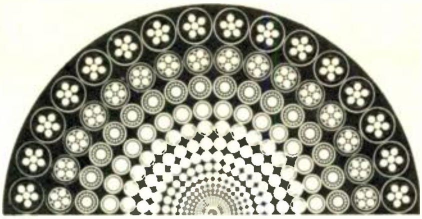
The Lenkurt

JUNE 1970

DEMODULATOR

Cable Developments



Improvements in cable construction have eliminated some serious shortcomings and have increased overall performance.

Telephone service was still in its infancy when the transition from open-wire transmission to cables began. The motivating factors were quite simple: aerial congestion quickly became intolerable in the urban areas where service was concentrated and open-wire lines were highly susceptible to storm damage.

This transition has essentially taken place, although open-wire continues to set longevity records in some rural areas. Not only do the same factors that sparked the trend toward cable still apply, but a new one has been added — increasing public concern with aesthetic values. As yet, no method has been found to make aerial transmission lines (open-wire or cable) an asset to the environment.

One solution has been to bury the cable. Despite the industry's many years of experience with cable, both electrical and physical problems remain. There is room for improvement in traditional applications, and newer developments, such as PCM transmission, make new and greater demands on the cable plant.

Cable Matures

A multi-pair cable is far from an ideal transmission medium for either voice or carrier frequencies. Its shortcomings, such as the tendency to act as a lowpass filter, have been well documented (see the May 1970, Demodulator). Some of the solutions have also been presented: loading for voice frequencies, equalization and repeaters for carrier frequencies.

Equally important, however, is the physical construction of cable, because construction determines the electrical characteristics.

The basic characteristics of a transmission line largely depend on such factors as the size and material of the conductors, as well as their electrical proximity (physical spacing and the dielectric between them). Open-wire lines, of course, are insulated from each other by air space; so are most coaxial cables. However, multi-pair cables also must depend on other types of insulation.

The conductors in the first cables were wrapped with cotton string for insulation. Later, paper tape and pulp came into widespread use. These methods worked reasonably well as long as the insulation remained dry. Moisture can be kept out with a waterproof sheath. Lead has been widely used as a waterproof sheath, but it easily develops fatigue cracks which let in moisture. It is also heavy, difficult to handle, and expensive.

Another approach to keeping moisture out is to fill the cable sheath with dry air under pressure. Since this is quite expensive, it is often not economically justifiable, particularly for long cables that may contain only a few pairs.

A major advance was the development of Polyethylene Insulated Conductor (PIC) cables. This waterproof plastic insulation solved most of the problems caused by wet conductors, although PIC cables occasionally have defects allowing moisture to enter.

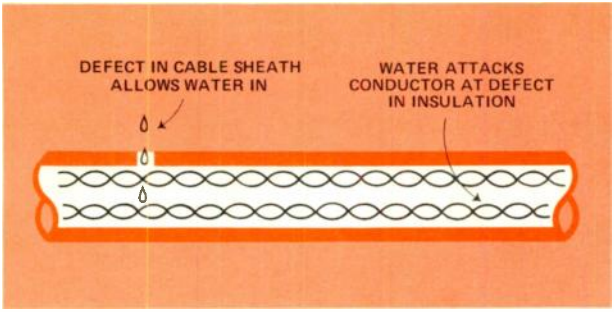


Figure 1. Cable acts as a pipe permitting water to enter the sheath at one point, then travel hundreds of feet before attacking the conductors.

Dry conductors alone are not enough for good transmission characteristics. Impure water has poor dielectric properties. And water inside a cable sheath, even though it does not reach the conductors, increases the capacitance between the conductors. In an extreme case where the cable is full of water, the transmission loss can increase about 55 percent at voice frequencies, and as much as 75 percent at carrier frequencies.

Polyethylene is also used to insulate and waterproof the sheathing. It usually forms an outer jacket over the metal sheathing, providing electrical shielding and mechanical support. This outer jacket is easily damaged while the cable is being buried. A lightning strike can also melt tiny holes in the jacket.

Another significant problem is the damage caused by gophers and other pests. In areas where such rodents are prevalent, cables are armored with a thick copper shield for protection.

Because about half the space inside a cable is filled with air, the sheath acts as a pipe. Thus any water that does penetrate can flow for hundreds of feet along the cable – even uphill where temperature variations create pressure differentials. This complicates repair, because some of the problems caused by moisture may not be close to the point where the water entered the cable (see Figure 1).

