The Lenkurt® Demodulator

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THE BEHAVIOR OF OPEN-WIRE LINES AND CABLES
at Frequencies above 150 kc

In the development of carrier systems for toll transmission, the channel capacity of an open-wire lead or a multi-pair cable was increased by using higher and higher frequencies. For a number of reasons, the maximum frequency commonly used for medium- and long-haul toll circuits in the United States is about 156 kc for open-wire lines, and 264 kc for multi-pair cable. However, higher frequencies are used for carrier channels applied to coaxial cable.

Recently, carrier systems for subscriber service have been developed to operate at frequencies up to about 350 kc. In this article, the characteristics of open-wire lines and cables in the 150-kc to 350-kc region are discussed.

Unprecedented demand for telephone service has been felt strongly in rural areas as well as in the urban and suburban areas. This demand has occurred at a time when telephone service is being "up-graded" in anticipation of Direct Distance Dialing; so that in addition to increasing the service in rural areas it is also necessary to improve this service.

The extension and improvement of rural service is being met in a number of ways. For example, multi-pair 19-gauge voice-frequency loaded cable is being installed in some areas. The cable provides the backbone of the rural service line, and open-wire drops extend from the main cable to the subscriber location.

Another method which has been gaining in popularity in the last few years is in the use of carrier that is designed for rural subscriber service. In this application, the subscriber end of the carrier channel and its associated equipment effectively provide the central-office facilities (talking battery and ringing current) as well as the communication channel—but at a location remote from the office. A number of subscribers may obtain service from one carrier channel.

In many cases, the toll-lead route will be followed by the rural lead from the central office to the outlying areas. Where carrier is used on the toll lead, coordination is necessary between the subscriber carrier and the toll carrier.

Channel Number	Line Frequencies in Kilocycles							
	"A" Allocation		"B" Allocation		"C" Allocation		"D" Allocation	
	West	East	West	East	West	East	West	East
1	50	65	57.5	72.5	50	335	57.5	342.5
2	80	95	87.5	102.5	65	320	72.5	327.5
3	110	125	117.5	132.5	80	305	87.5	312.5
4	140	155	147.5	162.5	95	290	102.5	297.5
5	170	185	177.5	192.5	110	275	117.5	282.5
6	200	215	207.5	222.5	125	260	132.5	267.5
7	230	245	237.5	252.5	140	245	147.5	252.5
8	260	275	267.5	282.5	155	230	162.5	237.5
9	290	305	297.5	312.5	170	215	177.5	222.5
10	320	335	327.5	342.5	185	200	192.5	207.5

Fig. 1. Frequency Allocation Chart of an FM Subscriber-Carrier System.

The number of channels of subscriber carrier which may be used will depend upon the frequency spectrum occupied by the toll circuit. For this as well as other reasons, the frequency spectrum for some of the subscriber-carrier channels is above that used for toll applications.

A number of different types of wire and cable are used for rural subscriber circuits. Before carrier can be applied to a rural line the characteristics of the wire or cable should be known. Among the characteristics which should be considered are: (1) wire type and size, (2) line transposition, (3) attenuation, (4) crosstalk and (5) noise.

Effects of Wire Types and Sizes

Various types and sizes of wire are used in open-wire line construction. While copper is the better conductor, iron and steel wire are sometimes used because of their greater mechanical strength. However, iron wire or ungalvanized steel wire are rarely used in new construction. Copper-clad steel wire is becoming increasingly popular because it combines the strength of steel and the superior conductivity of copper.

The kind of wire as well as the size used in open-wire construction has a bearing on the attenuation. Over the frequency range from 1 kc to 360 kc, 102-mil copper-clad wire with a 30 percent copper content is more efficient than 80-mil copper-clad wire with either a 30 or 40 percent copper content; and above 220 kc a 102-mil, 30 percent copper-clad wire pair is more efficient than a 104-mil, 40 percent copper-clad wire pair. The attenuation of a 102-mil, 30 percent copper-clad open-wire pair with 12-inch spacing is only 0.56 db per mile at 360 kc, when using 25.5 pairs of #17 insulators per mile. Solid 104-mil copper-wire pairs, using the same wire spacing, but supported by 53 pairs of CS insulators per mile, have an attenuation loss of 0.65 db per mile at 360 kc, and when using 53 pairs of DP insulators per mile, the attenuation increases to 0.84 db per mile.

The attenuation in steel and iron wire is considerably greater than in copper or copper-clad steel wire. The attenuation of a 109-mil high-strength, zinc-galvanized steel wire pair, when new, is 5.16 db at 360 kc. The attenuation increases as the zinc coating thickness decreases from weathering. When the zinc coating is reduced in half, the attenuation at 360 kc increases to 6.63 db per mile and when the coating has completely eroded, the attenuation increases to 7.76 db per mile. The loss becomes even higher when the wire rusts or becomes pitted.

