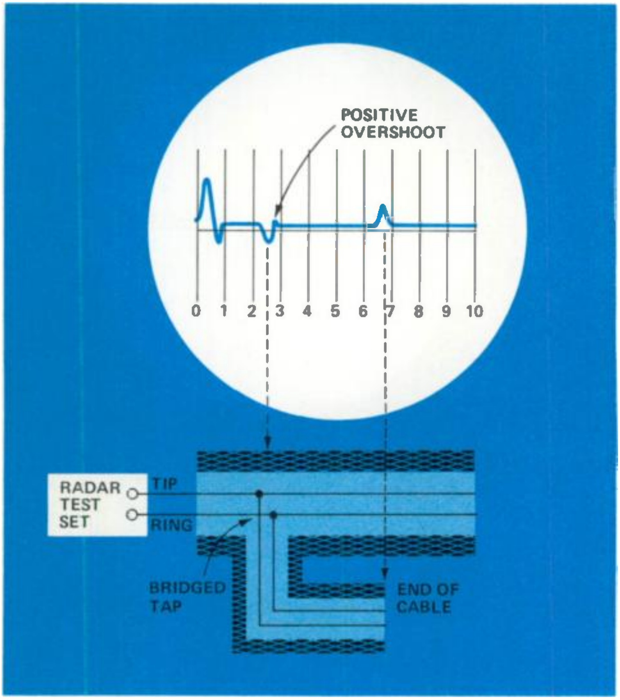


Figure 7. Bridged taps appear as negative pips with a positive overshoot.

Bridged Taps

For any type of FDM or PCM carrier operation, bridged taps must be removed since they represent a capacitance mismatch at high frequencies. These taps appear as negative pips, having a negative amplitude with a following positive overshoot or tail as shown in Figure 7. The amplitude of the overshoot is directly proportional to the length of the tap. Generally three or four taps with an average length of 100 feet will absorb all the output energy of the test set. In order to verify that all bridged taps are removed, it is necessary to repeat the test from the location of the last removed tap. A bridged cable and the main cable will present an overlapped trace. If a fault (short, cross or ground) also exists on the same cable pair, measurement from two locations is necessary to determine positively the location of the fault.

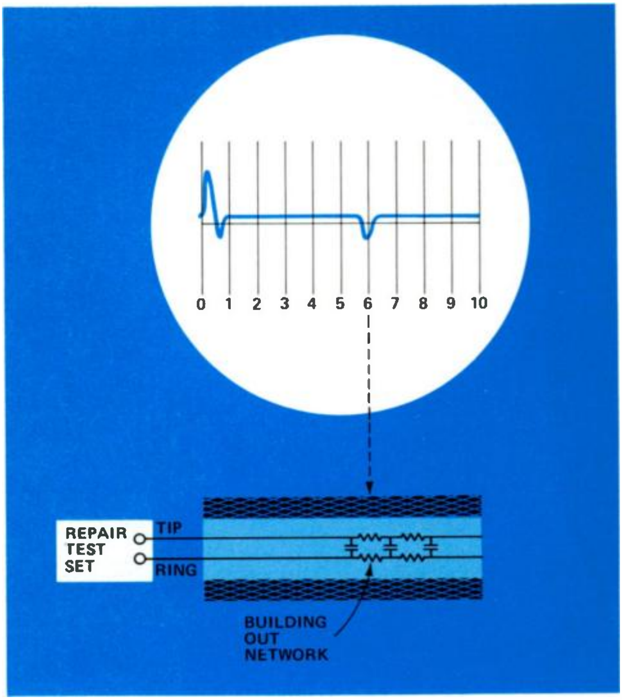
Loading Coil and Building-Out Network Detection

Loading coils and building-out networks that have been overlooked in the process of deloading a cable for carrier use, are perhaps the most difficult things to locate without the aid of an instrument such as a radar test set. A building-out network will appear on the oscilloscope display as a short circuit (the capacitors in the network short-circuit the radar pulse) and a loading coil appears as an open circuit since the pulse will not pass through the coil (see Figures 8 and 9).

Change in Wire Gauge

An increase in wire size such as at a splice decreases the resistance of the

Figure 8. Building-out networks appear as short circuits.



line and will give a negative pip similar to that of a bridged tap, but of lesser amplitude. The propagation velocity constant varies by approximately 1% per gauge number. (A change from 22 to 24 gauge will change the PVC by about 2%.)