Keeping the Water Out

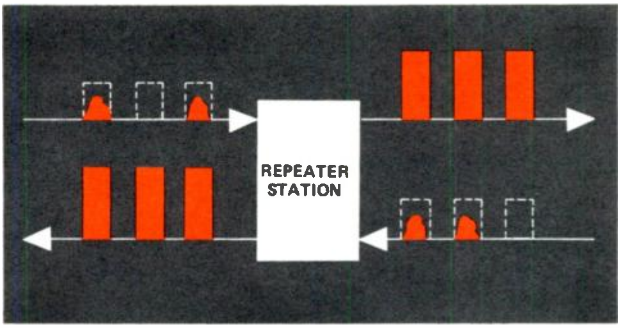
Many different methods have been tried to keep moisture out of cables. One early method was to fill the cable with kerosene. However, kerosene is lighter than water, causing it to float away when water enters.

Petroleum jelly, which has good electrical properties, has long been attractive as a water repellent in cables. The main problem with petroleum jelly is its low melting point. It is likely to melt and flow out of cables stored in the sun. At the same time, a stiff filling compound is not satisfactory because it does not allow the cable to flex easily.

Recently, petroleum jelly has been mixed with pulverized polyethylene to form an excellent filling compound. The addition of an antioxidizing agent allows the compound to retain its putty-like consistency for years.

This filling compound has necessitated some changes in the insulation surrounding the conductors. Since the compound can cause polyethylene to deteriorate, conductors are usually insulated with polypropylene. Furthermore, filling the cable increases the capacitance between conductors. Since the new cable must be interchangeable with older PIC cable, it has to meet mutual capacitance standards of 0.083 microfarads per mile. This is accomplished through a 40 percent increase in the thickness of the polypropylene

Figure 2. PCM systems use the same frequency band for both transmission directions; therefore, coupling from strong pulses leaving a repeater can seriously interfere with incoming pulses.



insulation on the conductors. The net result is a slightly larger cable.

While filled cable costs somewhat more than standard PIC cable, it offers a bonus in the form of reduced attenuation, particularly at carrier frequencies. Filling the cable permits the manufacturer to produce more uniform electrical characteristics. This can reduce attenuation as much as 15 percent compared with standard PIC cable (approximately 20 dB per mile at 772 kHz compared to about 23 dB per mile for 22-gauge PIC). This reduced attenuation is due to the filled cable's higher impedance and lower ac resistance caused by the thicker plastic insulation. This uncalculated bonus can result in fewer repeaters in a carrier system.

PCM Transmission on Cable

With few exceptions, cable carrier systems use four-wire transmission arrangements – two wires for each direction of transmission. In addition, "traditional" carrier systems that use frequency-division multiplexing normally use different frequency bands for the two directions of transmission. Otherwise, the low-level signal coming into the repeater could suffer severely from coupling by the high-level signal coming out of the repeater on an adjacent pair, as shown in Figure 2. This condition is defined as near-end crosstalk.

PCM systems, on the other hand, use the entire available frequency band for each direction of transmission. A primary cause of errors in PCM transmission is impulse noise produced by near-end crosstalk between PCM systems in the same cable sheath.

For this reason, it has been recommended that PCM systems, such as Lenkurt's 91A, use two separate cables dedicated to PCM transmission. Since one cable carries one direction, both cables can be filled to capacity. Another way to decrease the near-end coupling is to limit the cable fill to about 70 percent of capacity, when only one cable is used. Still another is to decrease repeater spacing to maintain the level difference between the two transmission directions.

A new development, called T-Screen* cable, shows substantial promise for PCM transmission. As shown in Figure 3, T-Screen cable incorporates a thin shield to divide the conductors into two separate compartments – effectively separating two cables in one sheath. The screen is made of polyester-insulated aluminum. The 4-mil screen is thick enough to provide the necessary electrical isolation, yet thin enough to flex with the cable without deforming.

