Reprinted May 1978

TRANSMISSION FACILITY DATA

CONTENTS

1. GENERAL AND HISTORY

1.1 Purpose

This section provides technical data and information for REA borrowers, consulting engineers and other interested parties. Specifically covered are transmission characteristics of telephone wire and cable facilities used in telephone systems of REA borrowers. Paired exchange cables are the primary facilities covered. For historical purposes, some data is furnished on open wire facilities. High frequency facilities such as coaxial cables and video pairs are covered to some extent. As a note of things to come, a small sample of transmission loss through optical fibers is also shown. Much work is currently under way on fiber optics transmission systems. Optical glass fibers are expected to be a low cost, high density transmission medium in years to come.

1.11 The attenuation data shown in this section is average or "nominal" loss. It is intended to be used to estimate the loss of cable for a direct comparison to measured loss. Engineering loss values are used to determine the repeater spacing of carrier systems. Station carrier systems are engineered based on nominal loss; thus, the data in this section can be used to determine the repeater spacing of station carrier. Other carrier systems, such as PCM carrier, use an engineering loss value based on the maximum cable temperature and other factors. Thus, the data in this section cannot be used to determine the maximum repeater spacing of PCM carrier. Engineering loss values for these systems are available from carrier manufacturers, and may be shown in the section of the TE&CM related to those carrier systems (i.e., Section 950 discusses the maximum repeater spacing for T1 type carrier systems).

1.12 A review of transmission data from different sources shows there are variations in this data -- depending on the data source. At high frequencies, there are variations in transmission characteristics at 68°F. This can be due to the small differences in manufacturing. It can vary between manufacturers and within one company. However, these variations generally are small. The data shown in this section compares closely with other published data. Most of the paired cable data is based on information from The Anaconda Company's engineering bulletins EB40-1 and EB49-0.

1.13 The transmission data in this section is based on typical cable parameters at 68°F, unless stated otherwise. Effects of temperature and other variables are discussed under the headings of voice frequency, carrier frequency and high frequency in subsequent paragraphs.

1.14 The data shown in the tables is primarily shown on a per mile basis. Some data is also shown on a per kilofeet basis. Conversion to metric units can be made as follows:

Temperature

$^{o}C = 5/9\ (^{o}F - 32)$

$^{o}F = 9/5^{o}C + 32$

Dimensions

Kilometers:	Multiply kilofeet by 0.3048
Kilofeet:	Multiply kilometers by 3.281
Kilometers:	Multiply miles by 1.609
Miles:	Multiply kilometers by 0.6214
Centimeters:	Multiply inches by 2.540
Inches:	Multiply centimeters by 0.3937

1.2 Scientists and engineers have probed into the transmission characteristics of metallic wire and cables for many years. Most of the basic fundamentals of wire transmission were well known by 1920. Work since that time has been important; but, for the most part, study, improvements, and "new" techniques during the last several decades are refinements of principles established two or more generations ago.

1.21 Early transmission facilities consisted of one wire and ground return, or two or more balanced wires on the same pole line. To offset wire losses due to capacitance, inductive loading was developed around 1917. Loading was applied to open wire toll lines, perhaps several hundred miles in length. Because of the quantity of pairs necessary along a transmission route, open wire was gradually replaced with balanced cable pairs. These cable pairs were insulated and shielded, and not as exposed to the harsh environment of rain, fog, ice and lightning as was uninsulated open wire conductors.

1.22 In the late 1950's, telephone companies began to direct-bury cables in the ground. In rural areas, this was a more economical means of establishing a cable route. Today, most of the facilities used by REA borrowers are buried cables. Voice frequency loading continues to be an economical means of providing service. Loading is a passive unit which will give an effective gain to non loaded cable, and provides a uniform impedance for active gain voice frequency repeaters.

2.252 To calculate attenuation using these formulas, the R, L, G and C values must be determined at the frequency of calculation. With dry cables (air core or filled), the first part of this formula can be omitted for a good approximation since G is small. Attenuation of <u>dry cables</u> can be estimated by:

$$\text{CF Attenuation (dB)} \cong \frac{R}{2}\sqrt{\frac{C}{L}} \times 8.686$$

2.253 Attenuation at carrier frequencies is directly affected by resistance changes. Changes in capacitance affects attenuation at a square root rate and inductance affects attenuation inversely at a square root rate.

2.254 To achieve 0.083 microfarads per mile (or other standard capacitance), certain conductor and insulator dimensions are established. These dimensions vary slightly among manufacturers. These dimensional changes are responsible for the small variations in attenuation and other characteristics at carrier frequencies. Further, these high frequency characteristics cannot be readily determined from low frequency characteristics such as 1000 hertz mutual capacitance.

2.255 If all other physical dimensions remained constant, closer spacing of conductors would cause an increase in capacitance and a decrease in inductance at 1000 hertz. The capacitance increase would cause a corresponding increase in attenuation; the effects of inductance would be negligible at 1000 hertz. At carrier frequencies, the closer wire spacing would cause much larger changes in attenuation. A ten percent increase in capacitance would be matched by a corresponding ten percent decrease in inductance. The combined effect would cause approximately a ten percent effect in attenuation. But closer spacing of the wires also causes the ac resistance (at carrier frequencies) to increase; thus, the increase in attenuation would be greater than the increase in capacitance (including the effects of inductance and ac resistance).

2.256 Moisture in the cable core causes the mutual capacitance to increase and the mutual conductance to increase sharply. Both of these increases cause the attenuation to increase. It is estimated that the mutual capacitance and conductance contribute about equally to this attenuation increase. Thus, for a ten percent increase in capacitance, due to moisture, the attenuation would increase about ten percent. Limited study in this area demonstrate that results can vary widely.

2.257 The discussion in paragraphs 2.54, 2.55 and 2.56 is provided to demonstrate the effects of changing cable dimensions and moisture on cable parameters. Estimating attenuation from mutual capacitance values alone can lead to large errors. Capacitance increases may be due to other factors such as larger conductors. Larger conductors reduce the ac resistance and tend to offset loss due to higher mutual capacitance. With dry cable, the capacitance is usually the same at carrier frequencies as at 1000 hertz. But it is not practical to estimate the ac resistance, inductance and conductance from 1000 hertz values. While one manufacturer might establish these relationships for specific cables, it is not practical to establish these relationships on a generalized basis.

2.26 Characteristic Impedance of cable is also useful in understanding the need for impedance matching to reduce reflections. The characteristic impedance can be calculated by:

$$Zo = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

Note that the impedance increases with an increase in R and L and decreases with an increase in G and C. At carrier frequencies of 100 kilohertz and higher, the impedance can be found by this approximation formula:

$$Zo \cong \sqrt{\frac{L}{C}}$$

2.27 Other cable characteristics are less useful to the application engineers and craftpersons. These include wavelength (length per revolution or cycle) and velocity of propagation which ranges from 29,247 miles per second at one kilohertz to 116,267 miles per second at 200 kilohertz.

2.28 A word should be said for loaded cable. The characteristic impedance of non loaded cable at carrier frequencies is near 100 ohms and is resistive (very little phase angle). At 1000 hertz, the impedance is much higher and the phase angle is about 45 degrees. This means that the resistive and capacitance components of the cable are of near equal magnitude. By inserting lumped inductance (loading coils) at regular intervals, the impedance of the cable pair is further raised, and most of the capacitive component can be cancelled. This has the effect of providing gain (relative to non loaded cable).

Loading also stabilizes the impedance. Referring to Figure 2, loaded cable is like a low pass filter. Like a low pass filter, higher frequencies (beyond cutoff) are severely attenuated. The theoretical cutoff frequency is:

$$Fc = \frac{1}{\pi\sqrt{LC}}$$

Cutoff frequency is defined as the frequency of infinite impedance. The cutoff frequency of D-66 and H-88 loaded exchange cable is calculated to be 4627 and 3457 hertz. From a practical standpoint, the useful bandwidth of loaded cable is about 0.8 of the cutoff frequency. This would equate to a useful bandwidth of 3702 hertz for D-66 and 2780 hertz for H-88 loaded cables. The velocity of propagation in loaded cable is substantially lower than non loaded cable. At one kilohertz, the velocity of 22 gauge D-66 and H-88 loaded PIC cable is just over 12,000 miles per second. The velocity of propagation at carrier frequencies is 10 times that of loaded cables.

2.3 The crosstalk characteristics of paired telephone cable have always been an important parameter. In recent years with higher frequency carrier systems being applied to multipair cables, crosstalk performance becomes more important. Two factors primarily determine cable crosstalk performance. First, the mated wires of a cable pair must be uniform and have balanced (identical) electrical characteristics; and secondly, nearby pairs in a cable must be twisted at different intervals to create a random pattern of coupling between pairs.

