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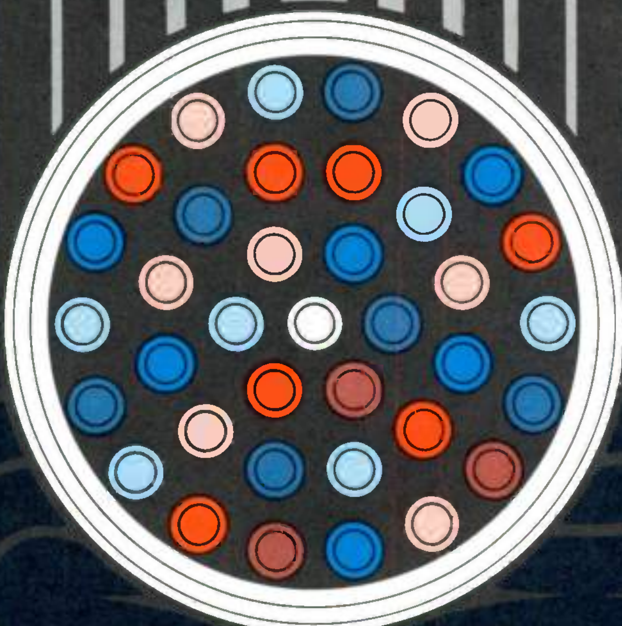

CABLES

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

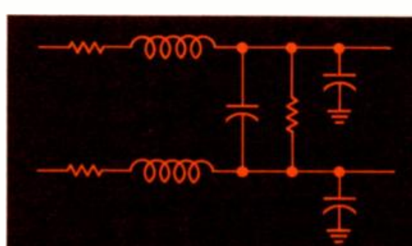

Figure 1. Line transmission characteristics are controlled by series resistance, series inductance, shunt capacitance, and shunt resistance.

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

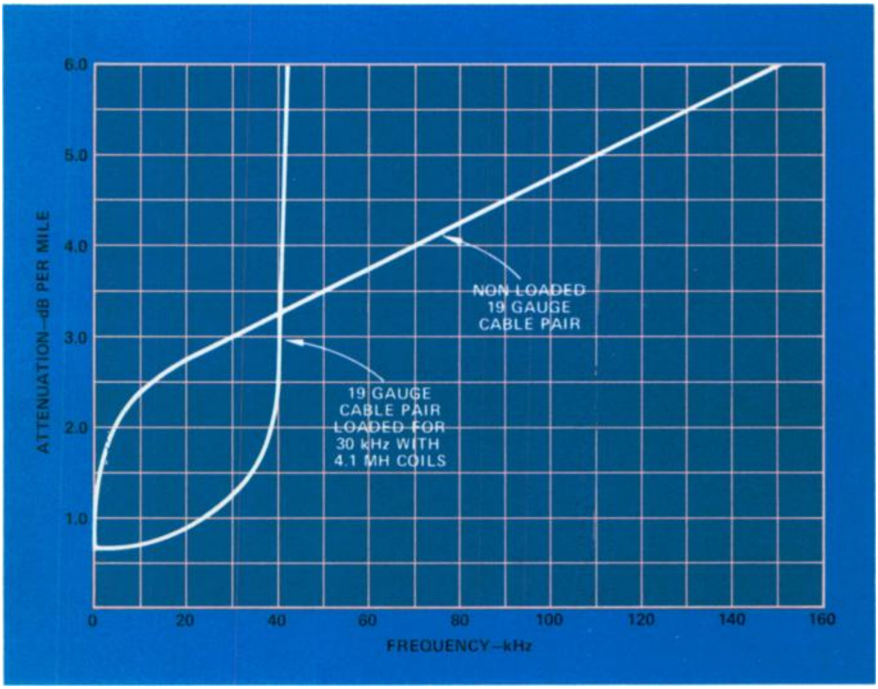

Figure 2. Non-loaded cable pair exhibits relatively constant slope, while loaded pair acts as a lowpass filter.

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

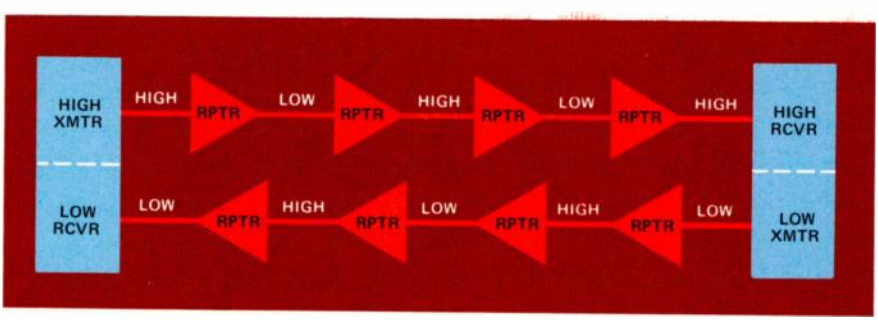

Figure 3. In frequency frogging, the entire frequency band is inverted at each repeater to equalize distortion.

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.

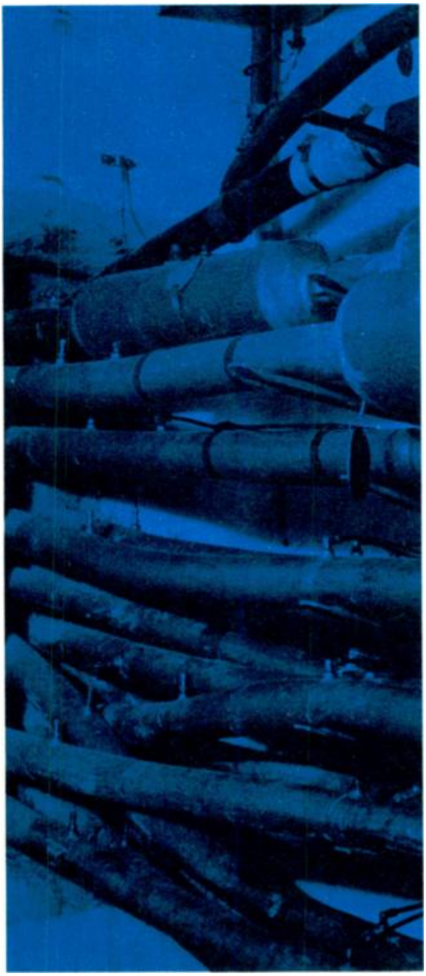

Figure 4. Photo shows crowded cable ducts.

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.

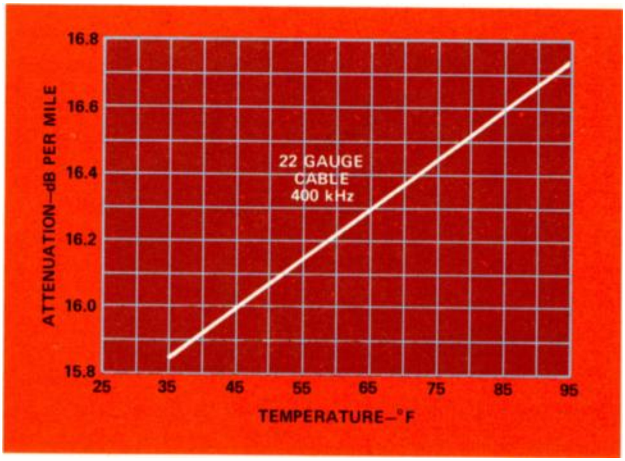

Figure 5. Effect of temperature on attenuation is not a major factor, but it must be considered.

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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