The best results are obtained by combining the T-Screen with the

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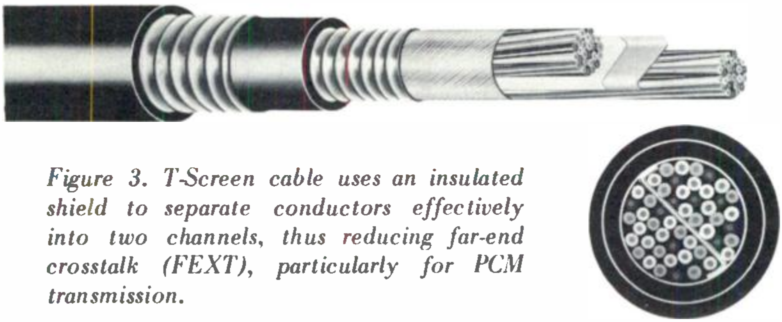

Figure 3. T-Screen cable uses an insulated shield to separate conductors effectively into two channels, thus reducing far-end crosstalk (FEXT), particularly for PCM transmission.

Courtesy of Superior Continental Corporation

filled-cable concept. The T-Screen decreases crosstalk (see Figure 4), and the cable filled with the petroleum jelly compound decreases attenuation and moisture problems. Reports from the field indicate that the use of this combination has permitted PCM repeater spacing to be "stretched" from 5,400 feet to 8,000 feet on 22-gauge cable. However, the savings obtained are partly offset by the increased cost of such cable (typically 5 to 20 percent, depending on the pair count).

Added economic advantages may be realized by using 24-gauge cable to produce 6,000-foot repeater spacing for PCM. Such spacing eliminates separate locations for carrier repeaters and voice-frequency loading coils, since standard H-88 loading coils are placed every 6,000 feet.

Coaxial Cable Developments

Like multi-pair cable, coaxial cable has been changing ever since its introduction to field use in the 1930's. Much of the change, however, has been in the application of coaxial cable, rather than in the basic design. The first commercial application in the United States carried 600 two-way voice channels on each pair of coax-

Courtesy of Superior Continental Corporation

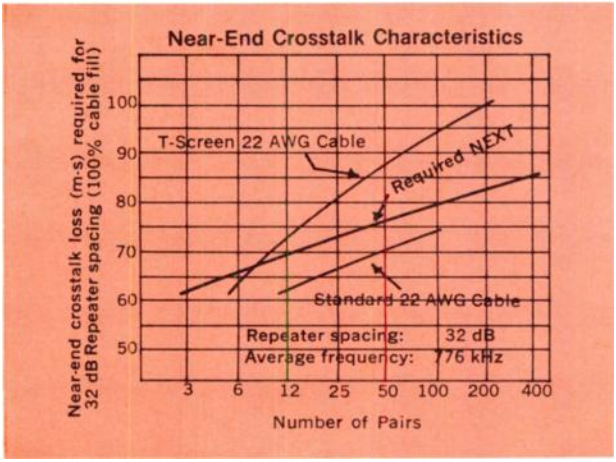

Figure 4. T-Screen cable substantially improves PCM crosstalk performance with 100 percent cable fill.

ials, using an L-1 carrier system. This version used a 0.27-inch cable and rubber discs to maintain separation between the conductors.

Soon, however, the standard size for high-density applications became 0.375 inches, as a compromise between cost and attenuation. Conductor separation was maintained with polyethylene discs to reduce the mutual capacitance. Increased circuit capacity was obtained by adding more coaxial "tubes" to a single cable, and by decreasing repeater spacing to permit more channels on each pair of coaxials.

Today, 20-tube cables are commonly used on heavy routes, and the L-4 carrier system transmits 3600 two-way voice channels on each pair of tubes.

While the electrical characteristics of an ideal coaxial cable are excellent, they are highly dependent on the physical relationship of the conductors. Since the outer conductor is hollow, and the inner conductor is normally held in place by thin discs about an inch apart, the tube is quite susceptible to crushing. Any such damage creates a discontinuity in the transmission path, resulting in deterioration of electrical characteristics.

Furthermore, the flexing involved in manufacturing, transporting, and laying the cable can cause fatigue in the outer conductor. For instance, flexing tests have shown that the conventional serrated-seam outer conductor develops "dimples" under each serration, even with normal handling.

Partly because of a desire to improve the mechanical and electrical characteristics of coaxial cable, and partly because of the specter of a world-wide copper shortage, Bell Telephone Laboratories set out to develop an improved coaxial cable. The result is CLOAX (corrugated-laminated coaxial) cable.

CLOAX uses a thin copper skin laminated to a tinned-steel sheet with a copolymer adhesive, as shown in Figure 5. The entire laminate is laterally corrugated to permit flexing and to add crush resistance.