2.31 The two types of crosstalk of importance are far end crosstalk loss (FEXT) and near end crosstalk loss (NEXT). Frequency division carrier systems are designed to transmit one set of frequencies in one direction, and different frequencies in the opposite direction. By doing this, the carrier signals are approximately at equal level <u>for a specific frequency</u> at any point in the cable. Thus, only equal level FEXT must be considered for frequency division carrier system engineering. Station carrier and N type carrier require cables with good FEXT characteristics.

2.32 Time division carrier systems transmit the same type signal in <u>both</u> directions. The received signals are weaker than transmitted signals by the loss of that cable section. NEXT is of first concern for engineering time division carrier systems because of unequal levels at carrier terminals and repeaters. For cable application where the NEXT is substantially improved (screened cable or two cable operation), the FEXT can become the controlling engineering limitation.

2.33 Interaction crosstalk is the indirect crosstalk that is coupled from the disturbing into the disturbed cable pair through other cable pairs (tertiary circuits). Interaction crosstalk has not been an important consideration with present analog and digital carrier systems. With higher frequency systems in the future, crosstalk through tertiary circuits may become very important. The random connection of exchange cables to subscriber drops of various lengths and characteristics (at high frequencies) could provide these tertiary circuits. These high frequency systems may be limited to dedicated trunk cables, and may require special handling and special hardware.

2.4 Some of the cable parameters are outlined in REA Wire and Cable Specifications (PE-22, PE-23, PE-39 and PE-54). Nominal values and maximum and/or minimum limits are stated for such characteristics as conductor resistance at dc, mutual capacitance at 1000 hertz, FEXT at 150 KHz, NEXT at 772 KHz, and others.

3. WIRE TRANSMISSION DEGRADATION

3.1 Wire transmission facilities are designed and manufactured to a high degree of precision. Exchange cables are made up of twisted pairs. Some degree of variation between one pair and another is acceptable; this is not as critical as other cable characteristics. The characteristics of a pair must be rather uniform along its length. A very high degree of precision is required to maintain nearly exact characteristics of both tip and ring conductors of a pair. Between the tip and ring conductors of a pair, certain parameters must be maintained to a difference (unbalance) of less than 0.1 percent.

3.11 To achieve these rigid goals, the cable must first be manufactured to high standards. During the construction and life of the cables, this high degree of balance must be maintained. In recent years, filled cables have been used to stop moisture ingress and maintain long term stability of these characteristics.

3.12 Existing air core buried cables without a continuous air flow system can be expected to contain some degree of moisture. Of special concern are the small size wire and cables. Moisture ingress into the cable core can make the wires and cables unsuitable for voice frequency or carrier system circuits.

3.13 This discussion deals with the causes and effects of degradation in telephone cables. When capacitance unbalance is discussed, conductance unbalance is considered to be a part of that unbalance even though it is not specifically mentioned.

3.2 Voice Frequency Noise: The circuit noise at a subscriber's telephone set is generally a function of capacitance unbalance to ground or resistance unbalance. Capacitance unbalance to ground is the combined capacitance unbalance of one pair to the shield and to all other pairs of the cable. Resistance unbalance is the resistance difference between the tip and ring conductors of the pair.

3.21 Capacitance unbalance to ground is a function of manufacturing controls, but the more serious problems have been due to moisture ingress while the cable is in service. Figure 3 demonstrates how this unbalance causes noise.

3.22 Resistance unbalance is primarily a manufacturing consideration. While cable resistance unbalance can be a major noise consideration, it usually is not. A defective conductor splice can cause resistance unbalance and high noise. Defective splices must be found and corrected.

3.3 Voice Frequency Crosstalk: Voice frequency crosstalk from one cable pair to another is primarily a function of pair-to-pair capacitance unbalance. (Crosstalk can be caused by resistance unbalance also, but this is a less predominant factor.) Pair-to-pair capacitance unbalance is a function of manufacturing controls, but can become degraded due to moisture ingress. Figure 4 demonstrates how this unbalance causes crosstalk. Carrier frequency crosstalk is caused not only by pair-to-pair capacitance unbalance, but by series resistance unbalance also.

3.4 Voice Frequency Return Loss: The return loss of a voice frequency loaded cable is a function of cable mutual capacitance, loading coil inductance, and the location of loading coils. Changes in these parameters affect the loaded cable impedance and in turn degrade the return loss. Considering only the cable, good return loss is maintained by uniform mutual capacitance. Mutual capacitance is the effective (total) capacitance between the tip and ring conductors of a pair.

3.41 Mutual capacitance is one of the basic design factors of a cable. Deviations in mutual capacitance are a function of manufacturing controls; deviation limits are established in cable specifications. The more serious concern has been high mutual capacitance caused by moisture ingress.

3.42 Voice frequency repeaters depend on a stable cable circuit impedance. High mutual capacitance degrades the return loss, and causes repeater instability as demonstrated in Figure 5. Irregularities can cause the repeater to become hollow or sing (oscillate). Improved repeater design has increased the repeatered circuit stability. But this is not a substitute for cable stability.

3.5 Carrier Frequency Loss: Carrier frequency loss is a function of series resistance and inductance, and shunt (mutual) capacitance and conductance. Normal loss or attenuation values are established for a specific cable construction.

3.51 Manufacturing deviations cause corresponding deviations in loss. Properly constructed, these deviations are usually small. Moisture can cause an increase in mutual capacitance and conductance, and a corresponding increase in loss. An increase in mutual capacitance causes a corresponding decrease in inductance, causing further increase in cable loss.

3.52 For a specified cable gauge and mutual capacitance, the voice frequency loss does not depend on cable construction (i.e., filled versus air core). Cable construction is a factor in carrier frequency loss. For a specified cable gauge and mutual capacitance, the carrier frequency loss of air core, filled, and foam-filled cables are each different. The selections and processing of materials such as conductor material, conductor insulation, filling compounds, and shield material can affect carrier frequency loss. Thus, more care is required in the manufacture of cables to maintain a uniform and stable carrier frequency loss.

3.6 Carrier Frequency Reflections: High frequency pulse carrier systems depend on uniform cable characteristics. Discontinuities along the cable cause reflections of these pulses. Discontinuities can be caused by a defect in manufacturing or installation, or due to moisture ingress while the cable is in service.

3.61 The pulse carrier system in wide use today is the T1 type. Pulses are transmitted through the cable at 1,544,000 bits per second. Each repeater monitors the incoming pulses and regenerates new pulses. Reflections cause the repeaters to generate incorrect pulses, or errors. This is demonstrated in Figure 6.

3.62 Poor splices and water pockets are major causes of reflections. Properly designed and manufactured filled cable has minimized water problems.

3.7 Filled Cable Stability: For the last five years, rural telephone companies in this country have used filled PIC cables extensively. Telephone companies in Canada have been using filled cable even longer, and England has well over ten years experience. Good experience with filled cables is reported from all types of users. Laboratory measurements, field measurements, and accelerated aging tests indicate that the electrical characteristics of filled cable should remain stable over a long period of time.

3.71 When filled cable was introduced, some problems were encountered. The most serious was the difficulty in fully filling the cable core. Some of these early filled cables were either low or high in mutual capacitance. With any new product, there is a learning period. Because of past problems, filled cable was checked more closely to verify its electrical characteristics. Reported problems with filled cable are now minor. Today's problems seem to remain with air core cables.

4. VOICE FREQUENCY ATTENUATION AND IMPEDANCE

4.1 Voice frequency attenuation data for non loaded cables and for D-66 and H-88 loaded cables are shown in both dB per mile and dB per kilofeet in Tables 1 and 2 for exchange cables at 0.083 microfarads per mile. As a rule of thumb, the attenuation of loaded cable is approximately 0.45 dB per 100 ohms at 1000 hertz. This data is based on air core polyethylene insulated conductor cables (PIC). At voice frequencies, there is basically no difference in the transmission characteristics of cables using different conductor insulation. This data can be used for paper insulated, filled PIC, or foam insulated-filled cables. Only a limited amount of voice frequency attenuation data is shown in Table 5 along with carrier frequency data for open wire and some miscellaneous cable facilities. This data is primarily intended for historical and comparison purposes.

4.2 The characteristic impedance data at voice and carrier frequencies is shown for non loaded cables and open wire facilities in Tables 6 and 7. Note that the phase angle is about 45 degrees at 1000 hertz for non loaded exchange cables. This means that the resistive and capacitive components of the cable are of near equal magnitude.

4.21 Loading raises the impedance of the cable and tends to balance out the capacitive effects. The midsection impedance of loaded cable is basically resistive. The midsection impedance data for D-66 and H-88 loaded cables are shown in Table 7. The midsection impedance is the impedance looking into one-half a loading section of cable followed by a loading coil and many full sections of cable and loading coils. Loaded cable impedance is most often referenced as midsection impedance.

