Coaxial Cable and Apparatus

By G. H. DUVALL and L. M. RACKSON

(Manuscript received December 10, 1968)

Impedance uniformity of the disk-insulated serrated-seam coaxial makes this Bell System standard a suitable transmission line for the L-4 system. As used in Coax 20, the nine in-service coaxial pairs and one reserve pair provide the capability of transmitting 32,400 simultaneous telephone conversations. To make the L-4 system a total communications network, support apparatus and enclosures which house and protect the electronic equipment from varied and rigorous environments were designed to complement the reliability and integrity of the Coax 20 cable.

I. INTRODUCTION

Greatly increasing requirements for long distance telephone circuits have made imperative the development of a new transmission system with greatly increased capacity. The transmission medium for the newly developed L-4 system consists of coaxial cable, manholes, repeater housings, and other required appurtenances. Critical to the system is the coaxial design. The uniformity of transmission characteristics over a very broad band of frequencies made the 0.375 inch disk-insulated serrated-seam coaxial the fundamental building block of the L-4 system.

The 0.375 inch coaxial cable shown in Fig. 1 has been standard in the Bell System for over 20 years; cables containing up to 12 coaxials were available until 1964. However, the increasing demand for telephone channels dictated the urgent development of Coax 20.

The transmission requirements established for the L-4 system necessitated placing repeater stations approximately every two miles along the cable route. At these locations, provisions must be made for the connection of electronic and associated support equipment to the cable.

Facilities at these locations include manholes, terminals, and sealed apparatus enclosures. The design and development of these facilities were directed at providing environmental, mechanical, and electrical protection for the electronic equipment at these sites. The natural hazards of total below-ground installations, that is, corrosion, water, humidity, induced earth currents, and lightning, require specific design treatment. In addition, hardening requirements to enhance the chances of system survival in case of nuclear attack, as well as the need for ready access to the electronic equipment for maintenance, represent additional criteria affecting design concepts. Reference 1 has a more complete description of system design parameters.

II. COAX 20, THE CABLE FOR L-4

2.1 *History of Serrated-Seam Coaxials*

Availability of the 0.375 inch disk-insulated serrated-seam coaxial shown in Fig. 1, was a major factor in the rapid development of a new system capable of transmitting over long distances a greater-than-ever cross section of simultaneous conversations. The coaxial has a 100-mil center conductor, air dielectric with polyethylene disk spacers, and a cylindrical outer conductor of 12-mil copper with interlocking serrated edges along a longitudinal butt seam. Two 6-mil steel tapes are helically applied over the copper to stabilize the structure and add electrical shielding.

The original version of (rubber) disk-insulated, serrated-seam coaxial has an electrical diameter (inside diameter of outer conductor) of 0.27 inch and saw its first commercial application in a 4-coaxial cable more than 25 years ago between Minneapolis, Minnesota, and Stevens Point, Wisconsin. As used with the L-1 carrier system, it provided a maximum capacity of 480 (later 600) two-way telephone conversations per pair of coaxials.

In 1946, a 0.375 inch coaxial, similar to the present design except for a 10-mil outer conductor, was installed in an 8-coaxial cable for an L-1 system between Dallas and Fort Worth, Texas. Its lower loss permitted an increase in distance between repeaters. This coaxial (with a 12-mil outer conductor) superseded the smaller design for future long distance installations.

A broadband L-3 commercial transmission system was introduced in 1953 on the improved coaxial, increasing the channel capacity per pair of coaxials to 1,860.[2, 3] Overall cable capacity was increased again in 1959 when the 12-coaxial cable design was developed and put into manufacture for the transcontinental L-3 transmission system between Maryland and California.

As exploratory development established the feasibility of the new L-4 transmission system, no significant problems appeared in trans-

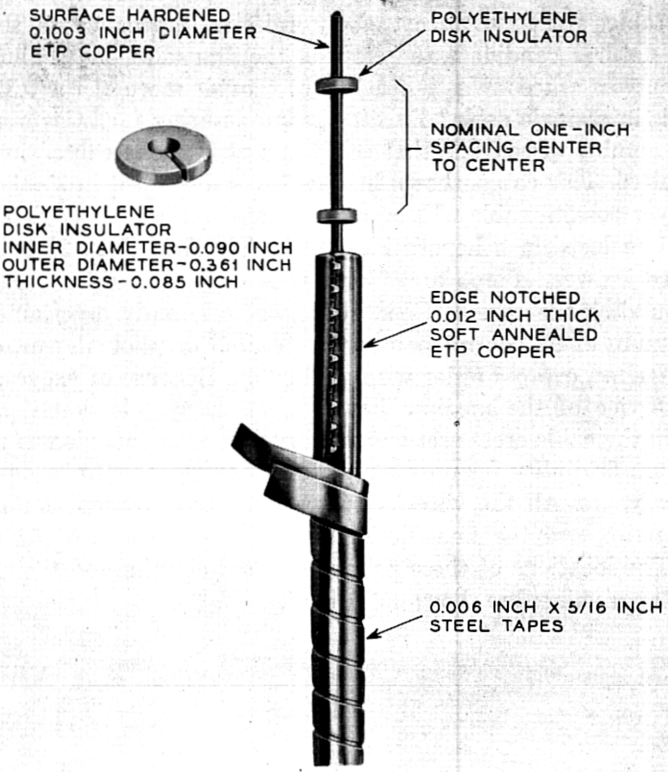

Fig. 1 — Air dielectric disk-insulated 0.375 inch serrated-seam coaxial.

mitting over the existing coaxial design. A field trial subsequently conducted in Ohio definitely established the feasibility of using the 0.375 inch coaxial for the new system.

2.2 *Development of Coax 20*

When forecasts of needed circuits indicated that the 9,300-channel cross section provided by the L-3 system on 12-coaxial cable was not adequate to keep pace with the anticipated demand for service, the American Telephone and Telegraph Company requested the urgent development of a larger facility. A facility was needed that could handle a growth of at least 2,500 voice channels per year.[4]

Over the years, the 0.375-inch coaxial had proved to be predictable, stable, and have an extremely uniform impedance; it therefore was a natural candidate to serve as the transmission medium. The question was asked: Was it feasible to provide more of the 0.375-inch coaxials in a single cable? Existing manufacturing facilities limited to 20 the number of coaxials that could be put into one cable, thus Coax 20 resulted. This cable, shown in Fig. 2 and described in Table I, is a two-layer coaxial cable with paper-insulated pairs and single conductors all enclosed in a Lepeth PJ sheath: The first Coax 20 cable was installed between Plano and Norway, Illinois, in 1964.

In building the core of Coax 20, it was originally determined that a minimum of 32 control pairs were needed for pilot alarms, outside plant alarms, express order wire, and so on. Because of expected long term service of the medium however, as many additional pairs as space in the cable cross section would permit were included to provide maximum flexibility for possible transmission systems to be developed in later years. All the wire circuits are 19 gauge except for four 16 gauge pairs, and the final design of the core consists of 52 control pairs. The locations of these paper-insulated circuits and their 1 kHz capacitance values are shown in Table I.

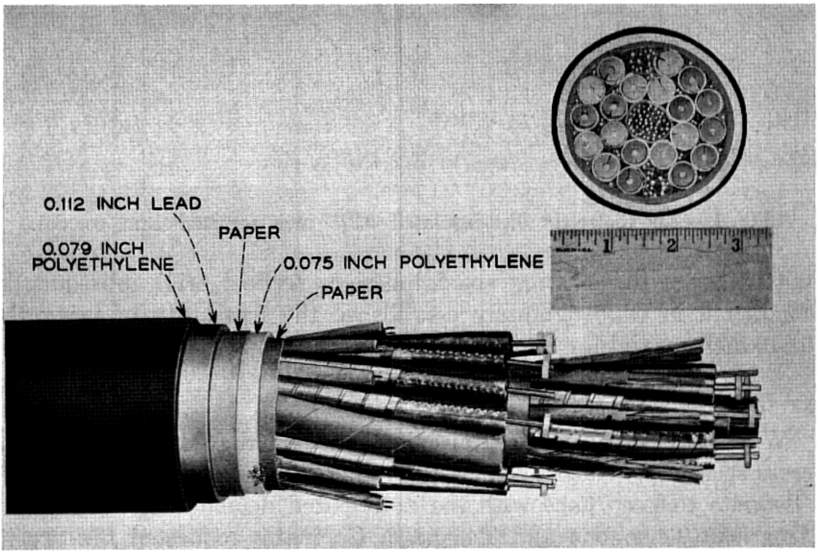

Fig. 2 — Coax 20: twenty 0.375 inch coaxials, forty-three pairs 19 gauge, four pairs 16 gauge, ten conductors 19 gauge, Lepeth PJ sheath.

TABLE I — DESCRIPTION OF COAX 20

Location	No.	Description
Center core	25	19 gauge pairs, 0.068 μF/mile
Inner coaxial layer	8 8	0.375 inch coaxials 19 gauge interstice pairs, 0.078 μF/mile
Outer coaxial layer	12 2 10	0.375 inch coaxials units each (2 16 gauge pairs, 0.064 μF/mile) (5 19 gauge pairs, 0.065 μF/mile) 19 gauge interstice conductors,* 0.089 μF/mile
Total	20 52	coaxials paired service circuits

* Capacitance to ground.