Because this design uses a soldered seam and does not deform easily, it has more uniform electrical characteristics; therefore, its transmission loss is said to be lower than conventional serrated-seam coaxial, and it provides better interference protection. CLOAX uses one-third as much copper as the previous design; it has twice the crush resistance, and four times the bending life (see Figure 6).

One seeming dark spot in the CLOAX picture is that continuous exposure to high humidities tends to destroy the copolymer-to-copper bond. However, initial tests at Bell Laboratories indicate that once the cable is fabricated and buried, this bond is no longer critical. As long as the cable is not disturbed, the inside

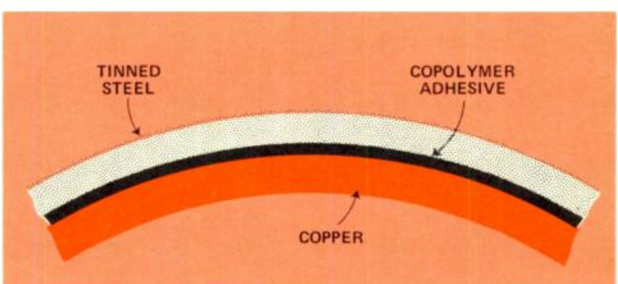

Figure 5. The CLOAX cable outer conductor and shell are a laminate of copper and steel — resulting in less copper, greater strength and improved electrical characteristics.

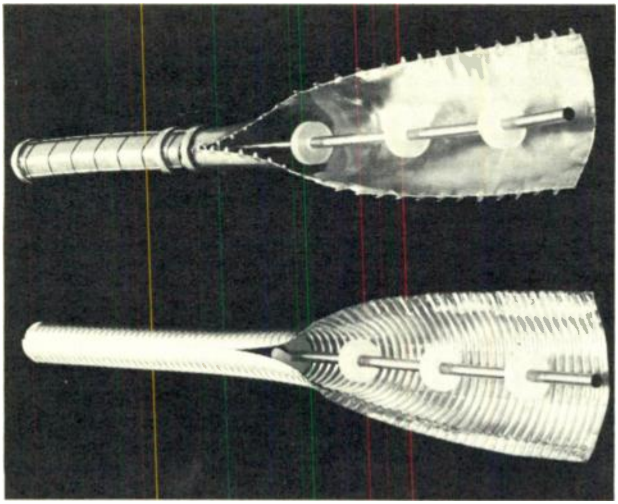

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Figure 6. The serrated–seam coaxial cable, on the top, uses a double wrapping of helically wound steel tape to give it strength. The corrugated-laminated coaxial (CLOAX), on the bottom, has greater strength, without such wrapping.

diameter of the conductor does not change. Therefore, the electrical characteristics remain constant.

The Future of Cable

The more sophisticated forms of transmission – microwave radio, millimeter waveguides, lasers – tend to receive the publicity. They definitely occupy a position of importance in the communications industry, but they also have their shortcomings.

There is nothing particularly glamorous about cable, but it still has its place. With the number of telephone circuits doubling about every seven years, cable's future seems assured.

Some of the recent developments in cable technology have been mentioned here. There undoubtedly will be others in the future – improved electrical materials, better protection from interference, better mechanical characteristics. Major efforts, in all areas, will be directed toward improved economy. For many applications, there is presently no technique in sight to compete economically with cable.

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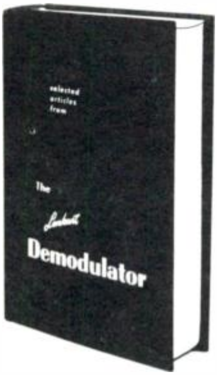