Change in Dielectric Material

A change from PIC to PULP (paper insulation) cable will also cause a reflection indication. In this case, the propagation velocity constant will increase, producing a decrease in surge impedance, thereby yielding a negative pulse on the oscilloscope screen. The resultant pip amplitudes are generally small, less than those caused by bridged taps. If the dielectric constant of the insulation is known, the change in propagation velocity constant can be calculated by the formula:

$$\Delta PVC = \frac{1}{\sqrt{e}}$$

where e is the dielectric constant.

DC Loop Resistance and Conductor Resistance Balance

This test is advisable to verify the correctness of loop resistance and conductor resistance balance, which is necessary for proper carrier operation. Because the allowable resistance variation between conductors in the conductor resistance test is a maximum of ±0.5%, it is necessary to use a Wheatstone bridge since its accuracy is dependable within this tolerance. Measured loop resistance should check within 10% of the calculated values given in Figure 10. Due to the relatively wide tolerance in the loop test, and the fact that the balance test is a comparison measurement, it is permis-

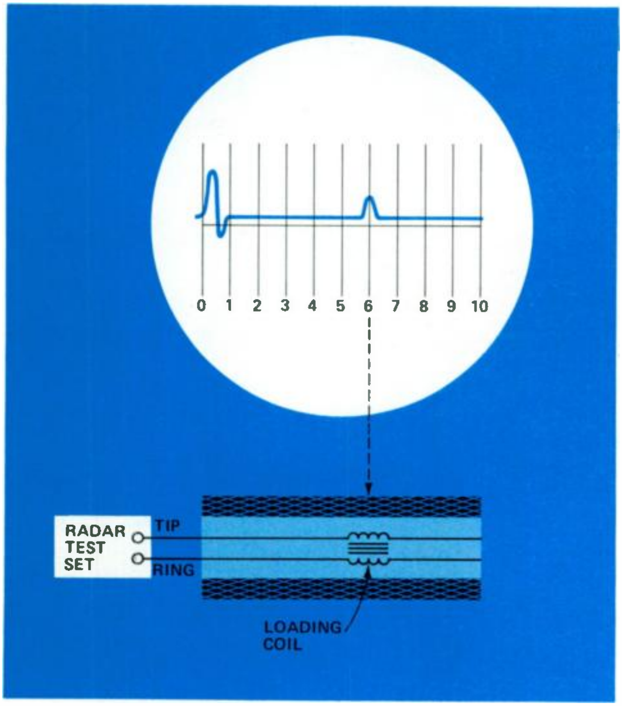


Figure 9. A loading coil appears as an open circuit.

sible to neglect the effect of temperature on the wire resistance.

With a Wheatstone bridge connected to the pair to be measured and a short-circuit placed across the distant end of the pair, the hookup will appear as in Figure 11A. The loop resistance should be within the required 10% tolerance of the calculated values given in Figure 10, noting that this is the total resistance "out and back." Removal of the short circuit at the distant end should indicate an open circuit. This step is necessary to verify that the pair being measured actually had a short circuit placed on it, and was not showing a loop due to some other connection.

Cable Gauge	Resistance Ω/kft at 68° F
16	8.03
19	16.10
22	32.28
24	51.34
26	81.62

Figure 10. Total "out and back" conductor loop resistance.

Example:

Assuming that 6200 feet (6.2 kft) of 22 gauge cable is used in one regenerator (repeater) section,

Loop resistance
= 6.2 kft x 32.28 ohms/kft
= 200.14 ohms.

Figure 11A. Loop resistance measurement.