4.3 Voice Frequency Correction Factors: The attenuation values shown in the tables for voice frequency can be corrected for temperature using the following approximation for copper conductor exchange cables:

(a) VF Non Loaded Cable - The attenuation (in dB) changes approximately one percent for each 10 degrees change in temperature. Attenuation changes are approximately proportional to the square root of resistance changes.

(b) VF Loaded Cable - The attenuation (in dB) changes approximately one percent for each 5 degrees change in temperature. Attenuation changes are approximately proportional to the resistance changes. If loop resistance is measured, the 1000 hertz loss of loaded cable can be estimated at 0.45 dB per 100 ohms, without regard to temperature.

4.31 While temperature does affect the characteristic impedance somewhat (mostly because of resistance changes), corrections are not provided. If exact impedances are required, they can be calculated from the formula in paragraph 2.26.

5. CARRIER FREQUENCY ATTENUATION AND IMPEDANCE

5.1 Carrier frequency attenuation data are shown in dB per mile and dB per kilofeet in Tables 3 and 4 for exchange cables at 0.083 microfarads per mile. Data is shown for PIC, filled PIC and paper insulated conductor cables. Some carrier frequency attenuation data is also shown for miscellaneous cable and open wire facilities in Table 5. This data is primarily intended for historical and comparison purposes. Carrier application to unshielded facilities is not recommended.

5.11 If attenuation and impedance were the only considerations for carrier application, jacketed RDW might be a suitable carrier frequency facility. Jacketed RDW is more stable than earlier RDW, drop wire, etc. The attenuation and impedance of wet jacketed RDW is similar to that of shielded cable. Weather conditions do cause the attenuation and impedance to change over a limited range. But unshielded facilities are not recommended for carrier application for additional reasons. Shielding is necessary to isolate the wire pairs from foreign interference. Also, shielding affords some degree of electrical protection to carrier systems. In areas of high ground resistance and high lightning incidence, low resistance shields connected to the central office grounds and other ground locations reduce the voltages and currents induced into the wire pairs.

5.12 Unlike voice frequency, the carrier frequency attenuation is affected by the conductor insulation material. A striking example of this is the loss of 22 gauge PIC (air core) cable versus 22 gauge filled PIC cable. At 772 kilohertz, the loss is 23.6 dB per mile (air core) versus 19.9 dB per mile (filled) at 68^{o}F. This allows T1 carrier repeaters to be spaced 18 percent further apart. Both PIC and filled PIC are designed to be 0.083 microfarads per mile. Because filling compound has replaced air in the filled cables, a thicker conductor insulation is required to achieve 0.083 microfarads per mile. The wires of filled cable are further apart. This decreases the ac resistance of a 22 gauge cable pair at 772 kilohertz from 532 ohms (PIC) to 491 ohms (filled PIC). This change has a significant affect on attenuation. A further improvement is obtained by the larger inductance of filled cable (also due to the increased wire spacing).

5.13 The insulation thickness of foam filled insulated conductors is much less than that of filled cables using solid PIC insulated conductors. Thus, the wires in a foam filled cable are closer, and have a higher carrier frequency attenuation than filled cable using solid PIC insulation. Complete data on foam and foam skin insulated conductors are not available at this time. The attenuation depends on the ratio of air space to PIC insulation in foam insulated cables. For reference purposes, attenuation data for filled 22 gauge **foam insulated** cable is shown in

Table 5. More stringent controls will be required for foam insulated cables to achieve stable and uniform transmission characteristics.

5.14 Copper conductors are standard in exchange telephone cables. There is a limited copper supply available. Substitute materials are sought. Aluminum conductor cables have been used on an experimental basis. To obtain the same resistance as copper, aluminum must be two gauges coarser. A 20 gauge aluminum conductor cable is similar to a 22 gauge copper cable. Attenuation data is shown for 20 gauge aluminum conductor, filled PIC insulated cable in Table 5. There are many advantages of copper conductors over substitute materials. But scientists and engineers must continue the research in the event that the copper supply becomes short. One solution to this problem might lie in optical glass fibers, and the transmission of light waves over those fibers. This is discussed under high frequency facilities.

5.2 The characteristic impedance of carrier frequency facilities is shown in Tables 6 and 7. The phase angle of the characteristic impedance is small at carrier frequencies. The impedance is basically resistive. The characteristic impedance of exchange cable is near 100 ohms at 100 kilohertz. An impedance (or resistance) of 135 ohms is often cited for cables at carrier frequencies. This was established in earlier years when carrier system frequencies were under 50 kilohertz. Note that at high frequencies the characteristic impedance varies little between cable gauges. At higher carrier frequencies, the characteristic impedance depends primarily on the inductance and capacitance as shown in the approximation formula:

$$Zo \cong \sqrt{\frac{L}{C}}$$

5.3 CF Correction Factors: The attenuation values shown in the tables for carrier frequency can be corrected for temperature using the following approximations for copper conductor exchange cables:

The attenuation (in dB) changes approximately one percent for each 7 degrees change in temperature. This can be expressed in the following manner:

$$At = A68 \left[1 + 0.0014(t-68)\right]$$

Where: At = Attenuation in dB at temperature t.

A68 = Attenuation in dB at 68°F.

t = Temperature in degrees F.

5.31 Temperature correction factors for cable attenuation at carrier frequencies are not a fixed constant value. However, the simplified correction factor shown in paragraph 5.3 is accurate enough for engineering purposes. Note in Table 10 that the temperature correction factors for resistance and attenuation are approximately equal for carrier frequencies above 100 kilohertz. At 10 kilohertz or lower, the resistance correction factor for all cable gauges (for temperature) is the same as for dc. But attenuation correction factors at these lower carrier frequencies vary widely with gauge.

5.32 Over the carrier frequency range, the carrier frequency attenuation of exchange air core cables varies one percent for each 5°F to 9°F change in temperature. By choosing 7°F as a compromise, the error is generally small. A 35 dB length of cable at 10°F would calculate 2.9 dB correction. The true correction could be as much as 4.1 dB, or 1.1 dB error in 35 dB. This 3 percent possible error is preferred to the alternative of more complex correction factors.

5.33 As discussed in paragraph 5.2, impedance is primarily a function of the ratio of inductance and capacitance at carrier frequencies. Corrections for temperature are generally not significant.

5.4 To aid in quickly finding the most frequently used data, a heavy or color line can be drawn to emphasize certain data. The following are frequently referenced carrier frequencies.

5.41 Station Carrier: The design frequency is 112 kilohertz. The highest frequency generally used for cable measurements is 140 kilohertz.

5.42 N Carrier: The design frequency is 176 kilohertz. The highest frequency is 264 kilohertz. For quick reference, attenuation at 180 kilohertz and 260 or 280 kilohertz might be noted.

5.43 T1 Carrier: The design frequency is 772 kilohertz. (The power in the T1 carrier pulse stream is the greatest near 772 kilohertz.)

6. HIGH FREQUENCY FACILITIES

6.1 Radio systems and multiplex channels are often separated for economic reasons. High frequency facilities such as coaxial cables are used to transmit these radio baseband frequencies between the radio and multiplex. High density carrier systems are transmitted over long distances over coaxial cables as an alternative to radio systems. The use of coaxial cables and other high frequency transmission facilities has been limited in rural areas.

6.11 The high cost of providing telephone service by conventional techniques has prompted much recent research in high frequency facilities. The cost reduction available using digital carrier techniques adds to the justification for seeking new, low cost transmission facilities with high frequency capabilities. Coaxial cables and video pairs are the basic high frequency facilities used today in rural areas. The high cost and limited supply of copper available lead scientists and engineers to seek other transmission materials and techniques. The transmission of light waves over optical glass fibers shows promise. While this technology is in its infancy, telephone system field trials are in progress.

6.2 Coaxial cables use a variety of dielectric materials and techniques. To maintain a standard impedance, the inner conductor, outer conductor, and dielectric must maintain certain dimensional ratios. These dimensional ratios depend on the dielectric material, including the ratio of air to solid material. Fused glass beads, spiral polyethylene and foam (expanded) polyethylene offer a mixture of air and solid material between the inner and outer coaxial conductors. For a given dimension, this lowers the loss and increases the characteristic impedance over a solid dielectric. Mechanically, solid polyethylene is more rugged than air combination dielectric materials. Also, solid polyethylene is superior in reducing moisture permeation into the coaxial cable.

6.21 Table 8 shows the attenuation of several 75 ohm coaxial cables from 1 to 100 megahertz and video pairs at 125 ohms. This data is shown as an example of coaxial cable attenuation data. Increased use of digital transmission systems could prompt the development of improved and/or lower cost coaxial cables.