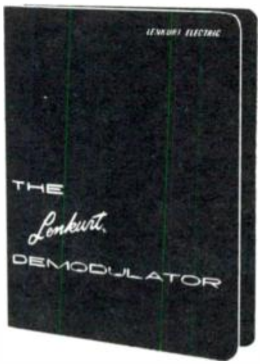

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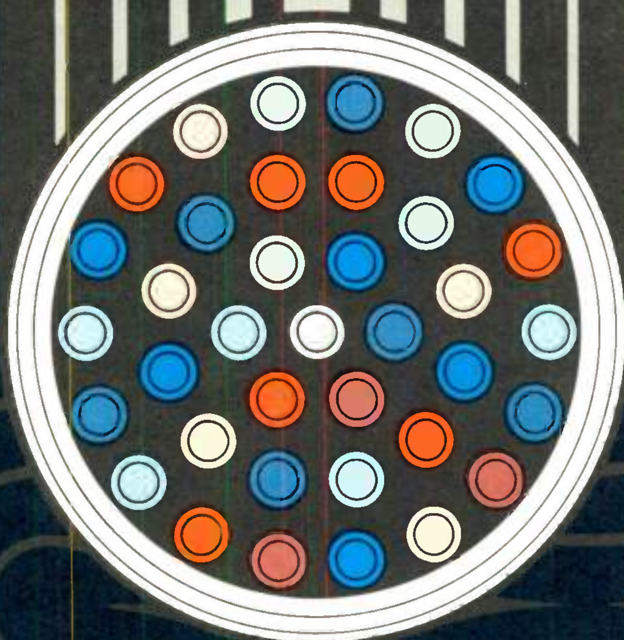

CABLES

Telephone cable

. . . the changing constant

Cable has long been accepted as a fundamental element in a telephone plant. In recent years, however, cable's "public image" has been increasingly overshadowed by microwave radio, satellite relay, and even more exotic transmission methods.

While such transmission methods reduce the importance of cable in toll plant applications, it is still the mainstay of exchange distribution. The design and function of cable is not static. In comes in an increasingly wide variety of sizes and shapes, with a correspondingly wide variety of transmission characteristics for a multitude of uses.

Furthermore, the role of cable in telephone exchange circuits is changing. For instance, just a few years ago each pair of wires in an inter-exchange cable typically carried a two-way, voice-frequency conversation. A fifty-pair cable carried 50 conversations. Today, the same cable may handle 25 carrier systems, each of which handles 24 conversations —600 channels in all. Naturally, this places entirely different transmission demands on the cable.

Cable Characteristics

The four fundamental electrical properties of the conductors in a cable are the same as those of any other transmission line:

1. *Series resistance* is the ohmic resistance of the conductors.
2. *Series inductance* is the self inductance of each conductor, plus the mutual inductance between the individual conductors.
3. *Shunt conductance* is the total resistance of the current leakage paths between the conductors.
4. *Shunt capacitance* is the electrical capacitance between conductors, including the capacitance effect of earth.

Since these electrical properties depend primarily on the physical configuration and the material used in the construction of any particular cable, they are sometimes considered to be constant —even though they change somewhat with temperature.

These are the four properties that define, for example, the attenuation characteristics of the cable. This produces the cable's "slope" —the characteristic attenuation-versus-frequency

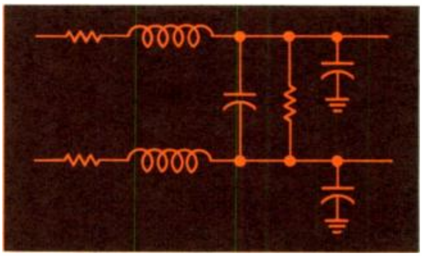

Figure 1. Line transmission characteristics are controlled by series resistance, series inductance, shunt capacitance, and shunt resistance.

curve shown in Figure 2. If the slope is not corrected, it distorts the level relationship of different frequencies within a signal.

The increasing attenuation with increasing frequency characteristic of cable is caused primarily by the small conductors used and by the short leakage paths between conductors. The small conductors have a fairly high series resistance, and conductor spacing is a major factor in determining shunt capacitance. Closely spaced conductors increase the shunt capcitance, making it easier for the high frequencies to follow the leakage paths between conductors.

Since economic considerations effectively rule out greater conductor spacing to reduce shunt capacitance, the traditional method of combating it is to "load" the line with series inductance. The idea is to balance capacitive reactance with inductive reactance.

This works well for lower frequencies, effectively eliminating the slope over a limited frequency band. Unfortunately, however, a loaded line acts like a lowpass filter. While the low frequencies suffer comparatively little attenuation, the line has an effective cutoff frequency. At higher frequencies, attenuation increases very rapidly (see Figure 2). This cutoff frequency can be increased by using loading coils of smaller value and size and placing them closer together. But above about 35 kHz the coils become too small and the spacing too close to be economically feasible.