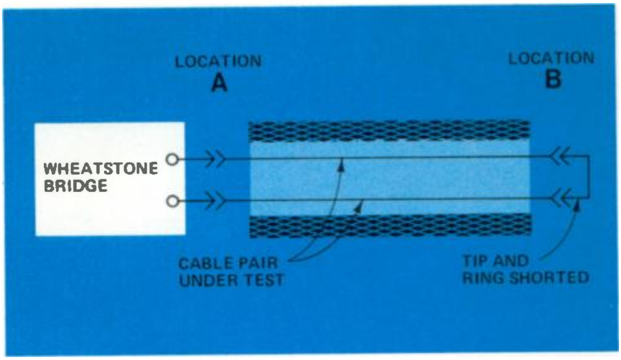
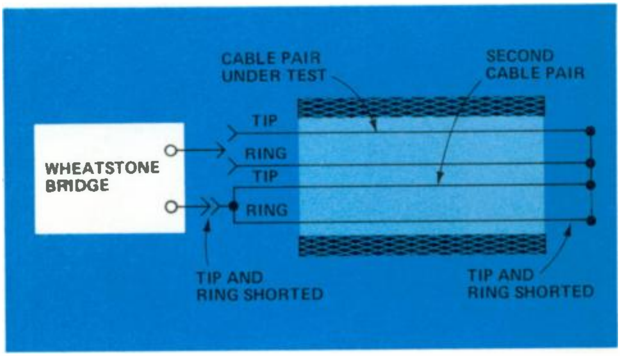


Figure 11B. Conductor resistance balance measurements.



To measure the conductor resistance balance, the Wheatstone bridge should be connected as shown in Figure 11B, using a second pair in the same cable as a third conductor. Individual measurement of the tip and ring conductors of the pair under test is necessary and is performed as shown by the arrow connections. First the tip then the ring of the pair under test is measured using the second cable pair as a return path.

Example:

For 6.2 kft of 22 gauge cable,

Loop resistance

= 6.2 kft x 32.28 ohms/kft
= 200.14 ohms

Average tip or ring resistance

$$= \frac{200.14}{2} = 100.07 \text{ ohms}$$

Average tip or ring resistance plus third-conductor resistance (1/4 of loop resistance)

= 100.07 ohms + 50.03 ohms
= 150.10 ohms

0.5% Tolerance in ohms

= 150.10 ohms x .005
= .75 ohms

Therefore, total resistance of tip or ring plus the resistance of the second cable pair should be between 149.35 ohms (150.10 - .75) and 150.85 ohms (150.10 + .75).

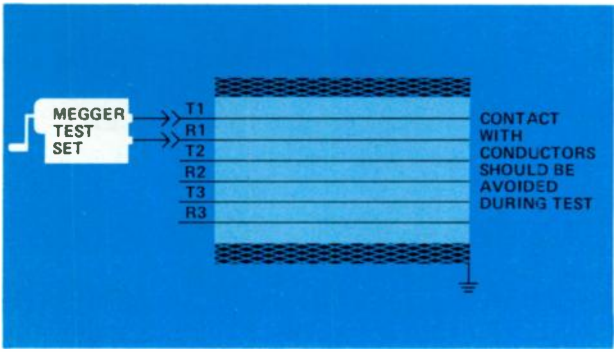


Figure 12A. Megger test on one cable pair.

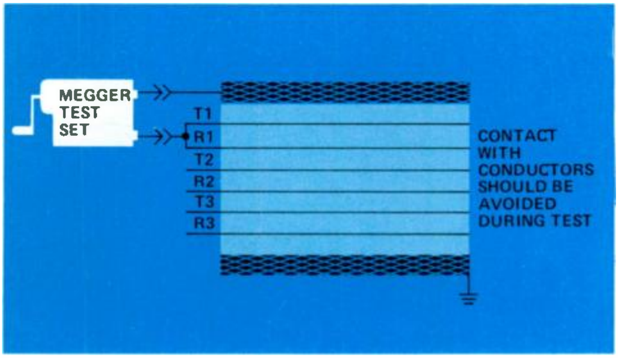


Figure 12B. Megger test of cable pair to ground.

Insulation Resistance Measurement

A megger test set is used to measure the insulation resistance between each conductor and ground and between each conductor of the pair. The distant end of the pair should be open and ungrounded for this test.

The operator should exercise extreme caution in avoiding contact with any of the terminals or wires during this test since the circuit is at a potential of several hundred volts above ground.

Once the megger is put into operation the resistance is then indicated on the megger test set meter. This resistance reading is then divided by the length in miles of the cable under test. The insulation resistance should be the same between the two conductors of a pair (Figure 12A) and between the pair to ground (Figure 12B). Paper insulated cable should indicate a minimum insulation resistance of 500 megohms per mile. Polyethylene insulated cable should indicate a minimum insulation resistance of 1000 megohms per mile.