2.3 *Sheath*

Coax 20 is normally provided with a Lepeth PJ sheath which consists of an extruded polyethylene jacket over the core, a paper heat barrier, a lead sheath, a flooding of asphalt, and finally a black outer polyethylene jacket (Fig. 2). The reliability of this enclosure has been demonstrated by several years service of thousands of miles of coaxial cable. The lead provides the hermetic seal vital to maintaining the dryness of the core. The inner polyethylene layer provides high voltage protection between core and sheath. The outer polyethylene jacket provides protection against electrolytic corrosion of the lead. Layers of wire armor or gopher protection are added to the sheath when the cable is to be installed in areas where such added protection is needed.

2.4 *Manufacture*

The disk-insulated coaxial is made in a single operation on an automatic forming machine.[5] Immediately after forming, each coaxial is tested for corona and high voltage dielectric strength. A pulse echo test then measures the coaxial impedance uniformity and terminal impedance. The average of the terminal impedances for each coaxial is the basis for assigning the position of that coaxial in the final cable. The lowest impedance coaxial is assigned position 1, and so on. This scheme allows flexibility in the procedure of placing the cable and minimizes the mismatch that might occur as the cables are field spliced.

Stranding of coaxials into Coax 20 core takes place in two stages. The inner layer of eight coaxials is stranded over the core of 19 gauge pairs from eight positions of a two-bay, twelve-position floating carriage strander. Interstice wires and pairs (see Fig. 2) are stranded from fixed carriages attached to the back of one of the strander bays. After testing for impedance uniformity and high voltage requirements, the outer coaxials and associated paper-insulated circuits are stranded into position in a second operation. Because of differences in core diameter, the inner and outer coaxials are stranded using 20 and 36 inch lay lengths, respectively. This results in a helix or stranding take-up of 1.5 percent for all coaxials in the cable and provides for equal physical length of coaxials in both layers.

Each of the strander carriage positions is capable of holding sufficient coaxial to manufacture two lengths of Coax 20, each 1,750 feet long. The carriages are geared to impart a 37° backtwist to the coaxials as they are stranded into core. In effect, the steel tapes are tightened; this secures the longitudinal serrated seam, adds some rigidity to the structure, and provides a more uniform transmission line. After stranding, each core is tested for high voltage characteristics and impedance uniformity; then it is vacuum dried, sheathed, and retested. The finished cable is about 3 inches in diameter and can be shipped in maximum lengths of 1,750 feet. The average length has been 1,400 feet. When fully loaded, the shipping reels weigh about 8.5 tons each.

2.5 *Cable Characteristics*

2.5.1 *Attenuation*

The physical dimensions of the coaxial components shown in Fig. 1 and the parameters listed in Table II were used for computing the coaxial's attenuation at 55°F. This attenuation α was divided by the square root of the frequency, f, to permit a greatly expanded scale; the result is plotted in Fig. 3. The figure includes for comparison the attenuation-frequency characteristics measured on a one-half mile length of Coax 20 installed at the Chester, New Jersey, Bell Telephone Laboratories and corrected for stranding take-up.

2.5.2 *Impedance Uniformity-Echoes*

Echoes are divided into two catagories: internal and junction. Internal echoes are related to impedance discontinuities within a coaxial; junction echoes are related to the terminal impedance differences of coaxials joined in a field splice. The discontinuity associated with the splice components is discussed in Section 3.2.

Table II — Parameters for the 0.375-inch Coaxial

Parameter	Specification	
Surface hardened inner conductor	Diameter	0.1003 inch
	Conductivity*	100%
Polyethylene disks	Thickness	0.085 inch
	Spacing	1.00 inch
Annealed outer conductor	Thickness	0.012 inch
	Inside Diameter	0.369 inch
	Conductivity*	100.5%
Effective dielectric constant		1.098

* International annealed copper standard.

A measure of the worst internal echo in each coaxial is made at the factory using a 250 nanosecond raised-cosine pulse which contains a frequency spectrum to about 4 MHz. The averge of these data for 2,000 miles of coaxial cable was found to be 65.5 dB with a worst echo of 52 dB. A plot of these echoes expressed in dB is almost normally distributed as shown in Fig. 4.

The factory allocation of coaxials by impedance level minimizes the effects of impedance mismatch when coaxials in adjacent cables are field spliced. Factory-measured terminal impedance data was studied for 7,020 junctions, approximately the number needed for 2,000 miles of coaxial line; the calculated echoes resulting from mismatch were:

Condition	Echo	Number
Average	65.2 dB	—
Below	50 dB	25
Worst	48 dB	2

At 20 MHz, the junction echo resulting from the mismatch of coaxial

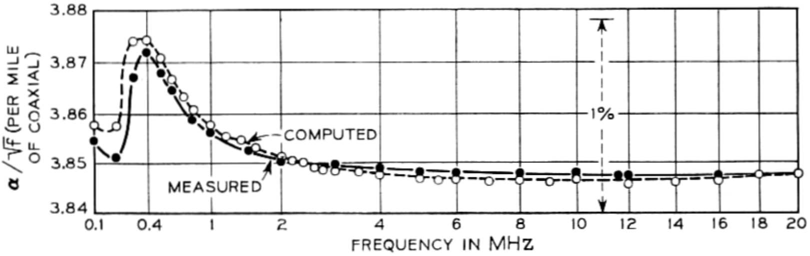

Fig. 3 — Attenuation divided by the square root of the frequency (per mile of coaxial). Derived from measurements on the installed Coax 20 at Chester, New Jersey (55°F).

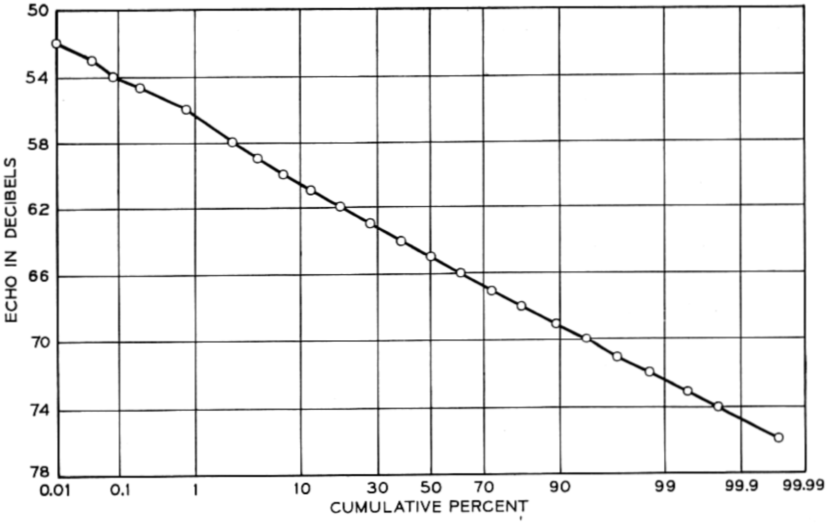

Fig. 4 — Distribution of the worst internal echo (out) for 7,520 readings. (Average = 65.62 dB; $\sigma = 3.48$)

impedance and splice components resolves to about 47 dB for the worst condition. When the impedances of the adjoining coaxials match, a junction echo of 65 dB caused by the splice is expected.

2.5.3 *Crosstalk*

The far end output-to-output crosstalk of adjacent coaxials in Coax 20 is plotted in Fig. 5. The plot shows the factory measured data of the inner and outer layer coaxials in 2,070 feet of cable (on its reel) and field data taken between repeater points (2 mile spacing) on normally installed Coax 20. Although it is difficult to assign causes for the difference in level, splicing and unit relaxation after installation are suspect. Additional comparative data taken at the Chester, New Jersey, and Baltimore, Maryland, Bell Laboratories also are shown.

2.5.4 *Structural Return Loss*

Shortly after Coax 20 went into commercial production, periodic deformation was observed in the outer coaxial layer. The deformation resulted from the cable pressing against guides in the factory process. Each coaxial presented itself briefly to the guide surface every 36 inches by virtue of its helix or stranding lay length. These irregularities escaped detection by the 250 nanosecond raised-cosine test but their presence was readily detected when a "structural return loss" test was instituted. For this test, the frequency of the input signal to the cable is swept from 8 to 220 MHz and the reflections are monitored. This test is extremely sensitive to periodic irregularities because the vector sum of reflections from regularly spaced deformations add inphase at the frequency for which the spacing is a half wavelength. At this frequency, not only is return loss maximum, but also a peak in the attenuation characteristic will occur.

The following expression can be used to predict at which frequency a structural return loss spike will appear for a given spacing of periodic deformation (conversely, the spacing can be determined if the frequency is known):

$$f = \frac{V}{2(\epsilon)^{\frac{1}{2}}S} W(1 - TU),$$

where V = velocity of light in air (feet/second),
ϵ = relative dielectric constant,
$W \approx \left\{1 - \frac{\text{internal inductance}}{2\ (\text{space inductance})}\right\}$,
f = frequency in MHz,
S = spacing between irregularities (feet),
TU = stranding take-up (1.5 per cent in Coax 20).