Since most modern carrier systems use a frequency band that extends far

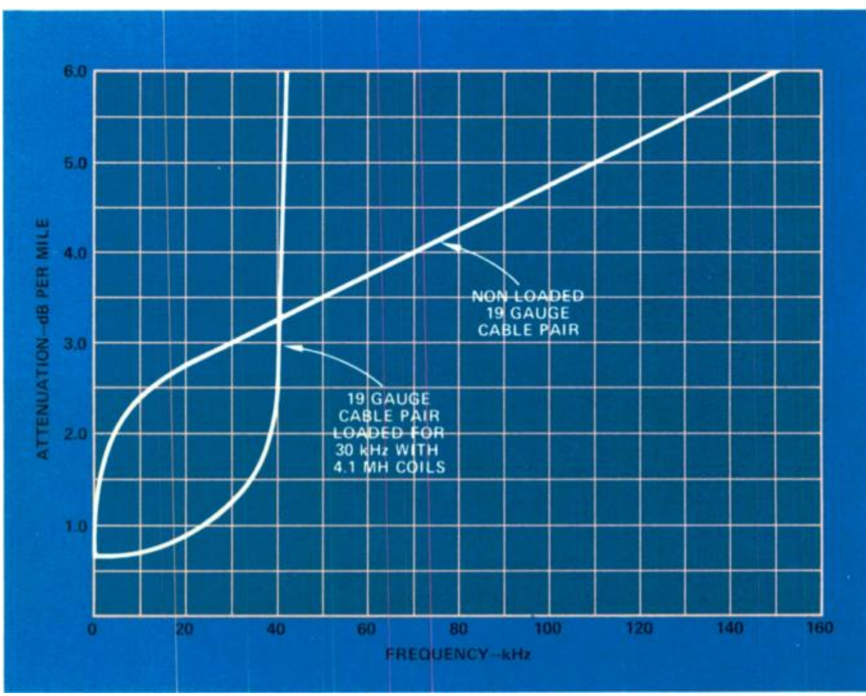

Figure 2. Non-loaded cable pair exhibits relatively constant slope, while loaded pair acts as a lowpass filter.

above 35 kHz, loading is not practical for cables used in carrier transmission (although loading is still used on long voice-frequency circuits). A common method used in carrier transmission to reduce distortion is the practice of frequency frogging, where the individual channels follow a "leap frog" pattern. The entire band of carrier frequencies is inverted at each repeater point (see Figure 3). Thus, the channel that occupies the lowest frequency slot (and hence suffers the least attenuation) in one section of the line occupies the highest slot in the next section.

Another way to compensate for slope is by using equalizing networks to introduce a slope opposite to that encountered in the line. An equalizer is much like a highpass filter with a slow and constant roll-off. When its characteristics are added to those of the line, the overall attenuation-versus-frequency curve is approximately flat. Some carrier systems have built-in slope equalizers, while others use external adjustable equalizers. Even with such corrective measures, cable is still a loss-prone transmission medium. Open wire, for example, introduces far less loss.

What makes cable attractice is economy. It is an inexpensive way to install a great many circuits. The economy, of course, lies in the way cables are constructed.

Cable Construction

A telephone cable consists basically of a number of insulated conductors inside an insulating sheath. Wire sizes run from 10 gauge to 26 gauge, depending on the application. Of course, large conductors (small gauge) introduce less loss, but they also raise the cost and make the cable more bulky.

And bulk should not be underestimated. In many metropolitan areas, cable ducts are already crowded nearly to capacity (see Figure 4), and additional space is costly. If ducts must be enlarged, or additional ones installed, the necessary construction work can be prohibitively expensive.

For these economic reasons, cables close to the central office most often use small conductors —typically 22 to 26 gauge. Farther out, larger cables are used.

Toll cables, on the other hand, may cover routes as long as 300 miles. Thus, there is a much greater opportunity for attenuation to build up. Therefore, toll cables are typically constructed of larger conductors. To give an example, 26-gauge, paper-insulated cable has a loss of about 26 dB

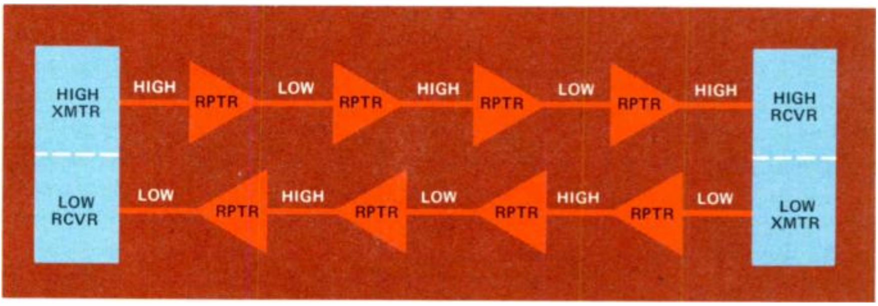

Figure 3. In frequency frogging, the entire frequency band is inverted at each repeater to equalize distortion.

per mile at 360 kHz, compared to only about 12 dB per mile for 19-gauge.