Insulated wire is sometimes used in carrier system applications. The insulation protects the conducting surface from the elements, thus reducing corrosion. In addition, a sturdy insulating jacket can reduce the effects caused when the wire rubs against trees and other objects. Depending upon the kind of insulation, however, an insulating jacket can introduce increased attenuation if it becomes saturated with moisture. This effect increases with higher frequencies since the portion of current that will flow in the damp insulating medium becomes greater because of skin effect which increases with frequency. This undesirable effect is minimized in new types of insulated wire, specifically designed for carrier applications, which employ modern insulating materials.

There is a considerable variance in attenuation among different kinds of cable. The highest losses occur in paper insulated cable with small size conductors. In cable with 26-gauge conductors, the attenuation at 360 kc is 26 db per mile compared to 12 db per mile for paper-insulated cable with 19-gauge conductors. Polyethylene-insulated cable is somewhat more efficient at these frequencies; the attenuation in cable with 19-gauge conductors being 11.8 db or 0.2 db better than paper-insulated cable.

Attenuation of the relatively new multi-pair plastic rural-distribution cable, under dry weather conditions, is very close to that of paper-insulated DNB exchange-area cable with 19-gauge conductors. Rural-distribution cable is currently used primarily for

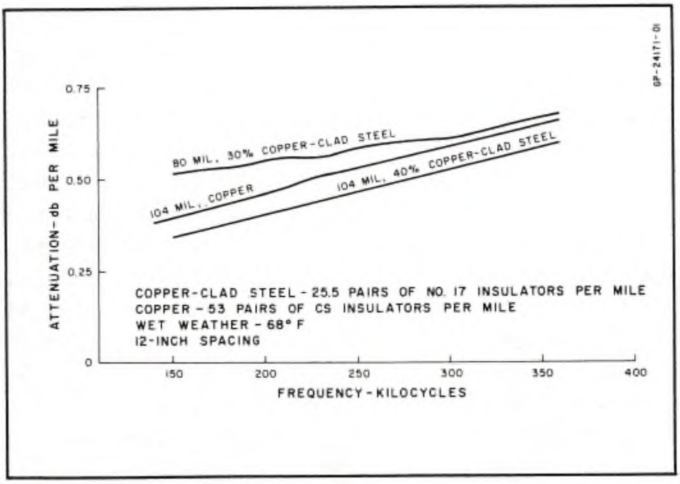

Fig. 2. Frequency-Attenuation Characteristics of copper-clad steel and hard-drawn copper open-wire pairs spaced 12 inches apart.

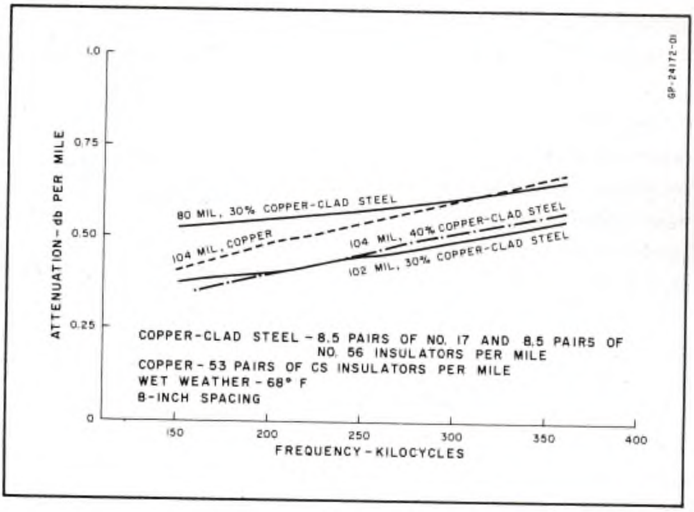

Fig. 3. Frequency-Attenuation Characteristics of copper-clad steel and hard-drawn copper open-wire pairs spaced 8 inches apart.

voice frequency distribution, although it has also been used for subscriber-carrier applications. In a 6-pair rural-distribution cable the attenuation when wet is 16.6 db per mile at 320 kc, and 10.2 db per mile at 180 kc. When dry, the attenuation is about one-half as great. The wet weather conductance (leakage) of this cable is about ten times as great as when dry.

Rural-distribution cable has much to offer in the way of convenience in installation and its life is estimated at about 15 years. However, because of the relatively high attenuation at high carrier frequencies, the distances over which it can be effectively used is limited.