For Coax 20 a spike will occur around 156 MHz which is the half wavelength frequency for the 36 inch stranding lay of the outer coaxial layer. As improved testing techniques become available, the structural return loss test frequency is being expanded to detect the impedance irregularities associated with the inner layer coaxial lay length. For this lay, a spike can be observed at about 285 MHz. Although these frequencies are well above the L-4 band, the coaxial structure irregularities are being corrected so that Coax 20 may be suitable for future analog as well as high-speed digital transmission systems.

III. INSTALLATION

3.1 *Placing*

Protection of the medium against some of the effects of a nuclear blast is provided by a "hardened" installation. Basically this requires a subterranean system with shield and shock resistant features built into the support apparatus and housings. Coax 20 is usually buried

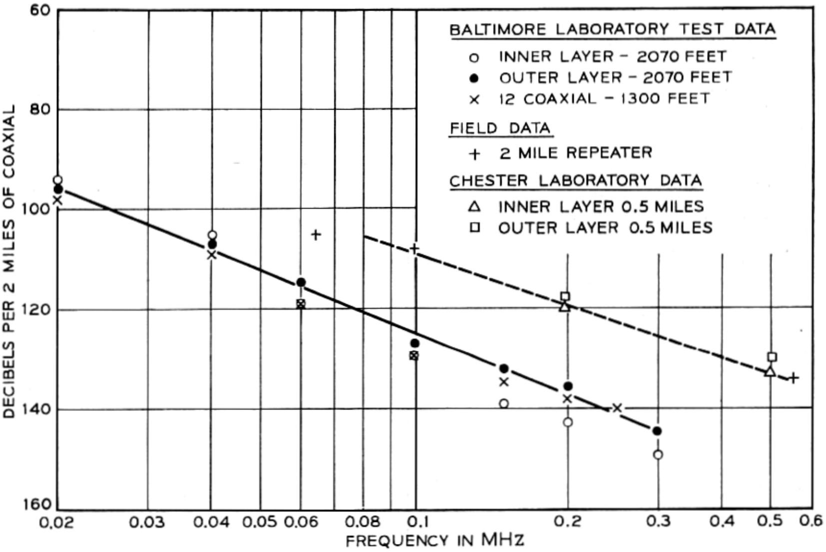

Fig. 5 — Far end crosstalk of adjacent coaxials for Coax 20.

a minimum of four feet in a trench along routes which avoid populated or strategic areas. Shield wires placed in the cable trench supplement the lead sheath conductivity. The trench digging, cable laying, and simultaneous backfilling and positioning 6 AWG copper shield wires about two feet above the cable are shown in Figs. 6, 7, and 8. Compared with coaxial cables installed by earlier methods, which did not specify shield wires or minimum four-foot depth, limited information indicates that the failure rate per route-mile for hardened cables may have been reduced by a factor of three.

3.2 *Field Splicing*

Figure 9 shows a typical field splice of a single coaxial and associated parts. The center conductors of adjacent coaxials are crimped into the S-100 sleeve; the outer conductor and steel tapes are compressed between the steel bushings and copper sleeves. Continuity is provided through the G-375 sleeve, which has its center section expanded to maintain, as closely as possible, a 75 ohm impedance through the whole splice. Based on measured components of the resistance and reactance in a splice, the total calculated return loss is 65 dB at 20 MHz. Return loss versus frequency is plotted in Fig. 10.

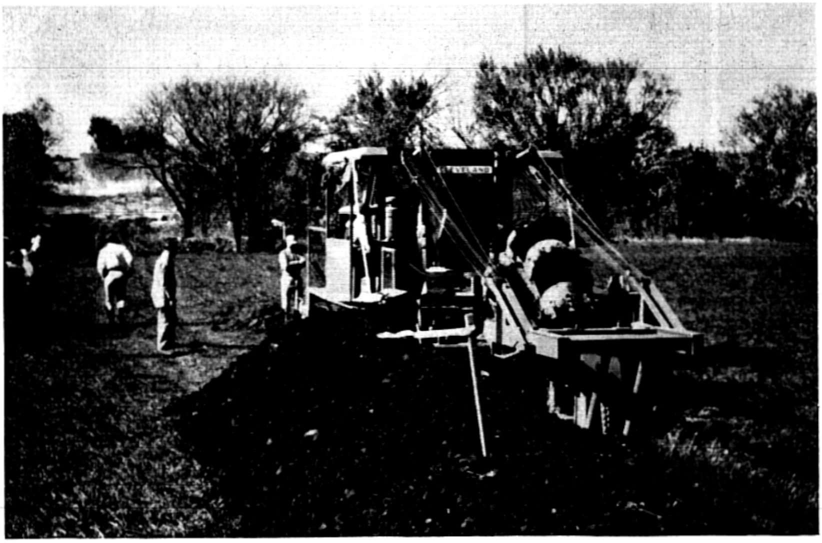

Fig. 6 — Trenching: four foot depth.

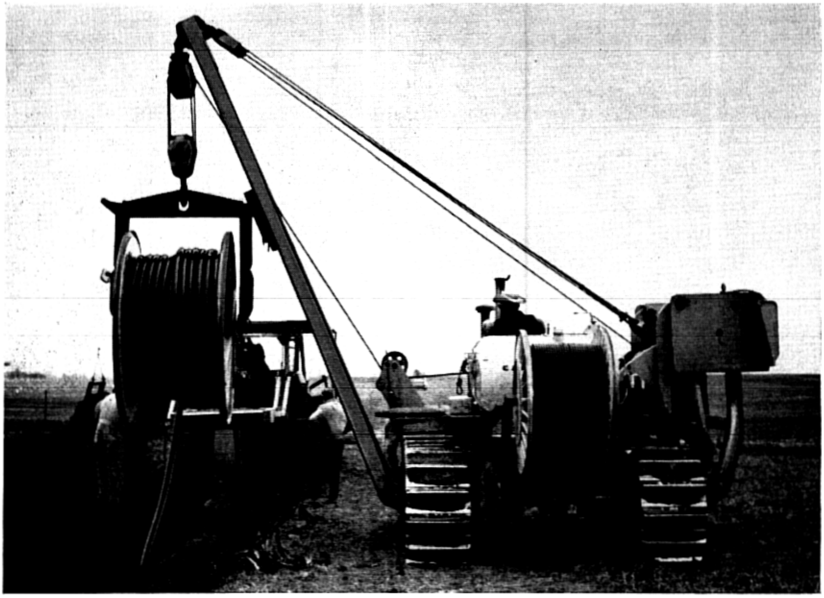

Fig. 7 — Laying Coax 20.

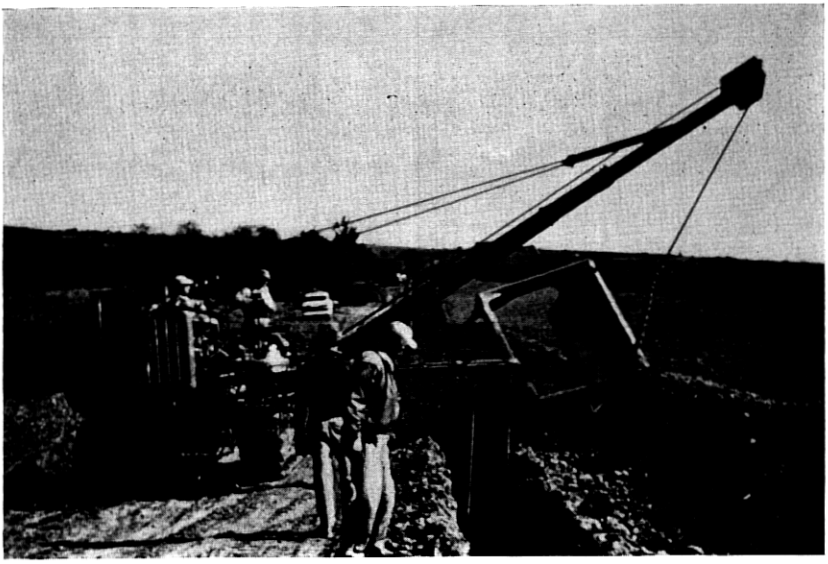

Fig. 8 — Backfilling and placing of shield wires.