Frequency Response

For PCM use, the cable pair frequency response must be checked to at least 1 MHz. Although the maximum energy of the PCM band occurs around 772 kHz, a considerable portion of energy exists up to 1 MHz. The frequencies above 1 MHz decrease in importance, so that measurements above this limit are not necessary.

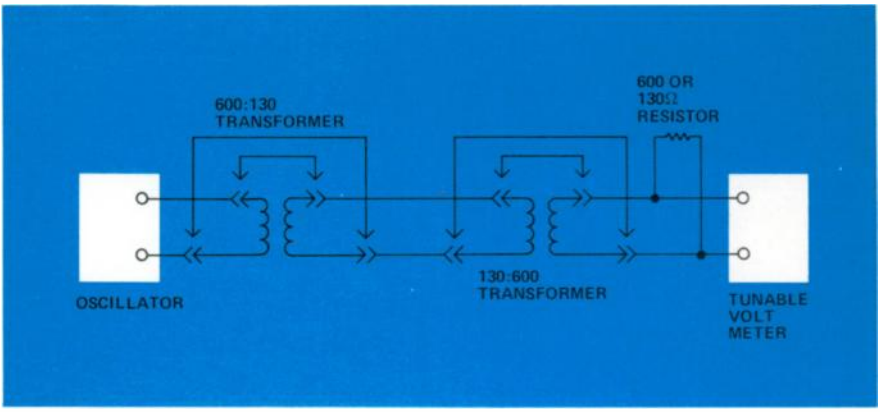


Figure 13A. Equipment arrangement for calibration.

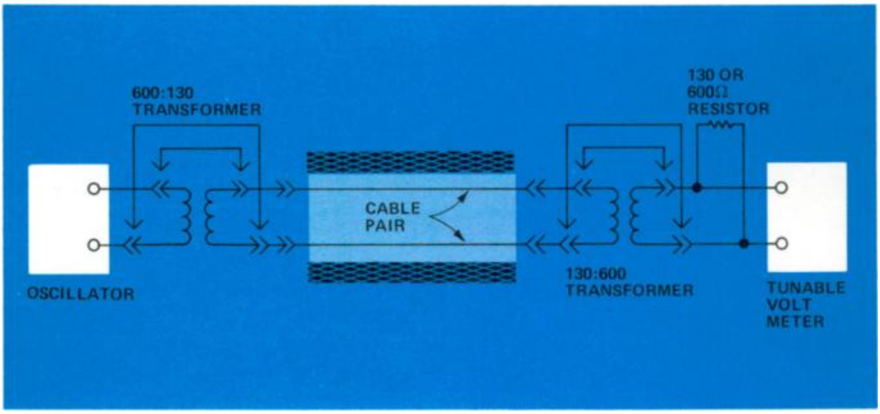


Figure 13B. Equipment arrangement for cable frequency-attenuation test.

Likewise, the frequencies below about 400 kHz decrease in importance for transmission of PCM circuits, so they can therefore be neglected during measurements.

To verify the frequency response and insertion loss of the test transformers, test equipment should be connected as shown in Figure 13A. The test transformers are necessary if the output impedance of the oscillator and/or the input impedance of the voltmeter is 600 ohms. At the frequencies of interest, the cable impedance is approximately 130 ohms. The oscillator frequency should be set to 1 MHz and the meter tuned to this frequency. The oscillator output level should be adjusted to indicate 0 dBm on the meter.

Tuning the oscillator between 400 kHz and 1 MHz, and tracking the frequency with the voltmeter tuner, any variation about the 0 dBm level, at every 50-kHz interval should be noted and recorded.

At the end of the test the oscillator output power must still be 0 dBm on the meter. The oscillator output level during the frequency run on the cable must not be changed.

To check cable attenuation the test equipment should be connected as shown in Figure 13B. The oscillator should be tuned from 400 kHz to 1 MHz, and the received level reading should be recorded at every 50 kHz interval. In addition, the received level at 772 kHz should be recorded. This frequency is used in transmission calculations for the PCM carrier, and can be used to verify the cable attenuation figures used for calculation.

The amount of progressive attenuation of the cable should be plotted at the end of the test and any abrupt change in received level should be noted since this would indicate a change in the transmission characteristics of the cable. Paper-insulated cable will usually exhibit a somewhat higher attenuation than PIC, perhaps 0.5 to 1.0 dB greater per thousand feet at 772 kHz.

