JUNE, 1967
VOL. 16, NO. 6

The Lenkurt DEMODULATOR

Coaxial Cable Communications

LENKURT ELECTRIC . *specialists in* VOICE, VIDEO & DATA *transmission*

Coaxial cable transmission systems have played an extremely important role in the phenomenal growth of the telephone industry in the U. S. and abroad. This article plots the history of the coaxial cable in communications, and describes some of the characteristics of the cable, the system, and its uses.

The heart of any communications system is the transmission medium over which the information signals pass. The makeup of the transmission medium places constraints on the design of the terminal communications equipment, such as multiplexing method, channel density and performance. These mediums include simple wire conductors, multipair cable, coaxial cable and microwave radio. Each medium has its own peculiar application advantages, and each plays an important role in our day-to-day communications.

The evolution of the coaxial cable in the 1920's—a significant structural innovation of a two-wire transmission line—has made possible the wideband, high-capacity communications of today.

Growth

In 1941, Bell System L1 coaxial cable routes were established between major metropolitan areas in the eastern United States. By 1948, a complete transcontinental coaxial cable facility was in operation. The L1 had a capacity of 600 message channels—an enormous amount compared to the few channels that could be transmitted over an open wire or multipair cable. Since microwave radio was not generally in use at that time, the coaxial cable medium was considered — and certainly was — the ultimate in multichannel communications.

As television became popular and network programming began to fill the airwaves, the coaxial cable seemed to be the ideal answer for conveying network broadcasts between stations. Although the L1 had only a 2.8-MHz bandwidth, performance was found entirely acceptable. The first TV application of the L1 was to transmit the Army-Navy game in 1945.

During the ensuing years the Bell System continued to develop multiplexing equipment and repeaters for more efficient use of the coaxial transmission line. In 1953, the L3 system went into service with an increased capacity of 1860 message channels, or 600 message channels and a 4.1-MHz TV signal on the same type of cable used for the L1.

More recently foreign systems have been developed with capacities up to 2700 message channels, and the Bell System L4 with 3600 channels is meeting the need for better utilization of existing and newly plowed-in cable routes in the U.S.

The coaxial cable has played an important part in long distance communications, accounting for about 25% of long distance services crisscrossing the country. Presently, about 13,000 miles of coaxial cable routes exist. An additional 10,000 miles is planned for the next five years.

The development of microwave in the late 1940's soon tended to stem expansion of coaxial cable systems. Microwave radio eliminated costly construction, right-of-way acquisition, maintenance, and other problems associated with establishing land lines. However, the relationship of microwave and coaxial cable proved to be valuable, mainly because the same basic multiplex equipment developed for coaxial cable could also be applied to the microwave baseband. Now, a second look is being given to coaxial cable in areas where allocations for microwave frequencies are not available.

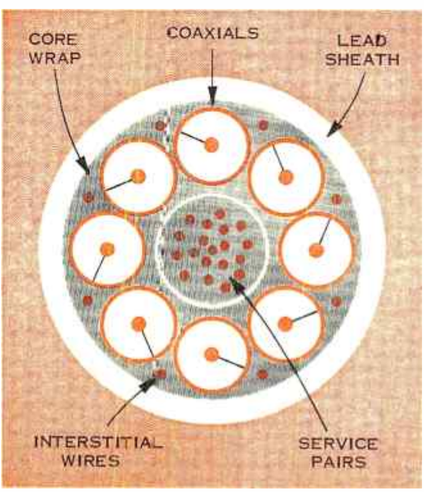

Figure 1. Typical communications coaxial cable consists of a number of "pipes" or "tubes" together with interstitial wires and service pairs inside a single sheath. Each pipe or tube provides one-way transmission for a large number of message channels or a TV signal.

Cable Construction

The communications coaxial cable consists basically of a single wire suspended in the center of a cylindrical conductor. The wire is held in the center of the tube by small disc-shaped dielectric or nonconducting insulators spaced closely together. Usually a number of these "pipes" or "tubes" (see Figure 1) are combined inside a single sheath.