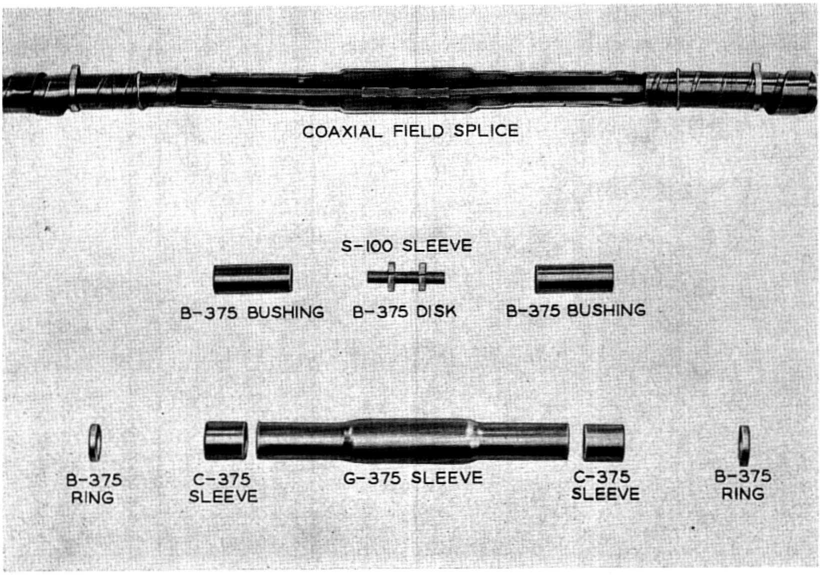

Fig. 9 — Coaxial field splice.

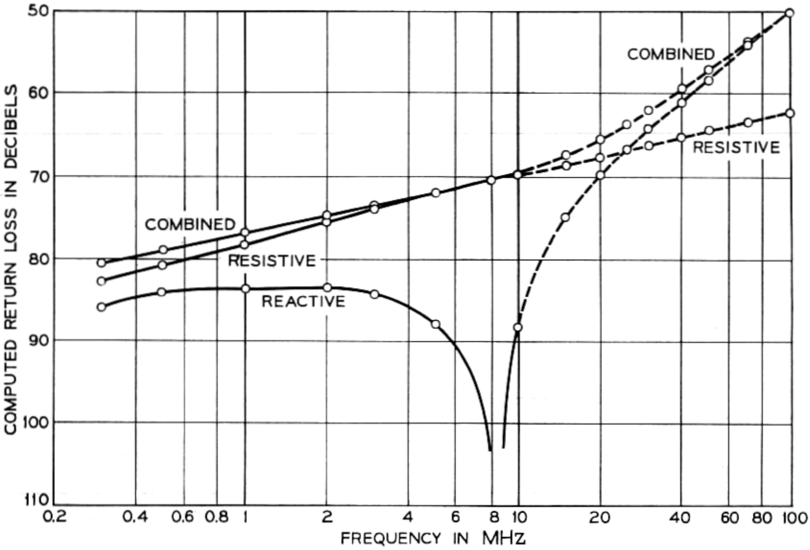

Fig. 10 — Return loss versus frequency for the G-375 coaxial field splice.

Normally, seven reels of cable are placed between adjacent repeater stations. The cables are spliced so that coaxials of similar impedance are joined together. The coaxial positions are identified by the color code of the paper-insulated interstice circuits. Figure 11 shows a typical "basket" formed by the spliced coaxials.

IV. APPARATUS FACILITIES

A typical equalizing cable section, shown schematically in Fig. 12, comprises one equalizing repeater station, three regulating repeater stations, and twenty basic repeater stations in which a multitude of additional support apparatus is required for the repeater to function properly.

The signal through the main coaxial cable is transmitted to the electronic equipment in the 471A1 apparatus case by the 66A1-4 cable terminal. As can be seen in the basic station schematic, Fig. 13, ten of these four unit coaxial terminals are connected to the ports of five apparatus cases, each capable of housing four basic repeaters and the monitoring oscillator. Coaxial patch cords carry the signal from the faceplate of the cable terminal to the repeaters.

The two 52-pair stub cables in the 472A1 apparatus case, which

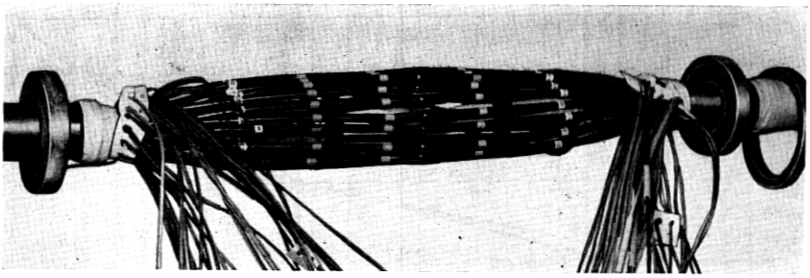

Fig. 11 — Basket formed of spliced coaxials. A steel sleeve is placed over the splice and solder wiped to lead sheath through lead disks and rings.

serves as a cross-connect facility, are spliced to the copper pairs in the main cable. The 26-pair stub cable feeds through the auxiliary splice to the 100A1-4 cable terminals attached to the 471A1 apparatus case to provide power for the monitoring oscillator and to the 100B1-4 cable terminals located in the collar of the manhole to provide voice facilities for the craftsman.

The schematic diagrams for the regulating and equalizing stations are shown in Figs. 14 and 15, respectively. The physical connections and function of the apparatus in these manholes are similar to the basic station, except for the amount of component apparatus required.

The following discussion illustrates the design philosophy behind some of the more complex items.

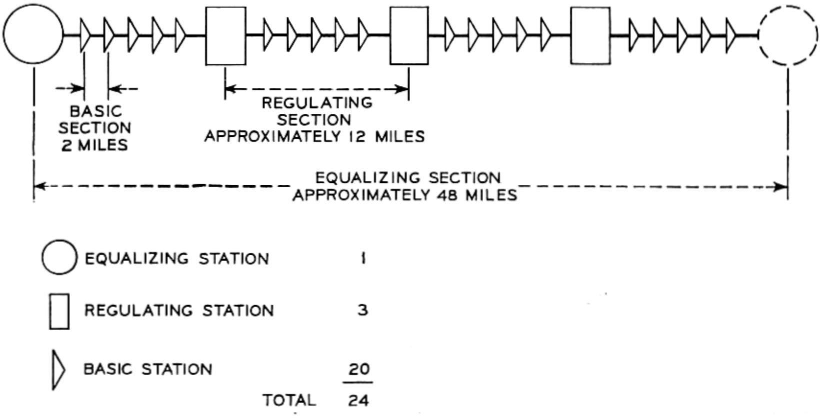

Fig. 12 — Equalizing section schematic.

4.1 *Manholes*

L-4 system requirements for a hardened installation together with limitations on space and economic considerations, dictated the design of special precast, segmented reinforced concrete manholes for the basic and regulating stations. The size required to accommodate all of the components associated with the equalizing station ruled out a precast design; therefore, a cast-in-place manhole was used.

The basic manhole, composed of three interlocking sections plus a collar, measures 10 feet long by 6 feet wide by 6 feet 6 inches high inside, and weighs 42,600 pounds. The regulating type, illustrated in Fig. 16, has four interlocking sections plus a collar, measures 12 feet long by 6 feet wide by 8 feet high inside, and weighs 58,400 pounds. Both manholes can withstand an overpressure of 100 pounds per square inch. Unistrut inserts are cast into the interior wall sections to support cable and equipment; inserts to facilitate handling and lifting are provided on the outer surfaces. The precast structures can be installed around an existing buried cable, existing conduit encased cable, or can be used on new cable construction.

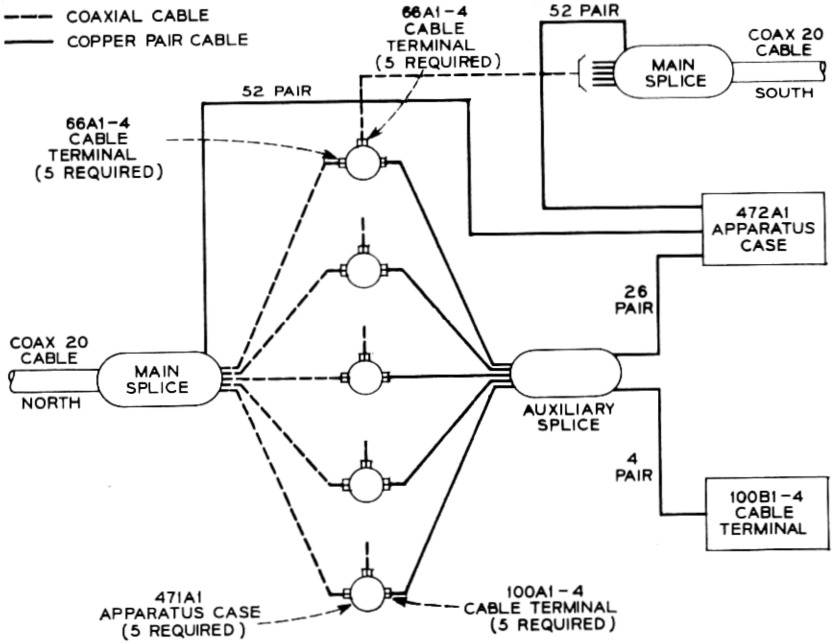

Fig. 13 — L-4 basic station schematic.