Economic Benefits

Returning to the original question – what is at fault on a system with new equipment and older cable, when only part of the total number of channels function properly? With pulse reflection, resistance, and frequency response tests complete, and with any unserviceable pairs removed, this question may now be answered.

Once equipment checkout is complete and verification of adequate crosstalk coupling loss in the system is made, the communications equipment user may then reap the economic benefits of using previously installed cable for his new equipment.

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DEMODULATOR

NOVEMBER 1971

LINE EQUALIZATION FOR DATA TRANSMISSION

The envelope delay and frequency response of a voice channel must be controlled for acceptable, high-speed data transmission.

A digital communications system is typically made up of a digital source such as a computer, a data modem that "conditions" digital signals for transmission over voice telephone lines, the telephone transmission line, and a receiving terminal with a modem and a data sink. The transmission line, which may be one or a combination of many transmission media such as microwave or coaxial cable, may be leased from the telephone company on a dedicated, private-line basis or through the switched telephone network.

In leasing a line, the potential user must first determine his data requirements in terms of transmission speeds and number of channels. A chart similar to the one shown in Figure 1, can be used to determine the data channel-allocations on a voice line and if it is necessary to condition the line for acceptable transmission. For example, it is necessary to have C2 conditioning to transmit 11, 150-bps channels over a single line.

A voice circuit or line can transmit a limited amount of data without special conditioning. But as data transmission speeds increase, the bandwidth required for each data channel also increases and fewer data channels can be transmitted on an unconditioned line. Conditioning a voice line provides a wider band of frequencies for data channel-allocation by adding equalizers that reduce the deviation in envelope delay and frequency response.

Line conditioning provides a certain level of envelope delay and frequency response on a voice circuit. Other transmission parameters such as impulse noise and phase jitter are not affected by line conditioning, but may need to be controlled.

Envelope Delay

During transmission some frequency components of a signal are delayed more than others. This phenomenon, illustrated in Figure 2, is called envelope delay distortion since it distorts the envelope of a multi-frequency signal. At low frequencies in a voice-frequency transmission facility, envelope delay is primarily caused by inductive effects of transformers and amplifiers in the total system. The capacitive effects are the primary cause at high frequencies. In carrier transmission facilities, the filters in the channel equipment also cause envelope delay.

Envelope delay must be equalized when the delay begins to interfere with the intelligibility of the signal. The human ear is relatively insensitive to the effects of envelope delay, so equalization is not needed for speech transmission.

Digital signals, on the other hand, can be misunderstood if the effects of envelope delay are not corrected. Data

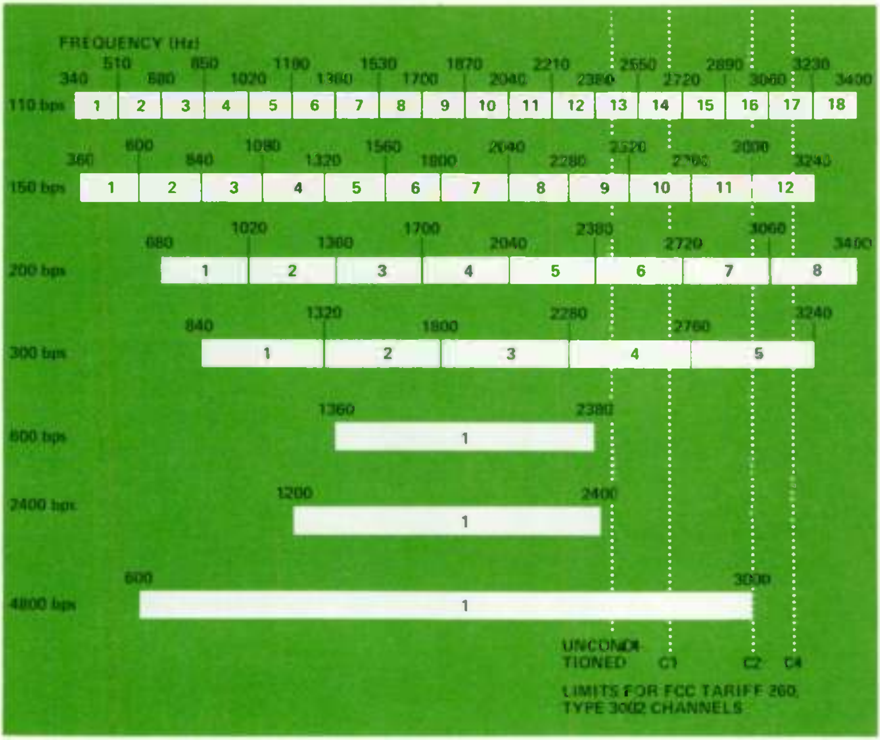


Figure 1. Data channel allocations and the necessary voice channel conditioning can be seen from this chart.