6.22 As an example of things to come, attenuation data for a "hair thin" optical fiber is shown at light frequencies. Refer to Table 8. Optical fibers are experimental today. Optical fiber systems may become standard practice within a decade.

7. CONDUCTOR AND SHIELD RESISTANCE

7.1 Table 9 show the dc resistance at 68°F for wire pairs and for shielding materials in common use today. Note that the shield resistance is an approximation. The actual value of shield resistance can vary quite a bit from the values shown; but these values can serve as a guide for expected values of shield resistance. Refer to Table 10 for resistance temperature corrections.

7.2 Actual values of dc loop resistance are sometimes different than values shown in these and other engineering tables. These variations are of secondary importance. What is important is that the tip and ring conductors are nearly equal. This is important at voice and carrier frequencies to minimize noise and crosstalk considerations.

Appendix 1

EXAMPLES OF TRANSMISSION CALCULATIONS AND CORRECTIONS

1. DC Loop Resistance

The dc loop resistance of a 4500 foot section of 24 gauge aerial cable measured 205 ohms at 20°F. Is that value normal? From Table 10, the expected resistance is corrected for length and temperature.

Length Correction: $274 \text{ ohms} \times \frac{4500}{5280} = 233.5 \text{ ohms at } 68^{\circ}F$

Temperature Correction:

$$Rt = R68 \left[1 + 0.0022\,(t-68)\right]$$

$$= 233.5 \left[1 + 0.0022\,(20-68)\right]$$

$$= 233.5 \quad 1 + 0.0022\,(-48)$$

$$= 233.5 \quad 1 - 0.106$$

$$= 233.5 \times 0.894 = \underline{208.8 \text{ ohms}} \text{ at } 20^{\circ}F$$

The 205 ohms measured is about 2 percent lower than the calculated 208.8 ohms. This is a reasonable variation.

2. CF Attenuation

The loss of a 7000 foot section of 22 gauge filled PIC cable was measured at 772 kilohertz and found to be 27.5 dB at 95°F. How does this compare with the expected loss? Refer to Table 4 for the filled cable loss data.

Length Correction: $3.76 \text{ dB} \times 7.0 = 26.3 \text{ dB at } 68^{\circ}F$

Temperature Correction:

$$At = A68 \left[1 + 0.0014(t-68)\right]$$

$$= 26.3 \text{ dB} \left[1 + 0.0014(95-68)\right]$$

$$= 26.3 \text{ dB} \left[1 + 0.0014(27)\right]$$

$$= 26.3 \text{ dB} \left[1 + 0.038\right]$$

$$= 26.3 \text{ dB} \times 1.038 = 27.3 \text{ dB at } 95^{\circ}F$$

Another approach is that the loss changes about one percent for each 7 degrees change in temperature. Thus, 27 degrees would cause a loss increase of 4 percent.

$$At = 26.3 \times 1.04 = 27.4 \text{ dB at } 95^{\circ}\text{F}$$

3. VF Attenuation and Resistance

The loss and resistance of a loaded voice frequency subscriber circuit of mixed facilities was measured to be 10.8 dB and 2360 ohms at about 68°F. This was calculated to be:

Length	Gauge	Resistance (ohms)	Attenuation (dB)
34 KF	24	51.89 x 34 = 1764.3	0.23 x 34 = 7.82
16 KF	22	32.39 x 16 = 518.2	0.15 x 16 = 2.40
4 KF	19	16.10 x 4 = 64.4	0.08 x 4 = 0.32
		Total = 2346.9 ohms	Total = 10.54 dB

An easier approach to estimating the loss of loaded cable is to estimate loss based on measured loop resistance.

$$A = R \text{ total} \times \frac{0.45 \text{ dB}}{100 \text{ ohms}}$$

$$= 2360 \text{ ohms} \times \frac{0.45 \text{ dB}}{100 \text{ ohms}} = \underline{10.6 \text{ dB}}$$

4. CF Attenuation

The approximate attenuation of 22 gauge PIC cable can be calculated from known values of R, L, G and C at 200 kilohertz.

$$AdB = \left(\frac{G}{2}\sqrt{\frac{L}{C}} + \frac{R}{2}\sqrt{\frac{C}{L}}\right) 8.686$$

$$= \left(\frac{41.7 \times 10^{-6}}{2}\sqrt{\frac{0.879 \times 10^{-3}}{0.083 \times 10^{-6}}} + \frac{271.1}{2}\sqrt{\frac{0.083 \times 10^{-6}}{0.879 \times 10^{-3}}}\right) 8.686$$

$$= (20.85 \times 10^{-6} \sqrt{10{,}590} + 135.55 \sqrt{94.43 \times 10^{-6}})\ 8.686$$

$$= (20.85 \times 10^{-6} \times 102.9 + 135.55 \times 9.717 \times 10^{-3})\ 8.686$$

$$= (0.0021 + 1.317)\ 8.686 = 1.319 \times 8.686 = \underline{11.46 \text{ dB}} \text{ per mile}$$

The actual attenuation is calculated to be 11.38 dB using exact formulas.

5. CF Impedance

The approximate characteristic impedance of 22 gauge PIC cable can be calculated from the same data at 200 kilohertz.

$$Z_o = \sqrt{\frac{L}{C}}$$

$$= \sqrt{\frac{0.879 \times 10^{-3}}{0.083 \times 10^{-6}}} = \sqrt{10{,}590} = \underline{102.9 \text{ ohms}}$$

The actual characteristic impedance is calculated to be 104.4 ohms with a phase angle of 6.8 degrees negative using exact formulas.

FIGURE 1

TRANSMISSION LINE

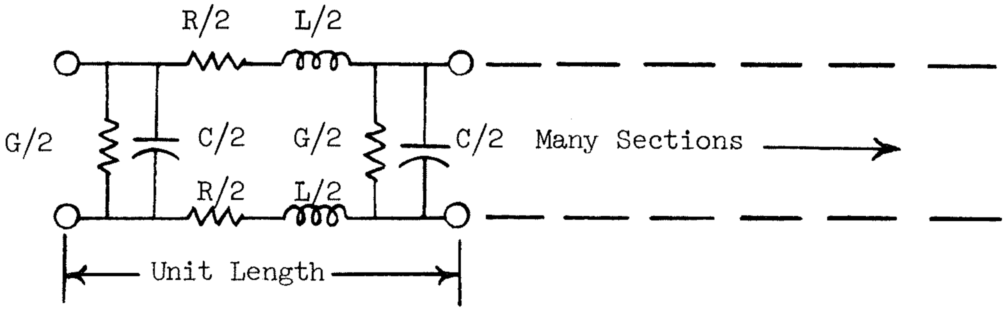


FIGURE 2A

LOADED CABLE (ONE SECTION)

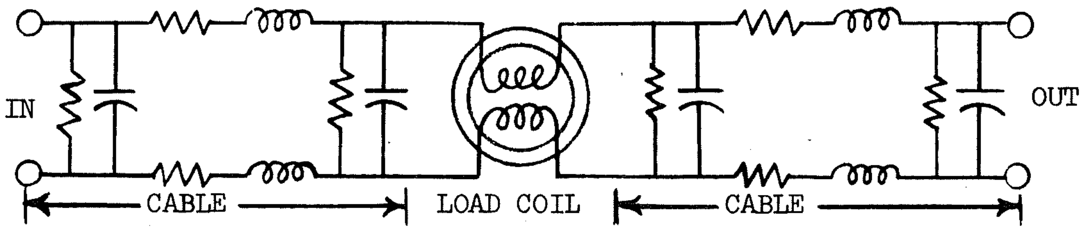


FIGURE 2B

SIMPLIFIED EQUIVALENT CIRCUIT

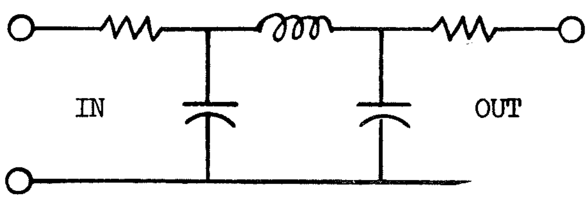
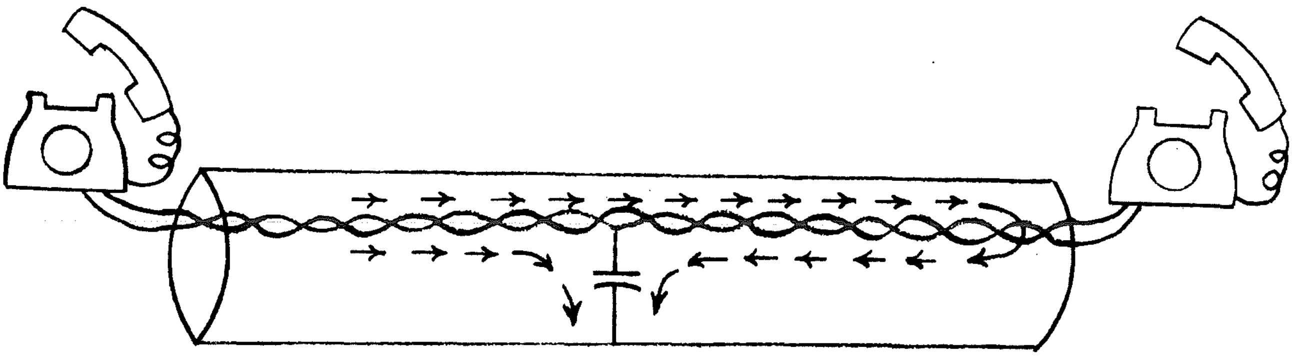