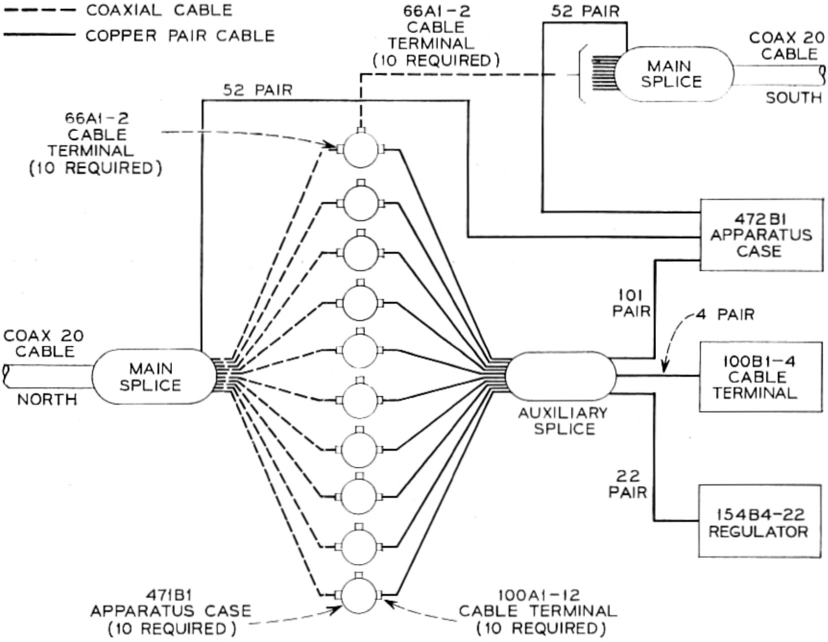

Fig. 14 — L-4 regulating station schematic.

The cast-in-place equalizing manhole is capable of withstanding a 50 pounds per square inch overpressure and measures 24 feet long by 12 feet wide by 8 feet high, inside. There is a unistrut framework down the center of the manhole for mounting auxiliary apparatus and cable.

4.2 *Apparatus Enclosures*

4.2.1 *Repeater Apparatus Case*

Environmental protection for the repeaters is provided by the sealed apparatus case shown in Fig. 17. These cases are available with internal chassis designs to accommodate one equalizing, or two regulating, or four basic repeaters. However, at equalizing points, each repeater and the associated control equipment requires two apparatus cases mechanically and electrically interconnected. The assembled units are about 16 inches in diameter, $22\frac{3}{4}$ inches high, and weigh 150 pounds.

Galvanic action between dissimilar metals, which is always present in below ground environments, demands the utmost care in choosing

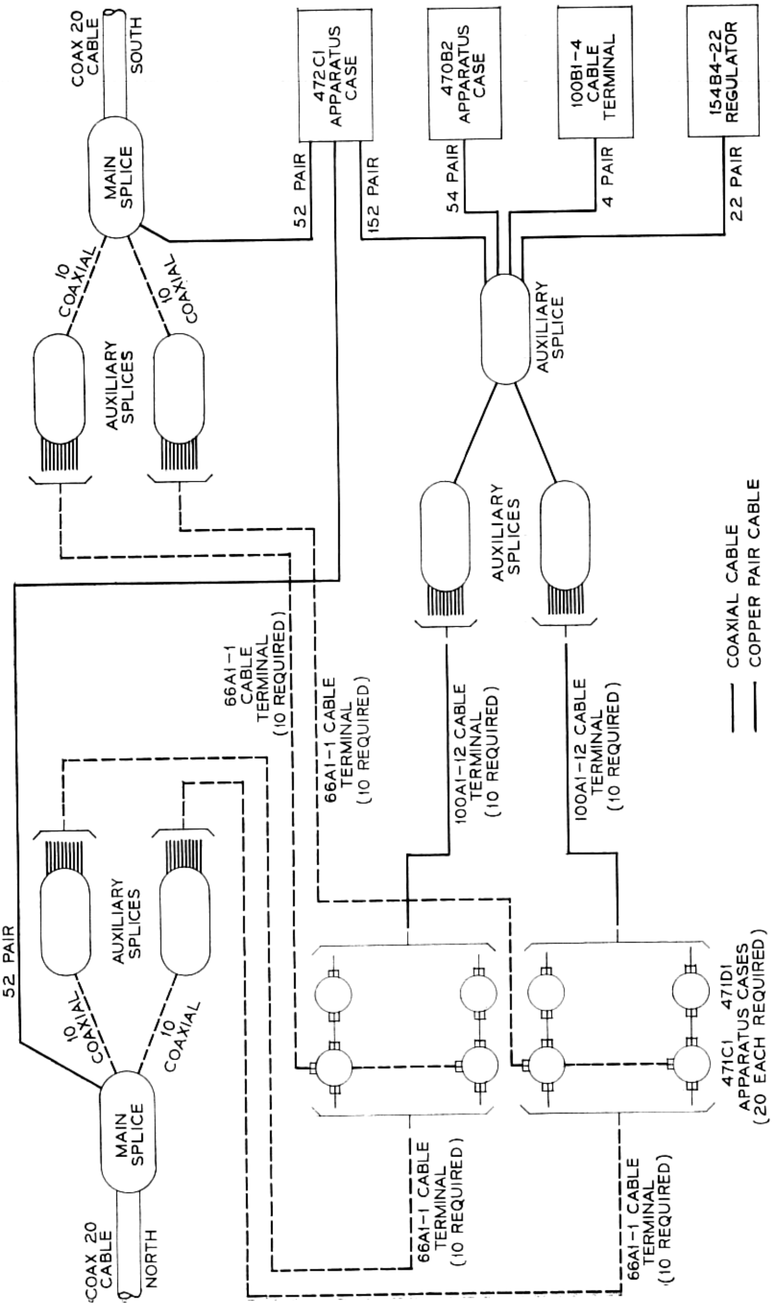

Fig. 15 — L-4 equalizing station schematic.

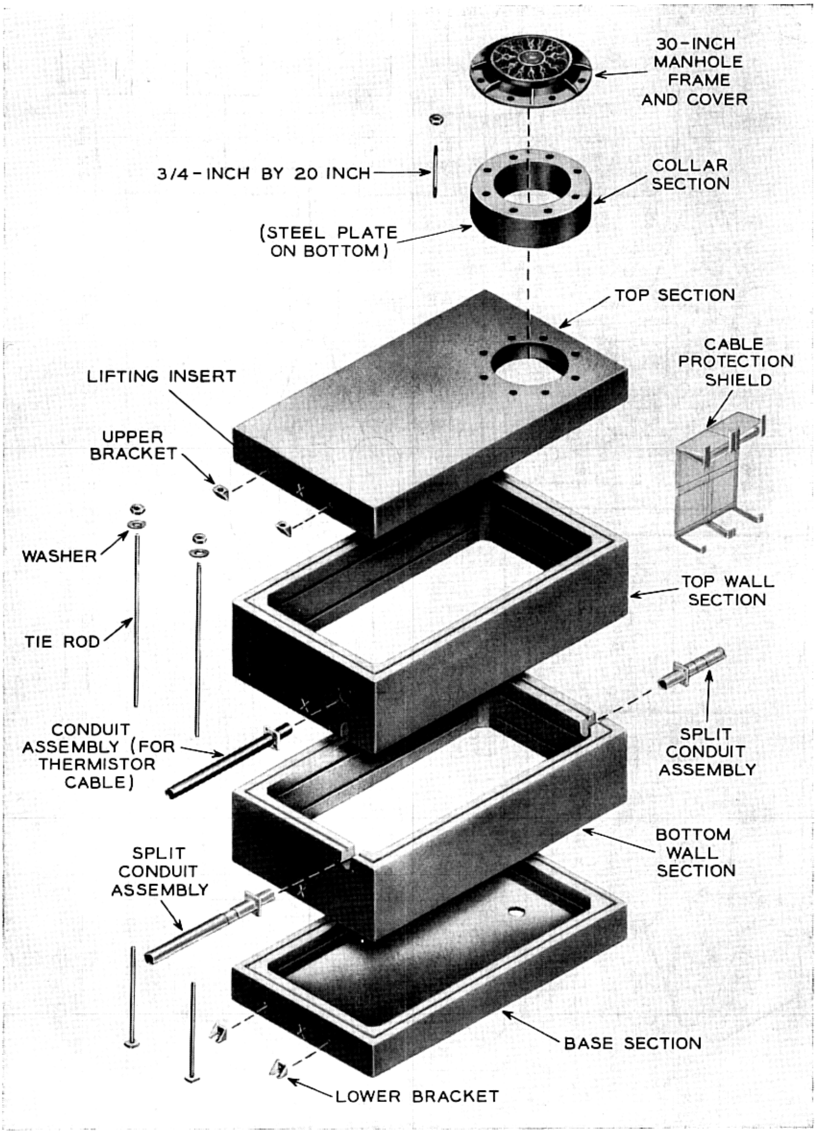

Fig. 16 — G manhole: exploded view.