bits usually originate as rectangular-shaped pulses which are used to modulate a carrier at a particular keying rate for transmission over a communications circuit. The AM or FM signals used in transmission are composed of many frequencies.

If such a multi-frequency signal passes through a circuit with a non-uniform delay characteristic, it becomes severely distorted. In fact, the signal energy may "spread out" to the point where the original signal is no longer intelligible.

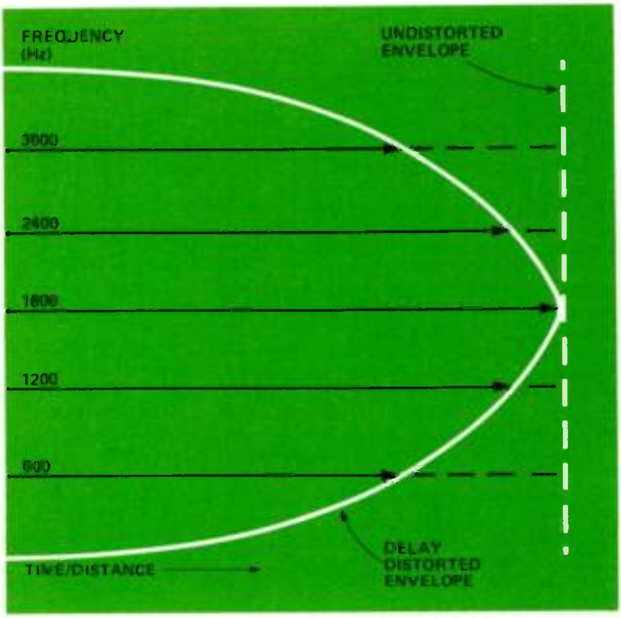
When considering the cause of delay distortion, it should be noted that an appreciable impedance mismatch between line sections, or between the line and the office apparatus, will also influence the delay characteristics of the facility.

Frequency Response

An ideal data communications channel has a flat frequency-response throughout. Some frequencies within the typical 4-kHz voice channel are attenuated more than others; consequently, the voice channel is not an ideal data channel. But, any multi-frequency communications channel exhibits this varying frequency attenuation, known as attenuation distortion.

This non-flat frequency response takes the form of band-edge roll-off and in-band ripple. An ideal transmission channel would have sharp cut-off frequencies, but band-edge roll-off re-

Figure 2. With envelope delay distortion, the frequency components of a signal travel at different speeds.



sults in the frequency response gradually diminishing at the edges of the band. Band-edge roll-off is usually caused by the characteristics of the bandpass filters in a voice multiplexing system, by the low-pass characteristics of loaded cable, or by the high-pass characteristics of transformers and series capacitors. In-band ripple which results in non-uniform frequency response in the middle of the channel is caused primarily by impedance mismatches throughout the system.

Frequency response is usually corrected at the receiving end of the circuit. An exception would be in cases where intermediate switch locations occur in long-haul circuits that can be separated into shorter segments for switching. In such cases, for purposes of equalization, each segment is treated as a separate circuit. In a dedicated network, conditioning may be applied at each transmitter location.

In the switched network rather than a dedicated network, compromise equalization effectively compensates for band-edge roll-off since all channels experience similar roll-off, regardless of how a channel selection is made. In this case the equalizer is adjusted to compensate for typical roll-off characteristics. The resulting equalized response will not be exact for every possible circuit connection, but it will generally be satisfactory throughout most of the network.

Conditioning

When a voice line is leased from the telephone company for data or alternate voice/data transmission, it is possible to specify the degree of line conditioning desired. In this case the telephone company is responsible for the quality of the line and guarantees that the line meets the FCC specifications for the desired level of conditioning. The specifications for envelope delay and frequency response for each degree of line conditioning are shown in Figure 3.