FIGURE 3

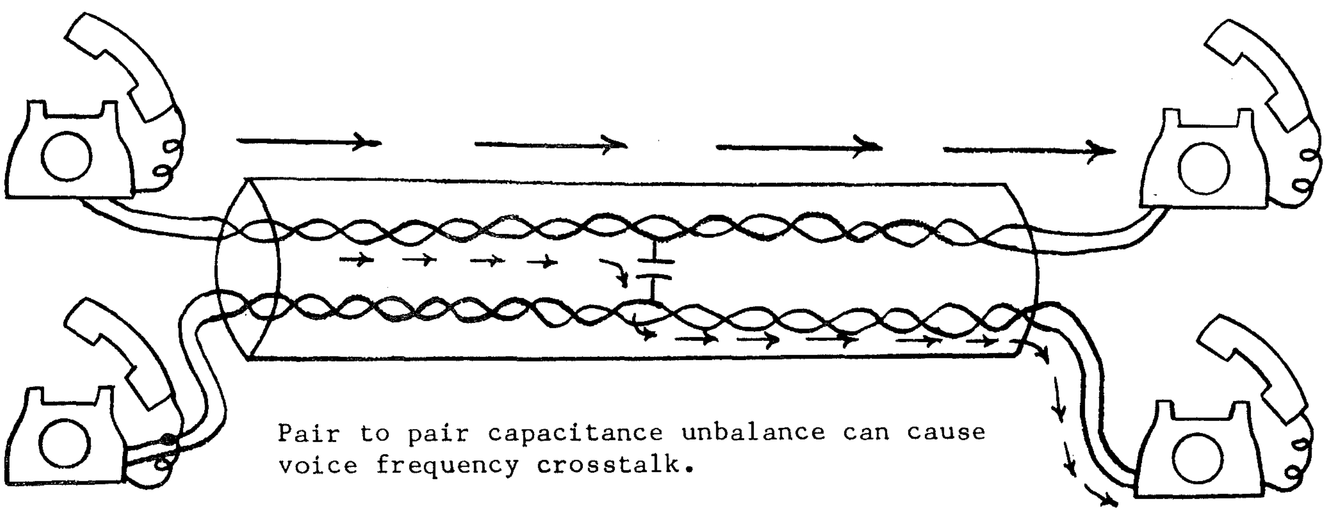
NOISE CAUSED BY CAPACITANCE UNBALANCE TO GROUND



Capacitance unbalance to ground can cause voice frequency noise. (Noise comes from electric power system induction into telephone cable pairs.)

FIGURE 4

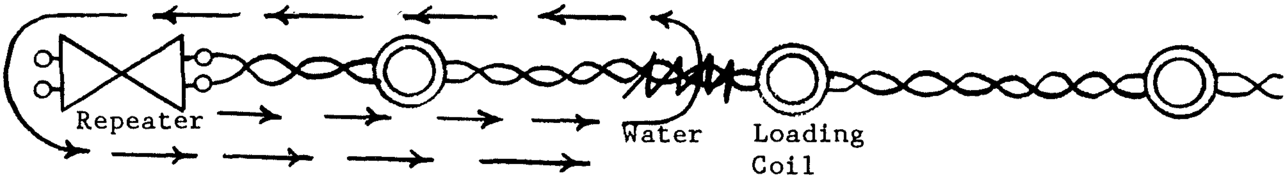
CROSSTALK CAUSED BY PAIR TO PAIR CAPACITANCE UNBALANCE



Pair to pair capacitance unbalance can cause voice frequency crosstalk.

FIGURE 5

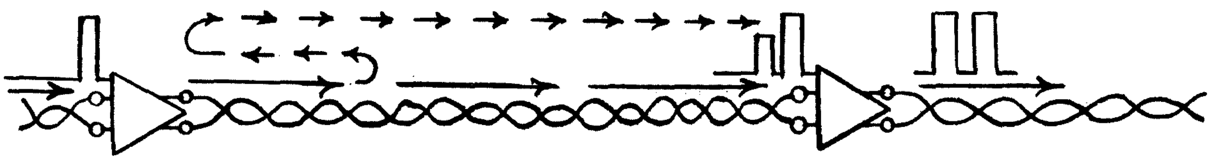
REPEATER INSTABILITY CAUSED BY WATER



Water causes high mutual capacitance in a cable section. This causes impedance irregularities and signal reflections which can cause the repeater to oscillate or "sing."

FIGURE 6

PULSE CARRIER REFLECTIONS CAUSED BY WATER



Water pockets in a PCM carrier span line can cause errors due to reflected pulses. The reflected pulse causes the next repeater to generate an incorrect pulse, or an error.

TABLE 1

VOICE FREQUENCY ATTENUATION DATA (dB/MILE)

Non Loaded PIC Insulated Cable (Air Core), D66 and H88 Loaded Cable, 0.083 µF Per Mile, 68°F

Freq. (Hz.)	Non Loaded Cable				D66 Loaded Cable				H88 Loaded Cable				Freq. (Hz.)
	19 Ga.	22 Ga.	24 Ga.	26 Ga.	19 Ga.	22 Ga.	24 Ga.	26 Ga.	19 Ga.	22 Ga.	24 Ga.	26 Ga.	
200	0.58	0.82	1.03	1.30	0.38	0.64	0.88	1.18	0.37	0.64	0.88	1.18	200
300	0.70	1.00	1.26	1.60	0.39	0.70	0.99	1.37	0.39	0.70	0.99	1.36	300
400	0.81	1.15	1.45	1.84	0.40	0.73	1.06	1.50	0.40	0.73	1.06	1.50	400
500	0.90	1.29	1.62	2.06	0.41	0.75	1.11	1.59	0.40	0.75	1.10	1.59	500
800	1.13	1.62	2.05	2.60	0.41	0.77	1.18	1.76	0.40	0.77	1.17	1.75	800
1000	1.25	1.80	2.28	2.90	0.41	0.78	1.20	1.81	0.40	0.77	1.19	1.80	1000
1200	1.36	1.97	2.50	3.17	0.41	0.79	1.21	1.85	0.41	0.78	1.19	1.83	1200
1400	1.46	2.12	2.69	3.42	0.41	0.79	1.21	1.87	0.41	0.78	1.20	1.85	1400
1500	1.50	2.19	2.78	3.54	0.41	0.79	1.21	1.87	0.41	0.77	1.20	1.85	1500
1600	1.55	2.26	2.87	3.65	0.42	0.79	1.22	1.88	0.41	0.77	1.20	1.86	1600
1700	1.59	2.32	2.96	3.76	0.42	0.79	1.22	1.88	0.41	0.77	1.20	1.86	1700
1800	1.63	2.39	3.04	3.87	0.42	0.79	1.22	1.89	0.41	0.77	1.19	1.86	1800
2000	1.71	2.51	3.20	4.08	0.42	0.79	1.22	1.89	0.41	0.77	1.19	1.86	2000
2200	1.78	2.62	3.35	4.27	0.42	0.79	1.21	1.89	0.41	0.77	1.19	1.86	2200
2300	1.81	2.68	3.42	4.36	0.42	0.79	1.21	1.83	0.41	0.77	1.19	1.86	2300
2400	1.85	2.73	3.49	4.45	0.42	0.79	1.21	1.89	0.42	0.78	1.19	1.86	2400
2500	1.88	2.78	3.56	4.54	0.42	0.79	1.21	1.89	0.42	0.78	1.20	1.87	2500
2600	1.91	2.83	3.62	4.63	0.42	0.79	1.21	1.89	0.42	0.79	1.21	1.88	2600
2800	1.97	2.93	3.75	4.80	0.43	0.79	1.21	1.89	0.44	0.81	1.23	1.91	2800
3000	2.03	3.02	3.88	4.96	0.43	0.80	1.22	1.89	0.47	0.85	1.29	2.00	3000
3200	2.08	3.11	4.00	5.12	0.44	0.80	1.22	1.90	0.54	0.96	1.45	2.21	3200
3400	2.13	3.19	4.11	5.27	0.45	0.81	1.23	1.91	0.83	1.41	2.02	2.88	3400
3500	2.15	3.24	4.17	5.34	0.45	0.82	1.24	1.92	1.95	2.44	2.94	3.67	3500
3600	2.18	3.28	4.22	5.41	0.46	0.83	1.25	1.93	3.94	4.08	4.29	4.72	3600
3800	2.22	3.36	4.33	5.55	0.48	0.85	1.28	1.97					3800
4000	2.27	3.43	4.43	5.69	0.52	0.90	1.34	2.05					4000

NOTE: This data may be used for PIC Insulated-Filled Core, Paper Insulated, and Foam Insulated-Filled Core cable at 0.083 µF per mile also.