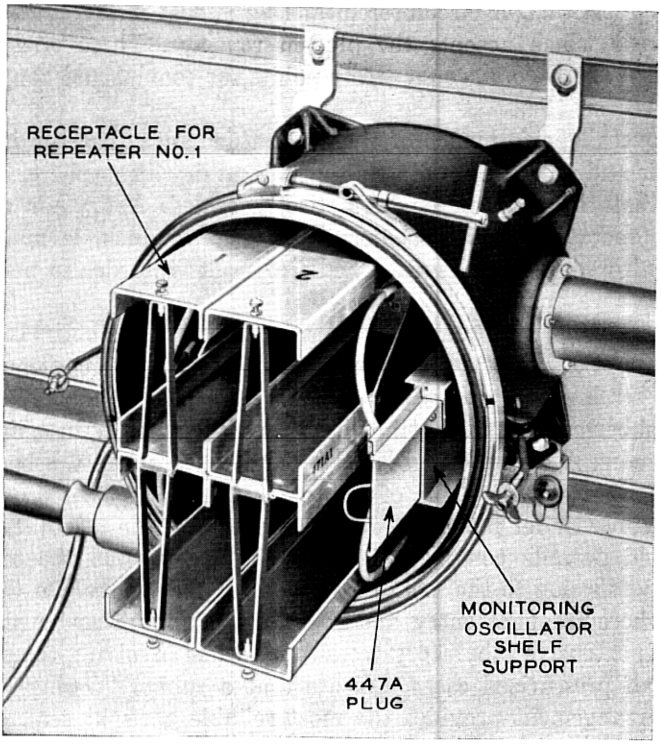

Fig. 17 — Basic repeater apparatus case with cover removed, mounted on the manhole wall.

the best available materials and coatings to provide long life for the apparatus housings. The choice of galvanized cast iron, where the casting process was most applicable, and fabricated galvanized steel is the result of many years of laboratory testing and evaluation to determine the best corrosion resistant material for underground use. Data on cast iron housings with a minimum wall thickness of 5/32 inch and a zinc coating of 2 ounces per square foot indicate a life expectancy of 20 years minimum in highly corrosive environments and more than 40 years in milder environments. These metals are also compatible with such other materials used in underground plant as the lead sheath on the cable and manhole racks.

The outer housing consists of a galvanized cast iron base with a 5/32 inch minimum wall thickness and a removable galvanized steel cover. Four reinforced pads are provided outside the base at the bottom, for mounting. A circumferential ring is cast inside as a seat for the chassis which accepts the plug-in repeater. Three openings on the side of the base serve as access points for coaxial and copper pair terminals.

The overall performance of the system demands that the inside of the cable and the repeaters be in a clean and dry atmosphere. This requires that the network be hermetically sealed. A dry air pressure system, operating at 6 to 9 pounds per square inch, is maintained and monitored to signal sheath and seal faults in order to permit repair before water enters.

The sealing technique involves two approaches, both based on experience. For apparatus where field assembly is a one-time operation, B sealing compound is used. This is a pliable, tacky, uncured butyl rubber compound that has been used successfully in splice cases for 15 years. A groove is provided around the ports in the base casting and on the face plate of the cable terminals to accept the B sealing cord. Under moderate clamping pressure, the pliability of the compound permits compact filling of the groove and the tackiness provides adhesion to the metallic surfaces of the groove. On the other hand, where frequent entry and resealing of apparatus housings are required, extensive laboratory testing programs involving temperature cycling of pressurized cases indicate that a rubber "O-ring-V-band" clamp arrangement provides the most reliable gastight seal.

An important feature of this type seal is that a load need be applied at only one point around the periphery to effect a seal. As tension is applied to the T-bolt, the V-band embraces the flanges of the cover and base for the full 360 degrees, thereby assuring equal distribution of pressure on the O-ring. The geometry of this assembly and the elastic energy stored in the V-band clamp provides the compliance needed to maintain positive pressure on the O-ring to assure its reliability. Figure 18 illustrates the V-band-O-ring principle.

Two slotted tabs are incorporated on the cover to accept an eyebolt and wing-nut arrangement and to provide a safety feature which prevents the cover from "blowing off" during disassembly in the event the pressure in the case has not been released.

Internally, the apparatus case has a removable fabricated aluminum chassis into which repeaters and associated control equipment are inserted. The receptacles are sized to provide a toleranced fit for the easy insertion of each type repeater. Although the outer wall of the receptacles "float" to aid initial engagement, a locking bar arrangement provided at the top prevents plug-in units from disengaging and re-

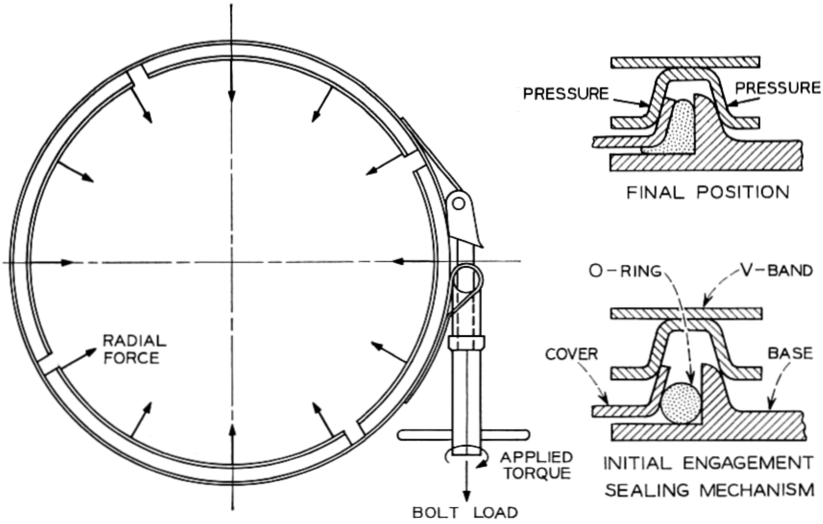

Fig. 18 — The O-ring-V-band sealing mechanism.

sults in a more positive and intimate contact between the surfaces of the repeater and the receptacle, enhancing heat dissipation. The eight slotted holes in the bottom plate serve a twofold purpose: they lock the chassis in the base and provide as much intimate contact between the base and the chassis as possible for maximum heat transfer.

Each chassis incorporates a network of coaxial cords and copper pairs terminated in connectors which provide an electrical link to supplementary apparatus. Short length coaxial patch cords are also provided to facilitate shorting the input side to the output side when required. The two chassis for the equalizing station are somewhat unusual in that additional connectors and two cords are required for some of the copper pairs in order to interconnect the two chassis electrically. To facilitate the mechanical interconnection between the two apparatus cases, a galvanized cast iron through pipe has been provided. The typical chassis for the basic apparatus case is shown in Fig. 19.

The temperature sensitive characteristics of the repeaters make it imperative to dissipate the heat generated by their operation. This required explicit design features in the apparatus cases to provide effective heat transfer paths. Power ratings for the basic, regulating, and equalizing repeaters were established as 13.8, 32.3, and 80.3 watts, respectively. However, the number of repeaters in the apparatus hous-

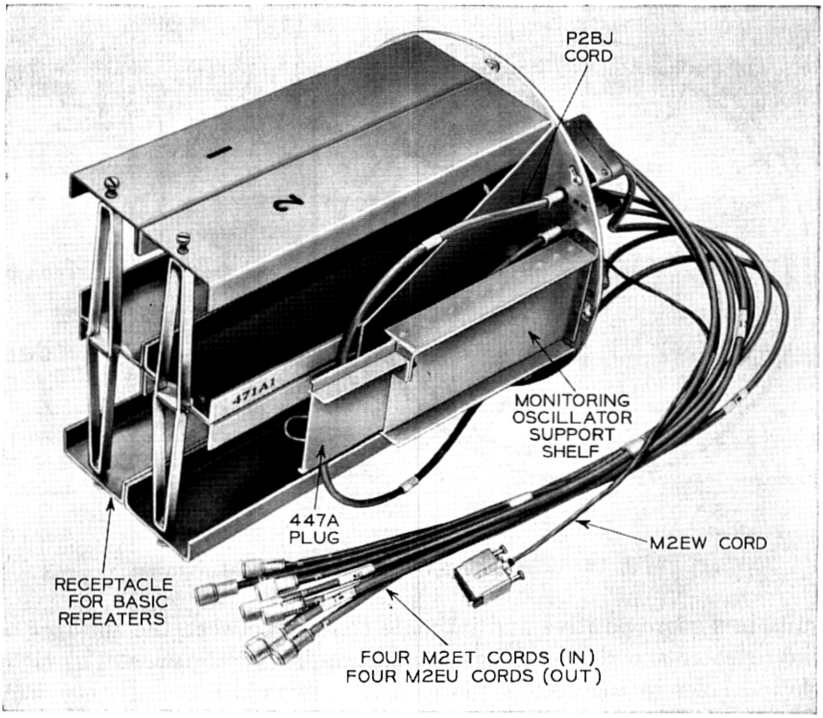

Fig. 19 — Chassis for basic repeaters.

ing varied according to type, that is, four repeaters in the basic housing and two repeaters in the regulating housing. This meant that the total power level was about 55 watts for the basic apparatus case and 65 watts for the regulating case. The equalizing repeater presented a somewhat different problem in that two apparatus cases were required to accommodate all of the plug-in equipment associated with the repeater. The power breakdown for the two cases was established as 60 watts for the transmitting case and 20 watts for the control case.