When the telephone company furnishes the modem and subsequent line conditioning to establish a data transmission system, the expected long-range error rate performance under normal conditions is one error in 100,000 bits (or an error rate of 10^{-5}). When the user leases an unconditioned or conditioned line for use with his own data system, he is responsible for the system's overall performance. Therefore, it is the responsibility of the customer to decide what conditioning arrangement is needed for his data transmission system.

If an unconditioned line is leased, the user, as a result of the Carterfone decision of 1968, may condition the line himself. By purchasing his own equipment, the user may condition the line for his desired service.

The types of conditioning that are available from the telephone company for standard 3002 voice lines are C1, C2, C4, C3, and C5, listed in increasing quality. The table in Figure 3 shows the differences in these line conditionings. The C5 conditioning was recently established for serial data speeds of 9600 bps and above.

Regardless of the level of conditioning used it is normally desirable to select channels from the middle of the band. This minimizes the effect of envelope delay and attenuation which are more severe at the edges of the voice channel.

When determining what type of service to lease from the telephone company, the user should consider the various options available. For example, a user who presently has a C1-conditioned line and is transmitting nine channels of 150-bps data, may find he has a requirement for 2 additional channels at 150 bps – or a total of 11 channels. Referring to Figure 1, there are three options available.

CHARACTERISTICS	UNCOND. 3002 CHANNEL	C1	C2	C4	C3		C5
					ACCESS LINES	TRUNKS	
FREQUENCY RESPONSE (dB)							
0.3–3.2 kHz	–	–2 TO +6	–2.0 TO +5.0	–2.0 TO +5.0	–	–	–
0.3–3.0 kHz	–3 TO +12	–	–	–	–0.8 TO +3.0	–0.8 TO +2.0	–
0.3–2.7 kHz	–	–	–	–	–	–	–1.0 TO +3.0
0.5–3.0 kHz	–	–	–2.0 TO +3.0	–2.0 TO +3.0	–	–	
0.5–2.8 kHz	–	–	–	–	–0.5 TO +1.5	–0.5 TO +1.0	–0.5 TO +1.5
0.5–2.5 kHz	–2 TO +8	–	–	–	–	–	–
1.0–2.4 kHz	–	–1.0 TO +3.0	–	–	–	–	–
2.7–3.0 kHz	–	–3 TO +12	–	–	–	–	–
MAX. ENVELOPE DELAY DISTORTION (μSEC)							
0.5–3.0 kHz	–	–	–	<3000	–	–	–
0.5–2.8 kHz	–	–	<3000	–	650	500	600
0.6–3.0 kHz	–	–	–	<1500	–	–	–
0.6–2.6 kHz	–	–	<1500	–	300	260	300
0.8–2.8 kHz	–	–	–	<500	–	–	–
0.8–2.6 kHz	1750	<1750	–	–	–	–	–
1.0–2.6 kHz	–	–	<500	<300	100	80	100
1.0–2.4 kHz	–	<1000	–	–	–	–	–
(ANY TWO FREQUENCIES 200 Hz APART)							

Figure 3. Each degree of line conditioning provides tighter specifications on envelope delay and frequency response.

First, the line can be conditioned for C2 or C4, to provide for additional future channels. Second, a new unconditioned line could be leased in addition to the existing C1 line. Or third, the conditioning on his present line could be removed and another unconditioned line added. The cost of leasing these different options will vary and the user must decide which is the most economical for his present increased needs and perhaps his future needs.

A line is conditioned to improve its transmission capability. With a leased, dedicated, private-line facility, it is possible to determine the envelope delay and frequency response characteristics in the system. Then depending upon the speed of data to be transmitted over the facility and the number of channels required, it is possible to condition the line to compensate for the distortions introduced by the facility. The higher the speed of transmission, the fewer distortions that can be tolerated by the data signal.

Switched Network

The switched telephone network (the standard dial-up voice network) provides a totally different picture as far as data transmission is concerned. Since slow-speed data such as telegraph can be transmitted over an unconditioned line, there is no problem with using the switched network. But for higher speeds or greater capacity low-speed systems, a switched network can prove to be unsatisfactory since it is not possible to predict the route the signal will take and consequently the distortions it will be subjected to.