TABLE 2

VOICE FREQUENCY ATTENUATION DATA (dB/KF)

Non Loaded PIC Insulated Cable (Air Core), D66 and H88 Loaded Cable, 0.083 µF Per Mile, 68°F

Freq. (Hz.)	Non Loaded Cable				D66 Loaded Cable				H88 Loaded Cable				Freq. (Hz.)
	19 Ga.	22 Ga.	24 Ga.	26 Ga.	19 Ga.	22 Ga.	24 Ga.	26 Ga.	19 Ga.	22 Ga.	24 Ga.	26 Ga.	
200	0.11	0.15	0.20	0.25	0.07	0.12	0.17	0.22	0.07	0.12	0.17	0.22	200
300	0.13	0.19	0.24	0.30	0.07	0.13	0.19	0.26	0.07	0.13	0.19	0.26	300
400	0.15	0.22	0.28	0.35	0.08	0.14	0.20	0.28	0.07	0.14	0.20	0.28	400
500	0.17	0.24	0.31	0.39	0.08	0.14	0.21	0.30	0.08	0.14	0.21	0.30	500
800	0.21	0.31	0.39	0.49	0.08	0.15	0.22	0.33	0.08	0.15	0.22	0.33	800
1000	0.24	0.34	0.43	0.55	0.08	0.15	0.23	0.34	0.08	0.15	0.22	0.34	1000
1200	0.26	0.37	0.47	0.60	0.08	0.15	0.23	0.35	0.08	0.15	0.23	0.35	1200
1400	0.28	0.40	0.51	0.65	0.08	0.15	0.23	0.35	0.08	0.15	0.23	0.35	1400
1500	0.28	0.41	0.53	0.67	0.08	0.15	0.23	0.35	0.08	0.15	0.23	0.35	1500
1600	0.29	0.43	0.54	0.69	0.08	0.15	0.23	0.36	0.08	0.15	0.23	0.35	1600
1700	0.30	0.44	0.56	0.71	0.08	0.15	0.23	0.36	0.08	0.15	0.23	0.35	1700
1800	0.31	0.45	0.58	0.73	0.08	0.15	0.23	0.36	0.08	0.15	0.23	0.35	1800
2000	0.32	0.47	0.61	0.77	0.08	0.15	0.23	0.36	0.08	0.15	0.23	0.35	2000
2200	0.34	0.50	0.62	0.81	0.08	0.15	0.23	0.36	0.08	0.15	0.23	0.35	2200
2300	0.34	0.51	0.63	0.83	0.08	0.15	0.23	0.36	0.08	0.15	0.23	0.35	2300
2400	0.35	0.53	0.65	0.84	0.08	0.15	0.23	0.36	0.08	0.15	0.23	0.35	2400
2500	0.36	0.53	0.66	0.86	0.08	0.15	0.23	0.36	0.08	0.15	0.23	0.35	2500
2600	0.36	0.54	0.67	0.88	0.08	0.15	0.23	0.36	0.08	0.15	0.23	0.36	2600
2800	0.37	0.55	0.70	0.91	0.08	0.15	0.23	0.36	0.08	0.15	0.23	0.36	2800
3000	0.38	0.57	0.73	0.94	0.08	0.15	0.23	0.36	0.09	0.16	0.24	0.38	3000
3200	0.39	0.59	0.76	0.97	0.08	0.15	0.23	0.36	0.10	0.18	0.27	0.42	3200
3400	0.40	0.60	0.78	1.00	0.08	0.15	0.23	0.36	0.16	0.27	0.38	0.55	3400
3500	0.41	0.61	0.79	1.01	0.09	0.15	0.23	0.36	0.37	0.46	0.56	0.69	3500
3600	0.41	0.62	0.80	1.02	0.09	0.16	0.24	0.37	0.75	0.77	0.81	0.89	3600
3800	0.42	0.64	0.82	1.05	0.09	0.16	0.24	0.37					3800
4000	0.43	0.65	0.84	1.08	0.10	0.17	0.25	0.39					4000

NOTE: This data may be used for PIC Insulated-Filled Core, Paper Insulated, and Foam Insulated-Filled Core cable at 0.083 µF per mile also.

TABLE 3

CARRIER FREQUENCY ATTENUATION DATA (dB/MILE)

PIC Insulated (Air Core), PIC Insulated-Filled Core, and Paper Insulated Cable, 0.083 μF Per Mile, 68°F

Freq. (KHz)	PIC Cable (Air Core)				PIC Filled Cable				Paper Cable				Freq. (KHz)
	19 Ga.	22 Ga.	24 Ga.	26 Ga.	19 Ga.	22 Ga.	24 Ga.	26 Ga.	19 Ga.	22 Ga.	24 Ga.	26 Ga.	
10	3.0	4.9	6.5	8.6	2.8	4.8	6.4	8.5	3.0	5.0	6.6	8.7	10
20	3.5	6.0	8.5	11.5	3.2	5.8	8.2	11.2	3.6	6.2	8.6	11.6	20
40	4.0	7.0	10.2	14.4	3.6	6.5	9.6	13.9	4.2	7.2	10.4	14.7	40
60	4.5	7.5	11.1	16.0	4.0	6.9	10.3	15.2	4.8	7.9	11.4	16.4	60
80	5.1	8.0	11.7	17.0	4.5	7.3	10.7	16.0	5.5	8.5	12.1	17.6	80
100	5.7	8.5	12.2	17.7	4.9	7.7	11.1	16.5	6.2	9.1	12.7	18.4	100
112	6.1	8.9	12.5	18.1	5.2	8.0	11.3	16.8	6.6	9.6	13.1	18.8	112
120	6.3	9.1	12.7	18.3	5.4	8.1	11.5	17.0	6.9	9.8	13.3	19.1	120
140	6.8	9.7	13.3	18.9	5.8	8.6	11.9	17.4	7.5	10.5	14.0	19.8	140
160	7.3	10.2	13.8	19.4	6.2	9.0	12.3	17.8	8.1	11.2	14.6	20.4	160
180	7.8	10.8	14.4	19.9	6.6	9.5	12.7	18.2	8.7	11.8	15.2	21.0	180
200	8.3	11.4	15.0	20.4	7.0	10.0	13.2	18.6	9.2	12.5	16.0	21.7	200
220	8.7	12.0	15.5	20.9	7.4	10.4	13.6	19.0	9.8	13.2	16.6	22.3	220
240	9.2	12.5	16.1	21.5	7.7	10.9	14.0	19.4	10.3	13.9	17.3	22.9	240
260	9.6	13.1	16.7	22.0	8.1	11.3	14.5	19.8	10.8	14.6	18.0	23.5	260
280	10.0	13.6	17.3	22.5	8.4	11.8	14.9	20.2	11.3	15.2	18.7	24.2	280
300	10.4	14.1	17.9	23.1	8.7	12.2	15.4	20.6	11.8	15.8	19.3	24.9	300
350	11.3	15.3	19.4	24.5	9.4	13.2	16.6	21.7	12.9	17.2	21.1	26.6	350
400	12.1	16.5	20.8	26.0	10.0	14.1	17.7	22.9	13.9	18.7	22.8	28.4	400
450	12.9	17.6	22.1	27.5	10.6	15.0	18.7	24.0	14.9	20.1	24.3	30.2	450
500	13.6	18.6	23.4	28.8	11.2	15.9	19.8	25.2	15.8	21.3	25.9	31.8	500
550	14.2	19.6	24.7	30.4	11.7	16.7	20.8	26.4	16.7	22.6	27.4	33.6	550
600	14.9	20.6	25.9	31.7	12.2	17.5	21.8	27.4	17.5	23.9	28.8	35.2	600
650	15.4	21.6	27.1	33.1	12.7	18.3	22.7	28.5	18.3	25.1	30.2	36.9	650
700	16.0	22.5	28.2	34.4	13.2	19.0	23.6	29.6	19.1	26.2	31.5	38.5	700
750	16.6	23.3	29.3	35.7	13.6	19.6	24.4	30.7	19.9	27.2	32.9	40.0	750
772	16.8	23.6	29.8	36.3	13.8	19.9	24.8	31.1	20.2	27.7	33.4	40.7	772