Initial heat tests utilized unpainted apparatus cases which had four internal lugs, on which the chassis seated, and four fastening screws. Likewise, the repeater units were unpainted. Additional tests indicated that an internal circumferential ring around the cast base, 8 fastening screws, and continuous welded joints between the upright structure and the mounting plate of the chassis improved the heat transfer mechanism. To further enhance this mechanism, an organic finish, black paint, was applied to the inner and outer walls of the apparatus case and cover and to the cover of the repeaters. A 23 percent improvement in the heat transfer path was realized as shown in Fig. 20.

Extensive laboratory shock tests were conducted at the Whippany, New Jersey, Bell Telephone Laboratories. A drop table simulated shock loads up to 250 g. The repeater apparatus case was tested in 3 planes and survived shock loads of over 200 g.

4.2.2 *Cross Connect Facility*

The 472 type apparatus case provides cross-connection and electrical protection features for the system and is similar to the repeater apparatus case in that an O-ring and V-band clamping arrangement is used to effect a gastight seal between a cylindrical cover and plate. The assembled case is approximately 11½ inches in diameter, 40½ inches long, and weighs approximately 125 pounds.

As shown in Fig. 21, a welded H-frame, which gives the desired strength and rigidity to meet the hardening requirements, is utilized to accommodate connecting blocks. Three 22 gauge PE-PVC (polyethylene-polyvinyl chloride) insulated Lepeth sheath stub cables are wired internally to the connecting blocks in each apparatus case. The

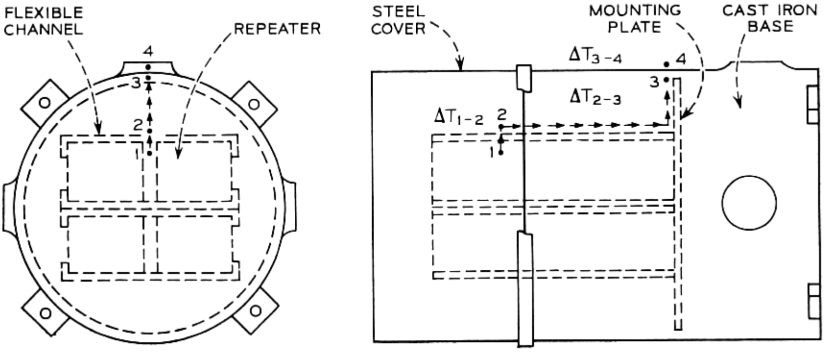

Fig. 20 — Temperature differentials in the L-4 basic repeater apparatus case. The length of the heat transfer path is 15 inches.

	ΔT — °F			
	ΔT_{1-2}	ΔT_{2-3}	ΔT_{3-4}	ΔT_{1-4}
Unpainted	17	17	6	40
Painted	13	15	3	31

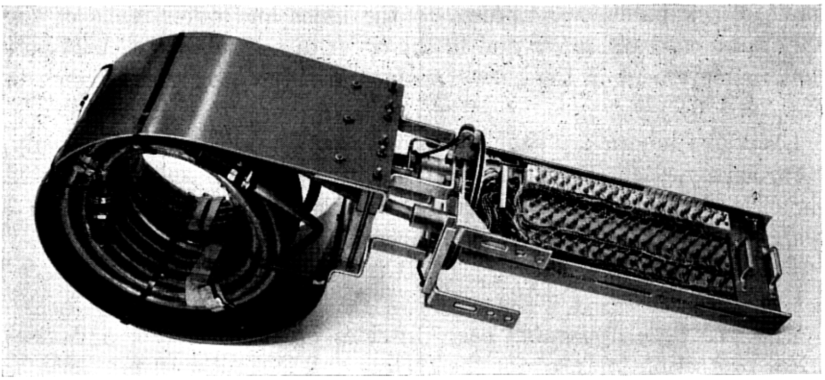

Fig. 21 — Cover plate and internal chassis for 472A1 apparatus case.

two 54-pair stubs in each case service the copper pairs in Coax 20. The size of the third stub varies depending on the cross-connect requirements peculiar to its station; these are 26 pairs for the basic, 101 pairs for the regulating, and 152 pairs for the equalizing repeaters.

Electro-magnetic protection has been provided with carbon block protectors on 50 pairs in the regulating case and all pairs in the equalizing case. In order to protect the critical circuits of the system for reliability, gas tube protectors have been provided on the ten pairs associated with the monitoring oscillator in all three apparatus cases.

In the shock testing program, the 472 type apparatus case survived shock loads of over 200 g.

4.3 *Cable Terminals*

4.3.1 *Coaxial Terminals*

The signal over the coaxials in the main cable is transmitted to the electronic equipment in the apparatus case by means of the 66-type cable terminals. Basically, these are gastight terminals using one, two, or four standard 0.375-inch disk-insulated air dielectric coaxials for use at the equalizing, regulating, and basic stations, respectively. The cable terminal for the basic stations is shown in Fig. 22.

The head of the terminal consists of a cylindrical tin-plated bronze housing with coaxial cable emanating from one end and a faceplate at the opposite end. A male screw connector is mounted on the faceplate for each coaxial. A circular trapezoidal groove for accommodating B sealing compound and four bolt holes in the faceplate

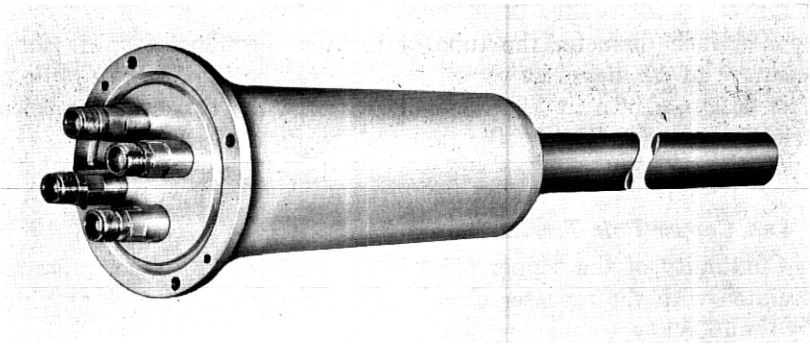

Fig. 22 — 66A1-4 cable terminal.

provide the means for attaching and sealing the cable terminal to repeater housings.

Internally, the inner conductor of the coaxial is spliced to an annealed copper wire which passes through the glass-bead seal located in the terminal head. The continuity of the outer conductor is maintained by means of a compensating sleeve which is crimped at the coaxial end and soldered to the male connector and the housing at the head end.

Electrical tests in the laboratory indicated that a 2 picofarad capacitive lump existed in the glass-bead area. The magnitude of the associated impedance discontinuity is shown in Fig. 23. A minor design change was subsequently made in the ⅝ inch splicing tube to

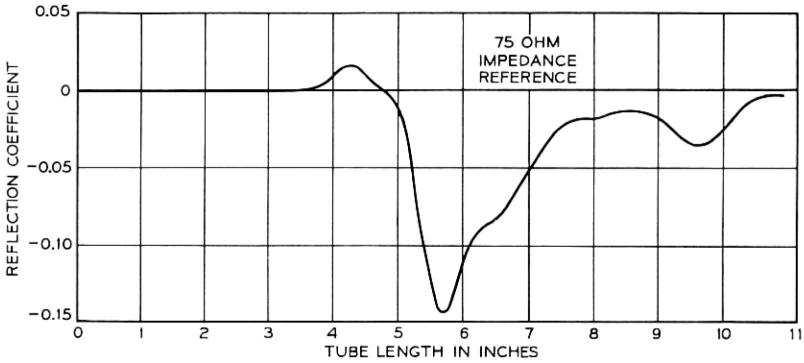

Fig. 23 — Impedance profile of the 66A1 type cable terminal with straight splicing sleeve.

improve its impedance uniformity. The modification was to expand to a $\frac{7}{8}$ inch diameter the tube at the inner conductor splice for a distance of $1\frac{1}{4}$ inches as shown in Fig. 24. The impedance profile of this design, shown in Fig. 25, indicates that the two areas are electrically compensating for the range of frequencies used in the L-type systems, thereby lowering the average impedance mismatch.

4.3.2 *Copper Pair Terminals*

Continuity of the copper pairs in Coax 20 to the copper pairs associated with the repeater chassis in the apparatus case, is provided by the 100A1 type cable terminals.

The 22 gauge PE-PVC insulated copper pairs in the cable are terminated on a female plug-in connector mounted on a tin-plated bronze faceplate. A gas dam is constructed in the Lepeth sheath cable stub to preclude the flow of air. The units attach to one of the ports in the base of the repeater case with four screws and sealed gastight at the interface with B sealing compound. A bypass valve facilitates control of gas pressure.

The 100B1-4 cable terminal, shown in Fig. 26, serves as the lineman's and cableman's order wire terminal and is mounted in the collar of the manhole for ready access from above ground. It is composed of a tin-plated bronze casting with a hinged cover and is sealed by means of an O-ring. A pressure plug is provided in the casting and the four 22 gauge PE-PVC insulated copper pairs in the Lepeth sheath cable stub terminate on two female plug-in connectors. Gas pressure is controlled by means of a bypass valve.