Use of the switched telephone network for high-speed data communications can be summed up in one word — unpredictable. With a dedicated system it is possible to determine the

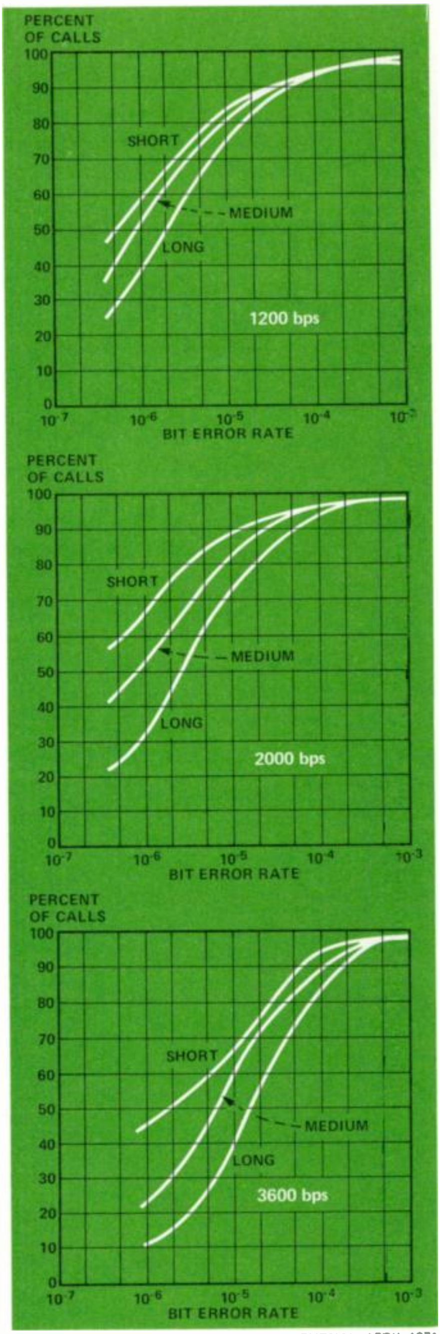


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Figure 4. The results of a statistical study are used to predict performance on the switched network.

performance on the line and then compensate for the envelope delay and frequency response. With the proper equalization, it is possible to keep these characteristics within tolerable levels for the desired transmission speeds.

But on a switched network, it is not possible to predict the exact route the data signals will take between central offices before it gets to its destination. Consequently, it is not possible to predict the distortions that the signal will be subjected to. What is possible, is to take a statistical sampling of signals sent over the switched network and determine the average performance of the network. It is then possible to design compromise equalizers that will compensate for average delay and attenuation distortions.

A compromise equalizer cannot be used to guarantee a certain level of conditioning. This means that for some of the routes the compensation will be greater than necessary and for other routes it will not be great enough.

With data up to speeds of 600 bps, it is not necessary to compensate for envelope delay and frequency response on a switched network. GTE Lenkurt's type 25 data modems work quite satisfactorily on the switched network.

As transmission speeds increase, the number of lines within the switched network, suitable for acceptable transmission, decreases. Therefore, the percentage of suitable circuits decreases and the probability of having an "error-free" transmission also decreases.

With compromise equalizers it is possible to have 80-90% of the circuits suitable for transmission speeds of up to 2400 bps. The GTE Lenkurt 26C data modem can be equipped with a compromise equalizer for use over the switched network.

The telephone companies also provide compromise equalizers. Such equalizers are used on the leased line from the terminal to central office which connects the user to the switched network.

On a dedicated line envelope delay and frequency response are the most important transmission parameters that the user has to be concerned with. But, with the switched network there is another area of concern – impulse noise (voltage spikes or transients). Each switching office along the data path introduces more impulse noise on the line. On a switched network it is possible to have some routes that are unsatisfactory for data transmission because the impulse noise gets too high and too frequent.

Figure 4 shows the predicted error rate for different data speeds through the switched network. These curves, which are the result of a Bell Labs study, take into consideration envelope delay, frequency response, impulse noise, and other impairments that might show up on a random sampling of the switched network.

Specific or Compromise

Whether the user wishes to use a dedicated, private telephone line, or a line into the switched telephone network, it is possible to equalize the line so that a high degree of reliability can be achieved in his data transmission system. This line equalization can be done with either specific C1, C2, C4, C3, or C5 line conditioning or compromise equalizers.

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