Coaxial cable has a very low attenuation factor coupled with extremely good shielding from interference. In addition to its importance in the communications industry, other important uses of coaxial cable are associated with CATV and ETV, radar, navigation aids, aircraft, and test equipment.

Construction of the communications coaxial cable differs from the other types of cable which have the area between the inner and outer conductors separated by solid dielectric material. In addition, these types of cable normally have a braided copper outside conductor instead of the rigid copper tube, providing the needed flexibility for their particular use.

Disc insulated coaxial lines have much lower losses than the solid dielectric lines, but are more difficult to manufacture because of the mechanical problem of keeping the conductors concentric. The communications coaxial line with its spaced insulators approaches the ideal condition of having air as a dielectric, and is often referred to as air dielectric cable.

Included in the typical communications cable sheath with the coaxial tubes are interstitial wires and a cylindrical core containing service pairs. These added wires "round out" the cable. Around the cables is a layer of heavy insulation and a lead sheath. Interstitial wires may be used typically for v-f order wire between attended repeater stations, and for monitoring and control functions at unattended repeaters.

The service pairs, if provided, may be used as physical v-f circuits or with a cable multiplex facility.

Coaxial tube dimensions (see Figure 2) are usually described in terms of diameters of the inner and outer conductors. For example, when dimensions of 0.102/0.375 inches are given for a coaxial tube, this means that the outside diameter of the inner conductor is 0.102 inches, and the inside diameter of the outer conductor is 0.375 inches. More commonly, only the outer diameter is given; for example, 0.375 inches.

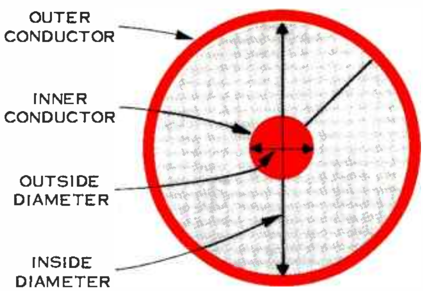

Figure 2. Coaxial tube dimensions are specified by the outside *diameter of the inner conductor, and the* inside *diameter of the outer conductor.*

Cable Sizes

The first cable installations in the U. S. were of coaxials having an outer diameter of 0.27 inches. Later installations were 0.375 inches, and this has become standard for long distance circuits. Other size cables in use include a 0.290 inch foam-filled dielectric cable used in Canada, and a "pencil gauge" cable of 0.174 inches.

The International Telegraph and Telephone Consultative Committee (CCITT) has established recommendations concerning the characteristics and performance of coaxial cable systems employing two standard size cables, the pencil gauge and 0.375 inch. According to their recommendations, the pencil gauge systems have a maximum bandwidth of about 6 MHz or 1260 voice-frequency channels, while the 0.375 inch systems have a capacity of 12 MHz or 2700 voice-frequency channels. Bell System technology has effectively exceeded this limit with the 3600 channels on 0.375 inch cable provided by the L4.

Characteristics

Electrically, what makes a coaxial cable attractive for communications is that it provides more conducting surface area than a two-wire transmission line and therefore suffers less resistance losses at higher frequencies. In addition, the electromagnetic energy propagation in a coaxial line is confined within the tube and isolated from outside interference or crosstalk because of its structure.

Generally, the effective bandwidth of a coaxial cable communications system is limited only by the required gain needed to maintain good signal quality. Spacing cable repeaters closer together makes it possible to increase the effective bandwidth by providing more amplification, and this approach has been used to increase the capacity of existing coaxial cable. However, economics and transmission reliability dictate certain limitations to such an approach.

Although a coaxial line will transmit signals down to zero frequency or dc, the lower practical frequency limit for communications is about 60 kHz. This is because the coaxial line does not provide good shielding at low frequency and because of equalization frequency limits.