Effect of Wire Spacing

Whether the conductors are spaced 8 inches or 12 inches apart has little effect on the frequency-attenuation characteristics of an open-wire pair. At 180 kc the attenuation per mile is 0.43 db for 12-inch spacing and 0.45 db for 8-inch spacing. When the wires are spaced 12 inches, the attenuation at 360 kc is 0.65 db per mile compared to 0.67 db per mile for 8-inch spacing.

However, where high carrier frequencies are used, it becomes increasingly difficult as the frequency increases to adequately reduce the crosstalk coupling effects between paralleling pairs. To overcome this difficulty, it is necessary, in addition to employing suitable transposition patterns, to employ wire spacings that will materially reduce the coupling coefficients between the various wires on the line. This has quite generally led to the use of 8-inch, and to some extent 6-inch, spacing of wire pairs, and a corresponding increase in the spacing between pairs.

In addition to reducing the crosstalk coupling, closer-spaced wires are also effective in limiting the noise due to induction, static, long-wave radio or other external sources of interference.

Line Transpositions

Absorption effects, caused by induction into surrounding circuits and producing drastic attenuation at certain frequencies, can be eliminated by using an appropriate transposition plan. Crosstalk and the pickup of radio and other interference can also be reduced by proper transposition of open-wire pairs, particularly where more than one carrier system is to be applied to the same open-wire lead.

Absorption effects, which cause transmission distortion, can be eliminated automatically by transposing lines to avoid crosstalk between like carrier systems. This may not be true, however, when all of the pairs on a line are not correctly transposed. A continuous succession of identical transposition sections will increase the likelihood and prevalence of absorption peaks while on the other hand a random succession of transposition sections of different lengths will reduce absorption effects.

Different transpositions are required at frequencies above 150 kc than for lower frequencies. For example, a pair transposed for a carrier system operating at up to 140 kc might have severe absorption peaks at frequencies above 200 kc.

Measurement of Line Attenuation

Transmission measurements may be made by applying a signal at one end of the line through a suitable matching transformer and measuring the signal level at the other end of the line with a frequency-selective voltmeter, suitably terminated and also connected through a matching transformer.

The signal source may be an oscillator with an output of at least +20 dbm and tunable over a frequency range of 5 to 350 kc. The frequency-selective voltmeter should be capable of measuring levels down to about −70 or −80 dbm over the same frequency range. The matching transformers must be capable of passing the frequencies involved.

Laterals, drops and spur lines should be disconnected from the main pair or treated with appropriate way-station filters when making initial transmission tests.

Crosstalk

When several carrier channels are applied to an open-wire lead crosstalk

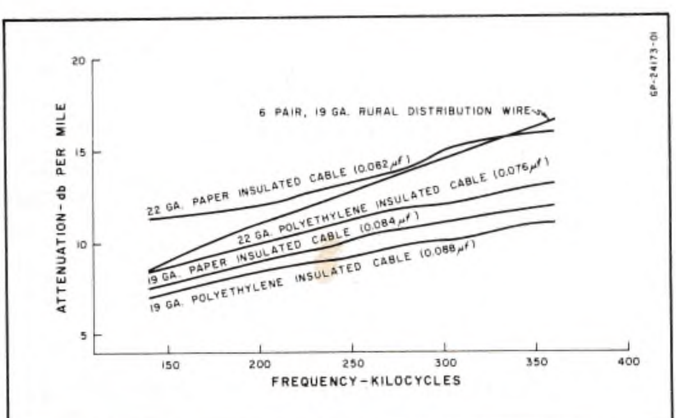

Fig. 4. Frequency-Attenuation Characteristics of multipair cable and rural distribution wire.

may occur. Crosstalk can be reduced by avoiding duplication of the same carrier frequencies on the same lead (different pairs), and by staggering the frequencies of the various channels.

Construction irregularities, such as difference in the sag of the various wires in each span, particularly between the two wires of each pair, will cause crosstalk. Variation in spacings of the wires may also contribute to crosstalk.

While like carrier systems can be used on the same pole line, when pairs are properly transposed, the use of two carrier channels, operating on the same frequency, should be avoided.

When several carrier channels are applied to various pairs on a lead, proper transposition is normally required. In some instances, it may not be possible to make use of all available channels due to excessive crosstalk interference from radio stations, or absorption at certain frequencies.

