The Evolution of Inductive Loading for Bell System Telephone Facilities

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(Continued from April 1951 issue)

PART IV: CABLE LOADING COIL CASES

General

Up to this point this review of coil loading has been primarily in terms of transmission features of the loading systems and the coils, and development economics, and for this reason the references to potting developments have been brief, so as to minimize diversions from the main theme. A complete chronological review of all important aspects of the potting development work would require much more space than is available for this present article. On the other hand, because of the substantial importance of the potting developments in the economics of loading, more should be said than was included in the brief references in Parts II and III of the story.

This particular part of the review accordingly describes the more important high spots of the potting developments. It is limited to cable loading coil cases because of the early obsolescence of open-wire loading. The discussion is in terms of the changes from time to time in the various important design features, as indicated by the side headings and paragraph headings, and is thus a departure from the individual project-description procedure followed in other parts of the review.

At this point it should be emphasized that the work on the cases, which has been more nearly continuous than that on the coils, has kept pace in design ingenuity with the work on the coils, and has been very much more than the mere accommodation of the case designs to the changing sizes of the loading coils and of the loading complements.(t)

Casing Materials

Until the late 1920's, cast iron casings were used for housing the coils. The moisture-proof seal between the case top and the main casing was obtained by "tongue and gutter" details, supplemented by metal gaskets. For the first decade or so, short lengths of wrought iron pipe with "pipe

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(t) Additional information on potting developments is given in Bibliography items (6), (8), (26) and (30).

cap" ends were used in potting the smallest complements of coils. For all cases, lead-sheathed stub cables contained the coil terminal leads.

During the late 1920's, new case designs using thick, copper-bearing, steel plate ($\frac{3}{8}$ inch thick) with welded seams were introduced for reasons of economy and to simplify manufacture. Because of the very great current demand for loading, and the extensive use of the large-size loading coil cases required by the larger loading complements, the foundry problems had become very formidable; also, the production schedules had become somewhat irregular because of the great difficulties encountered in getting enough satisfactory castings of the largest sizes. The use of heavy machinery for shearing the steel plates and forming them to obtain cases of rectangular cross-section gave adequate dimensional design-flexibility. The welded steel designs, however, are not generally so satisfactory as the cast iron designs with respect to resistance to corrosion of accidentally exposed steel surfaces. Accordingly different types of protective coatings were provided for cases intended for underground cable and buried cable installations, and those intended for

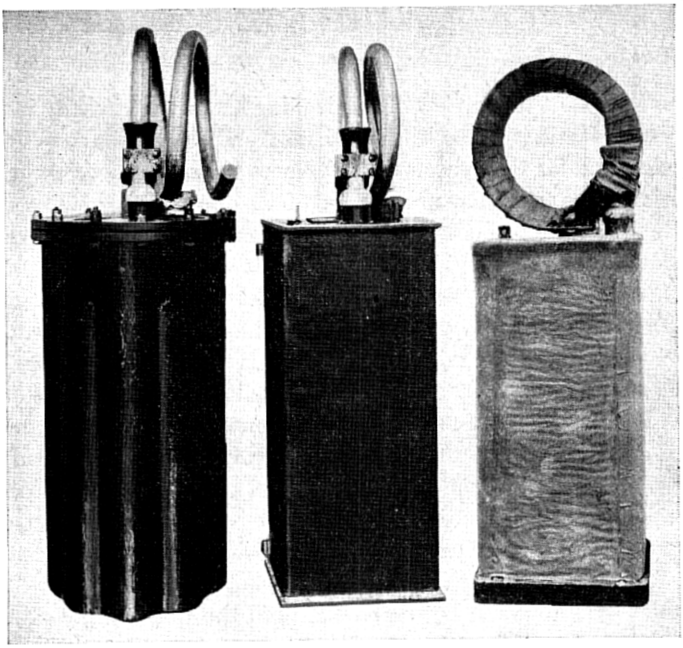

Fig. 19—Cast iron vs. welded steel loading coil cases. Complements of 84 P-type phantom loading units. At left: Cast iron case; In center: welded steel aerial case; At right: welded steel underground case.