The upper frequency limit for transmission in a given system is determined by cable dimensions, cable construction, and permissible attenuation. All three characteristics interact in such a manner that a compromise is usually made by giving appropriate attention to such factors as acceptable noise, repeater spacing, and amplification limits. The attenuation of a coaxial cable is given by the formula:

$$A = 40.1 \times 10^{-6} \frac{\sqrt{f}\left(\frac{1}{a} + \frac{1}{b}\right)}{\log \frac{b}{a}}$$

where:

A = attenuation in dB/1000 ft.

a = radius of inner conductor in centimeters

b = inner radius of outer conductor in centimeters

f = frequency in hertz

It can be seen from the equation that the attenuation of the cable varies directly with the square root of frequency and inversely with the size of the cable. Mathematically it has been proven that the minimum attenuation per unit length is accomplished with a ratio between the diameters of the inner and outer conductors of 3.6. With this particular ratio the impedance of a coaxial line, ignoring the losses of the dielectric, is obtained from the formula:

$$Z_o = 138 \log \frac{b}{a} \text{ ohms}$$

Using $b/a = 3.6$, Z_o is 77 ohms.

The insulating discs that support the center conductor of a coaxial cable represent shunt capacitive loading for the cable, and, therefore, lower the characteristic impedance and the velocity of propagation.

A coaxial cable having dimensions of 0.102 inches for the diameter of the inside conductor and 0.375 inches for the outside conductor has an attenuation of about 5.8 dB/mile at 2.5 MHz and a characteristic impedance of 75 ohms. A coaxial cable with dimensions of 0.047 inches and 0.174 inches has an attenuation of about 12.8 dB/mile at 2.5 MHz, and also a characteristic impedance of 75 ohms. See Figure 3 for a comparison of the attenuation versus frequency of the common types of communications coaxial cable.

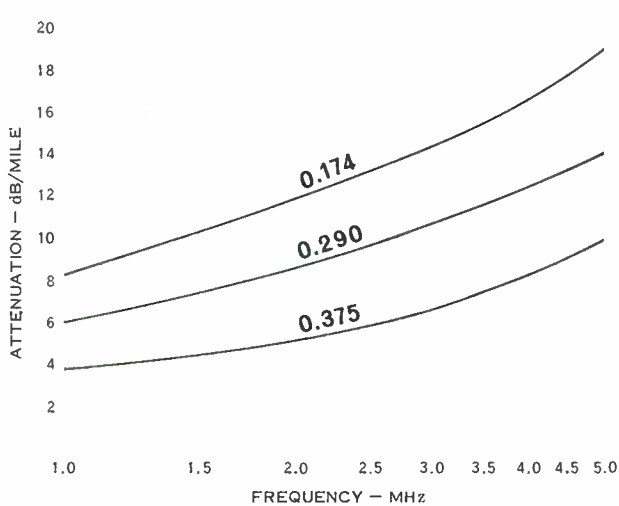

Figure 3. Response curves compare the attenuation versus frequency characteristics of the common types of communications coaxial cable.

The System

A communications coaxial cable system consists of a logical arrangement of repeater stations along the cable route. The basic requirement is that the cable network have uniform characteristic impedance, low losses and reflections, and proper protection from electric fields and disturbances such as lightning.

The original cable systems used vacuum tube repeaters. It was therefore mandatory that repeaters be spaced at wide intervals to increase reliability. With the invention of the transistor, more reliable repeaters were designed and power consumption was also substantially reduced. This made it possible to increase the number of repeaters and thereby increase the usable bandwidth of the coaxial cable.

A typical system usually contains widely spaced main repeater stations with several auxiliary stations situated between them. Customarily, the power feed for repeaters is through the center conductors of the coaxial pairs in a series loop from the main repeater stations. Hence, the maximum distance between main repeater stations is normally limited by the maximum voltage which can be efficiently applied to feed power from the main repeaters to the auxiliary repeaters. Intermediate repeater spacing depends on the loss of the cable and the problem of placing the repeater points at accessible locations.

Temperature variations are one of the most serious problems affecting the performance of a coaxial transmission system. Most of a coaxial system is buried underground, lessening the variations. Nevertheless, temperature-sensitive regulators must be employed to compensate for deviations in cable attenuation caused by temperature changes.