TABLE 4

CARRIER FREQUENCY ATTENUATION DATA (dB/KF)

PIC Insulated (Air Core), PIC Insulated-Filled Core, and Paper Insulated Cable, 0.083 µF Per Mile, 68°F

Freq.	PIC Cable (Air Core)				PIC Filled Cable				Paper Cable				Freq.
(KHz)	19 Ga.	22 Ga.	24 Ga.	26 Ga.	19 Ga.	22 Ga.	24 Ga.	26 Ga.	19 Ga.	22 Ga.	24 Ga.	26 Ga.	(KHz)
10	0.57	0.93	1.24	1.63	0.54	0.90	1.22	1.61	0.58	0.94	1.25	1.64	10
20	0.66	1.14	1.60	2.18	0.61	1.09	1.55	2.13	0.68	1.17	1.63	2.20	20
40	0.76	1.32	1.93	2.74	0.69	1.23	1.87	2.63	0.80	1.37	1.97	2.79	40
60	0.86	1.42	2.09	3.03	0.76	1.31	1.94	2.88	0.92	1.49	2.15	3.11	60
80	0.97	1.52	2.21	3.22	0.85	1.39	2.03	3.02	1.05	1.61	2.29	3.33	80
100	1.08	1.62	2.31	3.35	0.94	1.46	2.10	3.13	1.17	1.73	2.41	3.48	100
112	1.15	1.69	2.38	3.43	0.99	1.52	2.15	3.18	1.25	1.81	2.48	3.57	112
120	1.19	1.72	2.40	3.46	1.02	1.54	2.17	3.21	1.30	1.85	2.51	3.61	120
140	1.29	1.83	2.51	3.58	1.11	1.63	2.25	3.30	1.42	1.98	2.64	3.75	140
160	1.39	1.94	2.62	3.67	1.18	1.71	2.33	3.37	1.53	2.11	2.77	3.86	160
180	1.48	2.05	2.72	3.78	1.26	1.80	2.41	3.45	1.64	2.24	2.88	3.99	180
200	1.57	2.15	2.84	3.87	1.33	1.89	2.49	3.52	1.75	2.37	3.02	4.10	200
220	1.66	2.27	2.94	3.97	1.40	1.98	2.57	3.59	1.85	2.51	3.14	4.22	220
240	1.74	2.37	3.05	4.07	1.46	2.06	2.66	3.67	1.95	2.63	3.28	4.34	240
260	1.82	2.48	3.17	4.17	1.52	2.15	2.75	3.75	2.04	2.76	3.41	4.45	260
280	1.89	2.57	3.27	4.27	1.59	2.23	2.83	3.82	2.14	2.88	3.54	4.58	280
300	1.97	2.67	3.38	4.38	1.65	2.30	2.92	3.91	2.23	2.99	3.66	4.71	300
350	2.15	2.90	3.68	4.65	1.79	2.50	3.14	4.12	2.44	3.26	4.00	5.03	350
400	2.29	3.12	3.94	4.92	1.90	2.67	3.35	4.33	2.64	3.54	4.32	5.38	400
450	2.43	3.33	4.19	5.20	2.01	2.84	3.55	4.55	2.82	3.80	4.61	5.72	450
500	2.57	3.52	4.44	5.46	2.12	3.00	3.75	4.77	2.99	4.04	4.90	6.02	500
550	2.69	3.72	4.68	5.76	2.22	3.16	3.94	4.99	3.15	4.28	5.18	6.37	550
600	2.81	3.91	4.91	6.00	2.32	3.31	4.12	5.20	3.31	4.52	5.45	6.67	600
650	2.93	4.09	5.13	6.26	2.41	3.46	4.30	5.41	3.47	4.75	5.72	6.98	650
700	3.04	4.26	5.34	6.52	2.49	3.59	4.46	5.61	3.62	4.97	5.97	7.29	700
750	3.14	4.41	5.55	6.76	2.58	3.71	4.62	5.81	3.77	5.16	6.22	7.58	750
772	3.19	4.47	5.64	6.87	2.61	3.76	4.70	5.90	3.83	5.24	6.33	7.71	772

TABLE 5

ATTENUATION DATA OF MISCELLANEOUS CABLE AND OPEN WIRE FACILITIES

TABLE 5A: dB/MILE, 68°F - MISC. CABLE FACILITIES

FREQ. (KHz)	19 GA FOAM-PIC 0.045uF/Mi (NOTE 1)	19 GA PIC 0.066uF/Mi (NOTE 1)	22 GA FOAM-FILL 0.083uF/Mi (NOTE 2)	20 GA ALUM-FILL 0.083uF/Mi (NOTE 3)
0.3	0.6	0.6	1.0	1.0
1	0.9	1.1	1.8	1.8
3	1.5	1.8	3.0	3.0
10	2.2	2.6	4.9	4.8
50	3.3	4.0	7.1	6.7
100	4.0	5.0	8.4	7.7
150	4.7	6.0	9.7	8.8
200	5.3	6.9	11.0	10.0
250	5.8	7.8	12.4	11.1
300	6.3	8.7	13.6	12.2
350	6.8	9.6	14.8	13.2
400			15.9	14.1
450			17.0	15.0
500			17.9	15.9
550			18.9	17.0
600			19.9	17.5
650			20.8	18.3
700			21.6	19.0
750			22.4	19.6
772			22.7	19.9

NOTES:

1. This 19 gauge PIC and Foam-PIC (Air Core) cable data is included primarily for historical purposes.
2. This information on Foam Insulated-Filled Core cable is shown primarily for comparison purposes. It may be used for Foam or Foam Skin-Filled Core cable data. Exact attenuation values depend on the PIC to Air ratio in the Foam Insulation.
3. This information on Aluminum Conductor Filled Core cable is shown for comparison purposes. The 20 gauge aluminum conductor is intended to be an approximate replacement for 22 gauge copper.

TABLE 5B: dB/MILE, 68°F - OPEN WIRE FACILITIES

FREQ. (KHz)	COPPER-STEEL 0.080"-30%	COPPER-STEEL 0.104"-40%	ALUMINUM-STEEL 0.091"	ALUMINUM-STEEL 0.128"	1" RADIAL ICE (2)
0.3	-	-	-	-	-
1	0.28	0.16	0.29	0.20	-
3	0.36	0.19	0.39	0.27	-
10	0.41	0.20	0.47	0.31	-
50	0.47	0.23	0.54	0.35	1.2
100	0.50	0.28	0.59	0.40	3.3
150	0.53	0.34	0.64	0.45	5.4
200	0.55	0.40	0.69	0.48	7.5
250	0.58	0.46	0.73	0.52	9.6
300	0.61	0.51	0.76	0.55	11.7
350	0.65	0.56	0.80	0.58	-

NOTES:

1. This open wire attenuation data is based on 8" spacing with tandem insulator brackets, 68°F, wet weather (except ice data). The data is reasonably representative of open wire attenuation using other insulator brackets, and with 12" spacing.
2. The 1" radial ice data is estimated loss at temperatures below 32°F.

TABLE 6

CHARACTERISTIC IMPEDANCE OF CABLE FACILITIES (0.083µF/MILE)

IMPEDANCE EXPRESSED IN MAGNITUDE (OHMS) AND PHASE ANGLE (DEGREES) AT 68°F

TABLE 6A: NON LOADED PIC INSULATED CABLE (AIR CORE)

FREQ. (KHz)	19 GA.	22 GA.	24 GA.	26 GA.
0.3	737/44	1046/45	1317/45	1663/45
1	404/43	573/44	721/44	911/45
3	236/49	332/42	417/43	527/44
10	143/28	185/35	230/39	286/41
50	108/10	115/16	125/22	143/28
100	104/7	108/10	111/14	119/19
200	100/5	104/7	106/9	109/12
400	98/4	101/5	102/6	105/8
772	96/3	98/4	99/5	102/6

TABLE 6B: NON LOADED PIC INSULATED-FILLED CORE CABLE

FREQ. (KHz)	19 GA.	22 GA.	24 GA.	26 GA.
0.3	737/44	1046/45	1317/45	1663/45
1	404/43	573/44	721/44	911/45
3	236/39	332/42	417/43	527/44
10	146/26	186/34	231/38	286/40
50	116/8	121/14	130/20	146/26
100	113/6	115/8	118/12	125/17
200	110/4	113/6	114/7	116/10
400	108/3	110/4	112/5	113/6
772	107/2	108/3	109/4	111/5