Measuring Crosstalk

Crosstalk can be measured using the same instruments as were used for measuring attenuation. To measure "far-end" crosstalk from line A to line B, as shown in Figure 5 for example, the signal generator is connected through a suitable matching transformer to one end of line A, the other end of line A is terminated. The frequency-selective voltmeter is connected to the far end of line B, suitably terminated through a matching transformer, while the near end of line B is terminated, usually through a matching transformer. If the attenuation characteristics of line A are identical to line B, the far-end crosstalk coupling in db is the difference between the levels of the received signals at the far end of A and B.

"Near-end" crosstalk may be measured by connecting the frequency-selective voltmeter to the near end of line B, while continuing to apply a signal at the near end of line A. The far end of each line is terminated.

Noise

Noise is caused by static, dust storms, radio storms, power-line carrier systems, electrical-power transmission lines and electrical equipment which may be operating near telephone lines and drops. In some areas, power-line carrier systems employing both AM and FM subcarriers, may be operating near telephone lines and may introduce noise into the carrier channels. Some of these power-line carrier systems employ transmitters of considerable power and, when not in good order, may radiate spurious signals of the same frequency as some subscriber carrier channels.

Noise can sometimes be alleviated by transposition of lines and otherwise eliminating line unbalance. In some cases it may be necessary to avoid the use of certain carrier channels on a specific line, if the trouble cannot be corrected by improving the line or stopping the cause of the noise at its source.

Effects of Splices

Improper splices can cause problems, including the introduction of noise. A bad splice may act as a rectifier or detector, demodulating two or more radio signals picked up by the line and interjecting the sums, differences and other combinations of these signals into the line as noise. Splices can cause vastly

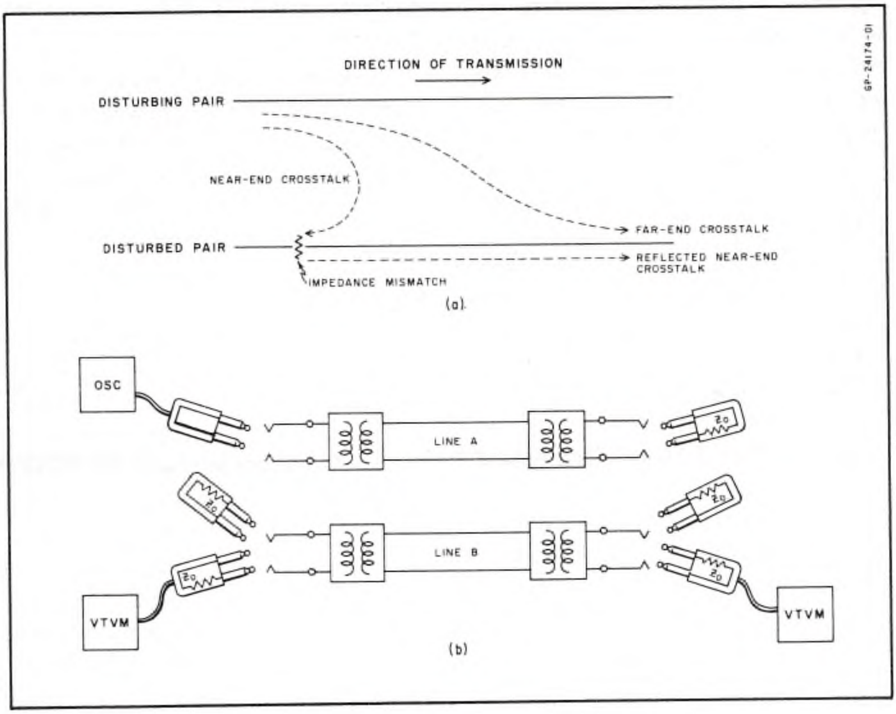

Fig. 5. Crosstalk—(a) An illustration of a way in which near-end and far-end crosstalk may occur. (b) A test set up for measuring crosstalk coupling losses.

different effects at the higher carrier frequencies than at voice frequencies.

Twisted splices, if used, should be well soldered. Splices of copper-clad steel or copper wire to steel should be made with special splicing sleeves designed for this specific purpose. When splicing copper to copper or steel to steel, standard compression sleeves may be satisfactory.

Effects of Weathering

Weathering of lines also causes adverse effects. The attenuation of a steel wire from which the zinc coating is partially or fully eroded is considerably greater than in new galvanized wire. Pitting, rusting and corrosion also increase attenuation and cause line unbalance. Dirty and broken insulators may cause excessive leakage. In the case of insulated wire, weathered insulation may permit the accumulation of moisture along the surface of the conductor, introducing attenuation which increases sharply with frequency.

Conclusion

Although a number of factors must be considered before high-frequency carrier is used to extend subscriber loops, the improvement of service and the ease with which additional subscribers may be added make the use of subscriber carrier attractive for many rural applications.

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