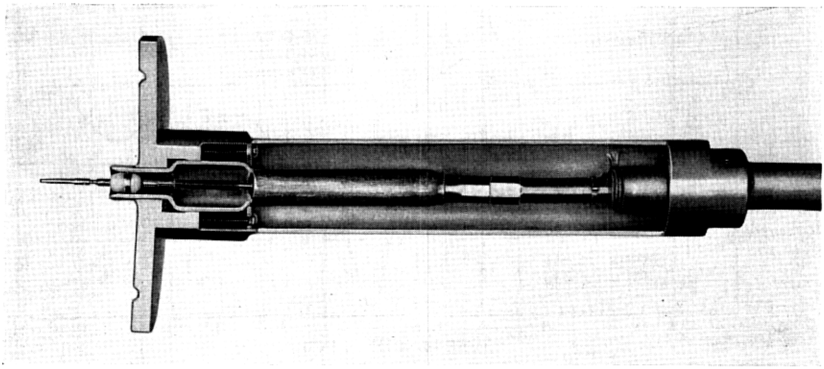

Fig. 24 — Cross section through head of 66A1-1 cable terminal with modified compensating sleeve.

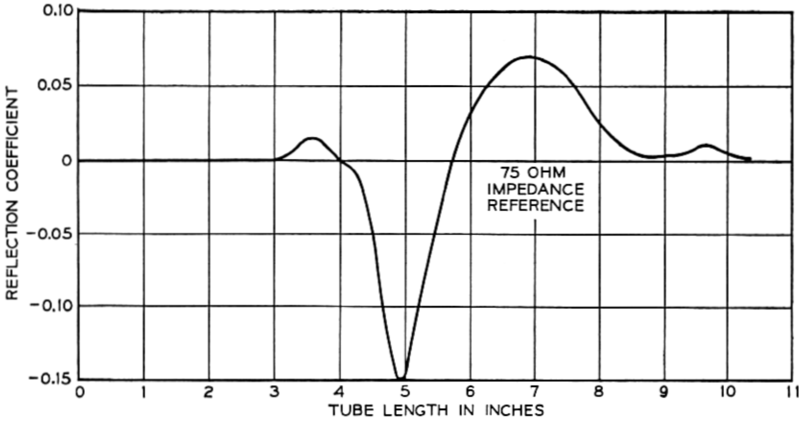

Fig. 25 — Impedance profile of 66A1 type cable terminal with modified compensating sleeve.

4.4 *Auxiliary Apparatus*

Although the main cable comprises 20 coaxials, economic considerations concerning initial plant investment required that apparatus be designed so that coaxials not initially in use could be equipped for service as warranted by system growth.

The repeater apparatus case, 471 type which represents a good size investment, has three ports for accepting coaxial and copper pair terminal facilities as discussed in Section 4.2.1.

To facilitate total racking of coaxial cables in the manholes and to provide a low cost item that could be substituted for the 471 type apparatus cases at repeater points, the 173A adapter, shown in Fig. 27 was made available. Basically, this is a galvanized cast iron "T" pipe having flanged openings that coincide dimensionally with the ports in the apparatus case. Continuity of the coaxial cable is maintained by patching through the adapter. When service is required, the terminating apparatus connections are broken, the adapter is removed, a 471 type apparatus case is installed on the bracket, and the connections remade.

V. RELIABILITY

Two fundamentally different approaches to achieving reliability are (*i*) to provide a very secure facility and (*ii*) to provide alternate standby facilities. Both approaches are being used. Economic considerations dictate that, since a full alternate facility would be prohibitively expensive, measures should always be taken to make the medium reliable. On the other hand, alternate standby facilities are provided at critical points along routes, such as river crossings. In the case of the L-4 system, reliability requirements have included hardening.

Many features are involved in hardening and, although hardening itself refers to the measures taken to increase chances of surviving a nuclear attack, most of the measures are effective in reducing the incidence of failures from ordinary causes. First, routes are chosen to circumvent major target areas and wires are placed above the cable in the trench to assist the sheath in carrying currents induced by an electromagnetic pulse as well as lightning. The cable is buried at greater depth than had generally been used in order to lessen shock and to reduce the hazards of accidental cable "dig-ups." And finally, there were requirements for ruggedness of components.

Also considered in designing for reliability were the slow wear out mechanisms of failure such as fatigue and corrosion. Although it is much too early to judge the effectiveness of design reliability, especially as regards wear out failures, early results indicate that the incidence of catastrophic failures, such as "dig-ups" by outside con-

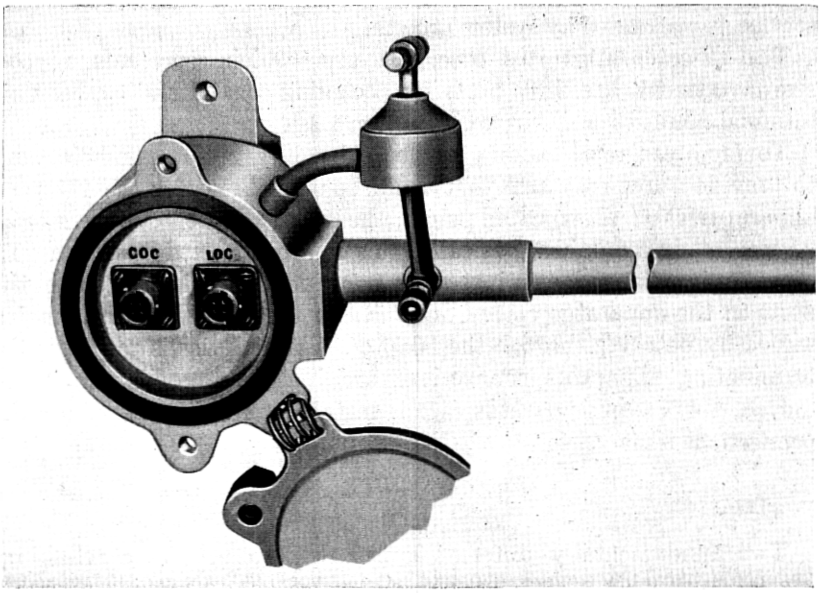

Fig. 26 — 100B1-4 cable terminal.

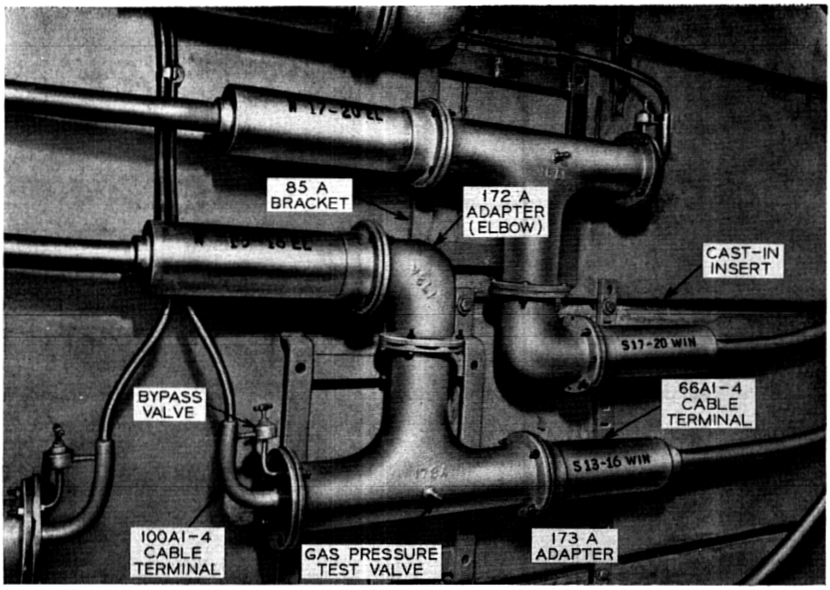

Fig. 27 — View of a typical manhole wall with dummy adapters.

tractors and lightning strokes, have been significantly reduced for the new hardened cable routes compared with similar but older facilities. At present, construction near roads and on farms appears to be the major cause of outages.

VI. SUMMARY

The overall success of the L-4 transmission system has stimulated much further work in the coaxial cable and apparatus design area. Needless to say, the features deemed responsible for the excellent performance of this system may be expected to be the basis for improved coaxial systems in the future.

REFERENCES

1. Blecher, F. H., Boyd, R. C., Hallenbeck, F. J., and Herr, F. J., "The L-4 Coaxial System," B.S.T.J., this issue, pp. 821–839.
2. Elmendorf, C. H., Ehrbar, R. D., Klie, R. H., and Grossman, A. J., "The L-3 Coaxial System—System Design," B.S.T.J., *32,* No. 4 (July 1953), pp. 781–832.
3. Klie, R. H., "The L-3 Coaxial Carrier System," Bell Laboratories Record, *32,* No. 1 (January 1954), pp. 1–4.
4. Klie R. H., and Mosher, R. E., "The L-4 Coaxial Cable System," Bell Laboratories Record, *45,* No. 7 (July-August 1967), pp. 210–217.
5. Kreutzberg J., and Kempf, R. A., "Cables for Educational TV Systems," Bell Laboratories Record, *42,* No. 6 (June 1964), pp. 200–204.