Another important factor in cable construction is the insulation, both on the individual conductors and in the outside sheath. Many cables use paper insulation around the conductors, primarily because it is inexpensive. The losses in paper-insulated cable are quite high because paper is not a particularly good barrier to the leakage paths. Furthermore, the varying insulation thickness causes conductance and capacitance to vary.

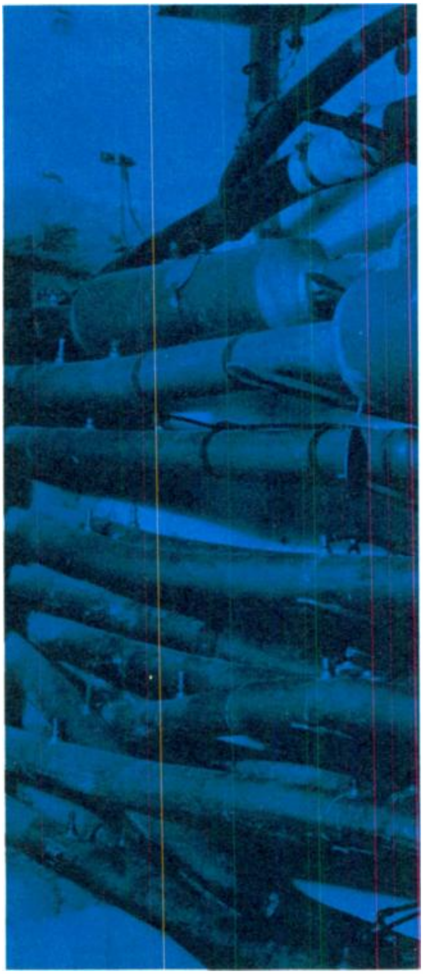

Figure 4. Photo shows crowded cable ducts.

If moisture penetrates the sheath (even a pinhole can permit it), the paper gets wet reducing the insulation resistance and transmission characteristics of the cable. For these reasons, the trend is toward plastic insulation, which provides a better dielectric barrier to the leakage paths. However, moisture can still be a problem. In plastic-insulated cable, moisture can increase the mutual capacitance of the cable pairs, with a corresponding increase in attenuation.

The outer sheath has two functions —mechanical and electrical. Mechanically, it holds the conductors together and provides an environmental barrier. Electrically, it offers some protection from outside interference. Normal practice is to use two sheaths, one of metal and the other of plastic or rubber.

Another factor that must be considered in the construction of cable is pair balance. A magnetic field is associated with the current in a line; an electric field is associated with the voltage. It is desirable to have both the magnetic and electrical relationships between each conductor and the earth the same for both conductors —in other words, to have a balanced line. An unbalanced line can result in excess noise, crosstalk, and absorption peaks at certain frequencies. Fortunately, there is a simple solution to a major portion of the balance problem: simply twist the two wires around each other. Thus, the unbalancing condition is reversed at short intervals, and the inductive effects tend to balance.

Getting the Best Out of Cable

Cable is not a perfect transmission medium. Properly used, however, it provides very satisfactory transmission. For many applications, it has no economic equal. It is not difficult to engineer a cable system if all new cable is to be installed. But often this is not the case. A typical cable carrier system, for instance, may use some new and some existing cable, often of different sizes —and almost certainly possessing different transmission characteristics.

The new cable should be chosen to provide the best transmission characteristics that are economically feasible, without regard to the characteristics of the existing cable. (If the existing cable has inferior transmission characteristics, there is no point in compounding them.)

Any pairs that are used for voice-frequency circuits are potential noise sources. They may pick up transients from switching equipment, for example. And if they happen to be connected to open-wire lines, these lines can act as radio antennas, introducing radio-frequency interference.