An example of a long-haul coaxial cable transmission system is the Bell System L4. This system employs three types of repeaters between main station repeaters: basic repeaters, regulating repeaters, and equalizing repeaters. Basic repeaters compensate for the normal loss of approximately 2 miles of cable. This repeater spacing is compared with 4 miles for the L3, and about 7.5 miles for the L1. Regulating repeaters spaced at up to 16-mile intervals provide additional compensation for changes in cable loss due to temperature variations. Equalizing repeaters at up to 54-mile intervals contain adjustable equalizers to compensate for random gain changes. These equalizers are remotely adjusted from the main station repeaters. Main station repeaters are spaced at up to 160-mile intervals. The main station repeaters contain all the functions of the other repeaters plus additional "mop-up" equalizers which compensate for un-

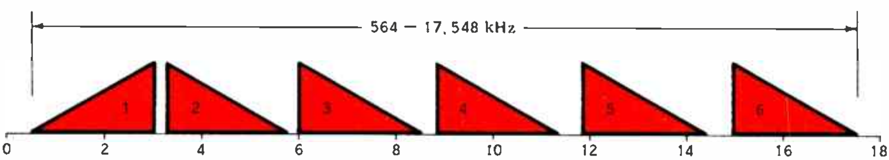

Figure 4. The modulation scheme used with the L4 combines six 600-channel mastergroups between 564 kHz and 17,548 kHz. Mastergroups 2 through 6 use the upper sideband while mastergroup 1 uses the lower sideband.

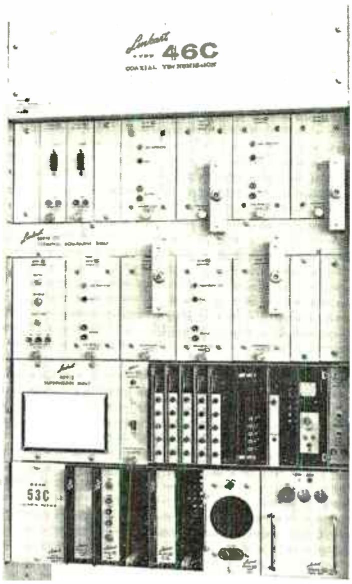

Figure 5. Up to 600 v-f channels may be processed by office arrangement of Lenkurt 46C Coaxial Transmission System shown above.

equal spacing of equalizing repeaters. These main station repeaters also supply direct current to the intermediate repeaters.

The multiplexing scheme for the L4 (Figure 4) is the combination of six 600-channel mastergroups with a frequency range of 564 kHz to 17,548 kHz. The mastergroups are separated by guard bands to permit dropping out any of the groups at a main station without demodulating the others.

Other Uses

The growth of the domestic telephone industry with each passing year decreases the number of frequency assignments available for microwave radio. For this reason increased emphasis is being given to the establishment of coaxial land lines as an alternative. Another use is in short haul cable extensions off backbone microwave radio routes. This particular application proves in some instances to be more economical than microwave.

For example, the Lenkurt 46C Coaxial Transmission System—which complements the Lenkurt 46A Radio Multiplex System — provides for as many as 600 voice channels for interconnection between microwave radio installations and coaxial cable plant. The system permits transmission on 0.174, 0.290, and 0.375 inch cables. Repeaters along the buried cable are in watertight cabinets installed in manholes.

While the system capability is 600 channels, it can be proved-in for lower capacity systems by spacing repeaters at greater distances. For example, a typical system with an initial need of 60 channels on 0.174 inch cable would require repeaters at about 10-mile intervals. Expansion to 300 channels can be achieved by inserting intermediate repeaters at 5-mile intervals. Repeater spacing for 600 channels is 2½ miles. Selected repeater sites may be equipped for dropping and adding channels according to local needs.

The future holds growing applications for coaxial cable. For example, a pulse code modulation (PCM) system now under development at Bell Laboratories will carry 3600 to 4000 channels over coaxial cable. The digital transmission system, designated T4, will operate at 281 megabits per second and will be employed on long-haul toll circuits. Its commercial use is expected by the early 1970's.

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