TABLE 6C: NON LOADED PAPER INSULATED CABLE

FREQ. (KHz)	19 GA.	22 GA.	24 GA.	26 GA.
0.3	737/44	1046/45	1317/45	1663/45
1	404/43	573/44	721/44	911/45
3	236/39	332/42	417/43	527/44
10	142/29	183/35	230/39	286/41
50	105/11	113/17	123/23	142/29
100	101/7	105/11	109/14	117/20
200	98/5	101/7	104/9	107/12
400	95/4	98/5	100/7	103/8
772	94/3	96/4	98/5	100/6

TABLE 7

CHARACTERISTIC IMPEDANCE OF MISCELLANEOUS CABLE AND OPEN WIRE FACILITIES AND MIDSECTION IMPEDANCE OF LOADED CABLE

IMPEDANCE EXPRESSED IN MAGNITUDE (OHMS) AND PHASE ANGLE (DEGREES) AT 68°F

TABLE 7A: MISCELLANEOUS NON LOADED CABLE

FREQ. (KHz)	Insul-Core	Foam-Air	PIC-Air	Foam-Filled	PIC-Filled
	uF/Mi	0.045	0.066	0.083	0.083
	Gauge	19	19	22	20
	Conductor	Copper	Copper	Copper	Aluminum
0.3		1001/44	835/44	1046/45	1046/45
1		553/42	461/43	573/44	573/44
3		321/39	272/39	332/42	332/42
10		211/24	168/25	185/35	186/34
50		170/9	131/9	116/16	121/14
100		162/6	128/6	110/10	115/8
200		159/4	126/4	106/7	113/6
400		156/3	124/3	103/5	110/4
772		--	121/2	100/4	108/3

TABLE 7B: OPEN WIRE FACILITIES, 8 INCH SPACING

FREQ. (KHz)	COPPER - STEEL 0.080"-30%	COPPER - STEEL 0.104"-40%	ALUMINUM - STEEL 0.091"	ALUMINUM - STEEL 0.128"	1" RADIAL ICE
1	1054/34	763/25	1090/34	820/26	--
3	738/21	640/13	750/21	660/14	ESTIMATED
10	641/8	608/4	641/8	609/5	420
50	617/2	604/1	617/2	604/1	410
100	607/1	603/1	607/1	603/1	410
200	606/0	603/0	606/0	603/0	410
400	605/0	602/0	605/0	602/0	410

TABLE 7C: LOADED CABLE (0.083uF/MILE)

FREQ. (KHz)	19 GA.	22 GA.	24 GA.	26 GA.
	D66 LOADED CABLE			
0.3	1056/16	1218/25	1420/31	1724/36
1	1003/5	1025/10	1065/15	1149/21
3	1271/2	1274/4	1278/5	1290/8
	H88 LOADED CABLE			
0.3	1056/16	1217/25	1420/31	1725/36
1	1022/5	1044/10	1083/14	1167/21
3	1900/3	1898/6	1893/8	1885/13

NOTE: Refer to Tables 1 and 7 for more information on these cable and open wire facilities.

TABLE 8

ATTENUATION DATA OF HIGH FREQUENCY FACILITIES

TABLE 8A: 75 OHM COAXIAL CABLE (dB/MILE, 68°F)

FREQ. (MHz)	DIELECTRIC MATERIAL				
	Expanded Polyethylene (Foam)			Solid Polyethylene	
	.412" OD	.500" OD	.750" OD	.650" OD	.870" OD
1	4.8	3.7	2.1	3.7	2.6
10	15.8	12.7	9.0	13.7	10.6
20	22.2	18.0	12.7	19.5	14.8
30	27.5	22.2	15.3	23.8	18.5
40	31.7	25.3	18.0	27.5	21.1
50	38.0	30.1	21.6	33.8	25.9
60	41.7	32.7	23.8	37.0	28.5
70	44.9	35.4	25.9	40.1	30.6
80	48.0	38.0	27.5	42.8	32.7
90	51.2	40.1	29.0	45.4	34.8
100	55.4	44.4	32.2	49.6	37.5

NOTE: Attenuation at other frequencies can be obtained by:

$$A_{F2} = A_{F1} \sqrt{\frac{F2}{F1}}$$

TABLE 8B: 125 OHM VIDEO PAIR CABLE (dB/MILE, 68°F)

FREQ. (MHz)	dB/MILE
0.1	3.2
0.2	4.3
0.4	5.8
0.772	7.9
0.8	8.0
1.0	8.9
2.0	12.5
4.0	17.7
8.0	25.2
10.0	28.2

16 Gauge Conductors

TABLE 8C: OPTICAL FIBERS (dB/MILE AT LIGHT FREQUENCIES)

FREQ. (MHz)	dB/MILE
1,000,000,000	3.2 to 32

NOTES:

1. In 1970, a fiber was developed having a loss component of 20 dB per kilometer = 32.2 dB per mile.
2. In 1974, a fiber was developed having a loss component of about 2 dB per kilometer = 3.2 dB per mile (frequency band = 10^6 GHz, wavelength band = 0.87 to 0.92 micrometers - hair thin fiber). For use in T1, T2 and T3 PCM systems.

TABLE 9

DC RESISTANCE OF CONDUCTORS AND SHIELDS

TABLE 9A: DC CONDUCTOR LOOP RESISTANCE (68°F)

Gauge-Metal	Ohms/Mile	Ohms/KF
19 Copper	85	16.10
22 Copper	171	32.39
24 Copper	274	51.89
26 Copper	440	83.33
20 Aluminum	171	32.39
0.080" - 30% Copper-Steel	55.9	10.59
0.104" - 40% Copper-Steel	25.4	4.81
0.091" Aluminum-Steel	61.0	11.55
0.128" Aluminum-Steel	32.5	6.16

TABLE 9B: ESTIMATED SHIELD RESISTANCE (68°F)

NOTE: The following data can be used to determine the approximate resistance of cable shields; the actual resistance can vary somewhat. For 5 mil. copper, 8 mil. aluminum or 6 mil. copper-steel shields, the resistance is approximately 0.75 ohms per kilofoot for a 1-inch diameter cable.

CABLE (Pairs & Gauge)	Diameter (inches)	OHMS PER KILOFOOT				
		5 Mil. Copper	8 Mil. Aluminum	6 Mil. C/S	10 Mil. Copper	5 Mil. Bronze
200-24	1.32	0.48	0.51	0.57	0.22	0.94
100-24	0.99	0.64	0.68	0.76	0.30	1.26
50-24	0.75	0.84	0.90	1.01	0.40	1.66
25-22	0.72	0.90	0.93	1.05	0.41	1.73
12-22	0.57	1.11	1.18	1.33	0.52	2.18
6-19	0.56	1.13	1.20	1.35	0.53	2.22

TABLE 10

TEMPERATURE CORRECTION FACTORS

TABLE 10A: DC RESISTANCE CORRECTION FOR TEMPERATURE FOR COPPER OR ALUMINUM

$$Rt = R68 \left[1 + 0.0022\ (t-68)\right]$$

One percent resistance change for approximately each $5^{o}F$ change in temperature.

TABLE 10B: AC RESISTANCE AND ATTENUATION CORRECTIONS FOR TEMPERATURE (Copper Cables at 0.083 microfarads per mile)

Resistance: $Rt = R68 \left[1 + Ct\ (t-68)\right]$

Attenuation: $At = A68 \left[1 + Ct\ (t-68)\right]$

TEMPERATURE CORRECTION FACTOR (Ct) x 10^{-3}

FREQ. (KHz)	19 Gauge		22 Gauge		24 Gauge		26 Gauge	
	Res.	Att.	Res.	Att.	Res.	Att.	Res.	Att.
10	2.20	1.67	2.20	1.42	2.20	1.29	2.20	1.21
50	1.77	1.69	2.03	1.86	2.14	1.80	2.19	1.65
100	1.44	1.42	1.73	1.67	1.96	1.83	2.07	1.82
200	1.22	1.20	1.43	1.40	1.67	1.67	1.86	1.77
400	1.12	1.11	1.22	1.20	1.37	1.34	1.53	1.50
772	1.10	1.06	1.10	1.08	1.16	1.15	1.27	1.26

From the above, the following is a table of the temperature change (^{o}F) required for one percent change in attenuation:

KHz	19 Gauge	22 Gauge	24 Gauge	26 Gauge
10	6	7	8	8
50	6	5	6	6
100	7	6	5	5
200	8	7	6	6
400	9	8	7	7
772	9	9	9	8

Simplified Attenuation Correction for Temperature:

$$At = A68 \left[1 + 0.0014\ (t-68)\right]$$

One percent attenuation change for each $7^{o}F$ change in temperature.

NOTES

Rt = Resistance at new temperature
t = New temperature
Ct = Temperature correction factor
A68 = Attenuation at $68^{o}F$
R68 = Resistance at $68^{o}F$
68 = $68^{o}F$
At = Attenuation at new temperature