Noise is also picked up at carrier frequencies, but if it is introduced while the signal is at a high level, the noise will have minimal effect. Therefore, if possible, the entire existing cable should be designated for carrier transmission. For this reason, also, it is often wise to use a short repeater run out of an office or in other high-noise areas. This keeps the signal level high in the areas where noise is most likely to be introduced.

If the new and existing cables are not the same, they will require a different repeater spacing and different equalization, depending on their individual characteristics.

Cable adequate for voice transmission is not necessarily satisfactory for carrier. For example, an imperfect splice that causes no trouble at voice frequencies can act as a diode rectifier at carrier frequencies, introducing substantial distortion.

Another consideration is the choice between aerial and buried cable. Often it is dictated by outside factors such as economics or aesthetics. For stable transmission, however, buried cable is more efficient. This is partly due to the fact that buried cable does not experience the temperature extremes of aerial cable. Since attenuation increases with temperature, as shown in Figure 5, high temperatures should be avoided when possible.

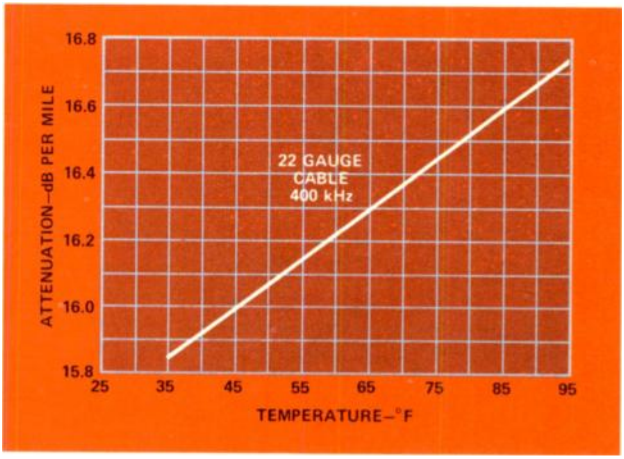

Figure 5. Effect of temperature on attenuation is not a major factor, but it must be considered.

Buried cable is thermally insulated by the earth, and its year-round temperature variation in some areas will be no more than a few degrees. Aerial cable, with no such insulation, suffers from an "oven effect" that exaggerates the sun's heat. Tests have shown that the internal temperature of aerial cable on a hot day may be 18 degrees higher than the ambient air temperature.

On the other hand, both aerial and buried cable are subject to attack by pests such as insects and rodents. It is difficult to say which presents the greater hazard without specifically studying a particular locality.

Coaxial Cable

Thus far, this discussion has concerned multipair cable. But coaxial cable has been receiving a great deal of favorable attention in recent years, after being overshadowed in the 1950's and early 1960's by microwave radio. A major reason for the renewed interest in coaxial cable is that radio frequency allocations are becoming increasingly congested in many areas. And for many uses coaxial cable can economically replace microwave transmission.

A coaxial cable consists of a solid inner conductor placed inside a hollow outer conductor. The two conductors are concentric and are separated by an insulator. This may be a solid such as plastic. But, in coaxial cables used for communications the insulator is usually air. The inner conductor is kept centered by support discs placed at intervals. This construction results in lower transmission losses than does solid insulation.

Regardless of the construction, however, a coaxial cable has much lower losses than a twisted pair. Since it also has a lower attenuation-versus-frequency slope, the usable bandwidth is much greater. While ordinary cable carrier systems are usually limited to 24 voice channels, coaxial systems often carry 600 or more channels. For extremely heavy routes, the Bell System L4 carries 3600 channels. Channel capacity as great as 10,800 is being planned.

Coaxial cable also provides good protection from interference, since the electromagnetic energy propagation is confined within the tube. This is particularly important in some specialized areas such as video transmission.

A relatively new application for coaxial cable is the transmission of digital information. Multipair cables are adequate for bit rates suitable for 24 PCM voice channels, but the rates needed for high density systems demand the greater bandwidth available in coaxial cable.

Cable Development

The basic factors in cable design are both well known and constant. But that does not mean improved cables are not being developed. On the contrary, the search is continuing for ways to improve the efficiency of both multipair and coaxial cables.

While the primary emphasis is on the development of new materials to reduce losses and distortion, other major objectives are to improve manufacturing methods while at the same time reducing costs.

Part of the development work is also aimed at new cables for specialized applications. These new cables will be the subject of the next Demodulator article.

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