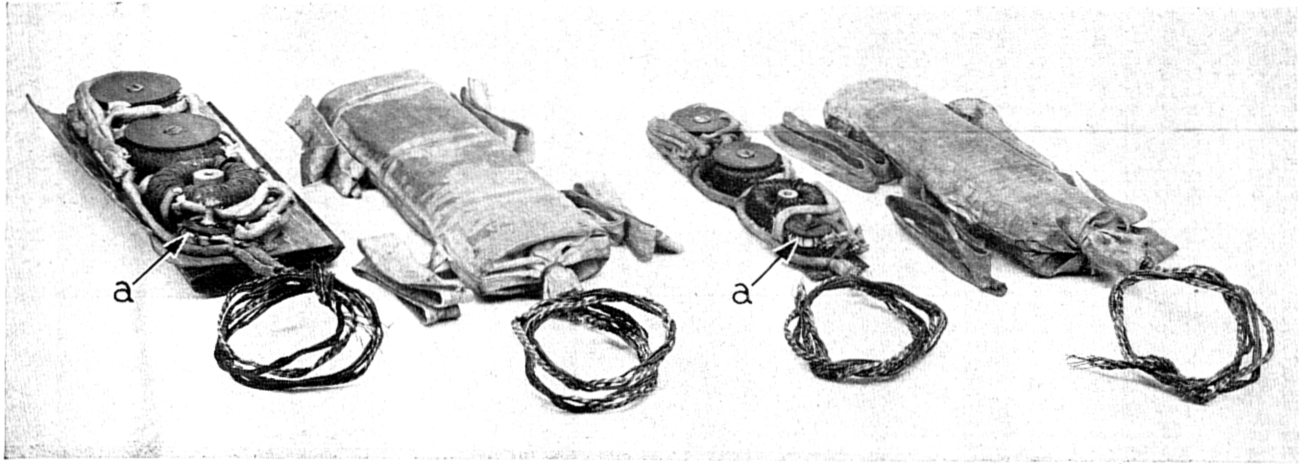

Fig. 20—Splice loading assemblies of individual phantom loading units. Assemblies before and after placement in canvas protective bags.
At left: M-type unit; At right: MF type loading unit.
"a" designates midget inductance coils used in crosstalk adjustments.

aerial cable jobs. Certain differences also were necessary in the mounting details. These various differences were recognized in the case code designations.

Beginning in the early 1930's, sections of lead sleeving with soldered lead (and later on, brass) tops and bottoms came into general use for small loading complements. To add mechanical support to the inherently weak, cylindrical lead sleeve, the larger-size lead cases were equipped with inner-lining steel tubes when used on cables maintained under gas pressure. The lead cases(u) are less expensive than rectangular-shaped welded-steel designs of equivalent potting capacity, and are suitable for use on underground and on aerial cables. On the lead cases used in buried cable projects, and on their stub cable sheaths, a special finish reinforced with armor provided protection against injury by rodents. Corresponding protection was also provided on the sheaths of stub cables of cast iron and welded steel cases intended for use on buried cables.

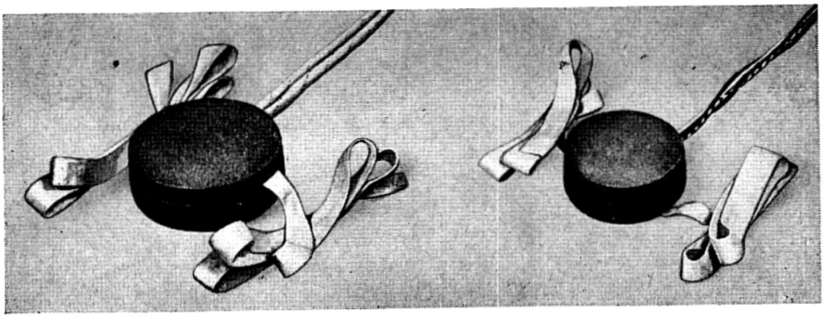

Fig. 21—Splice loading cases for exchange area loading. 88 mh coils potted in cardboard containers, and equipped with fabric tapes for fastening to cable core at splice. At left: 622 coil. At right: 632 coil.

Another general change in the design of loading coil cases started about 1940 with the introduction of cylindrical, $\frac{1}{8}$-inch steel-tubing in place of thick steel-plate rectangular designs.(v) While initially this was a steel conservation measure, it was found to be very advantageous with respect to manufacturing techniques and economy. This development will eventually reduce the use of the previously mentioned lead-sleeve designs.

The basic problem of securing the most economical designs for different potting complements and different installation conditions has included the provision of special case designs for placement in cable splices, which do not

(u) Some lead sleeve cases for exchange area loading are shown in Fig. 17 (page 467).

(v) Some of these cylindrical thin steel cases are shown in Fig. 18 (page 468) and in the installation photographs Figs 26, 27, 28A and 28B (pages 728, 729, 730 and 731, respectively).

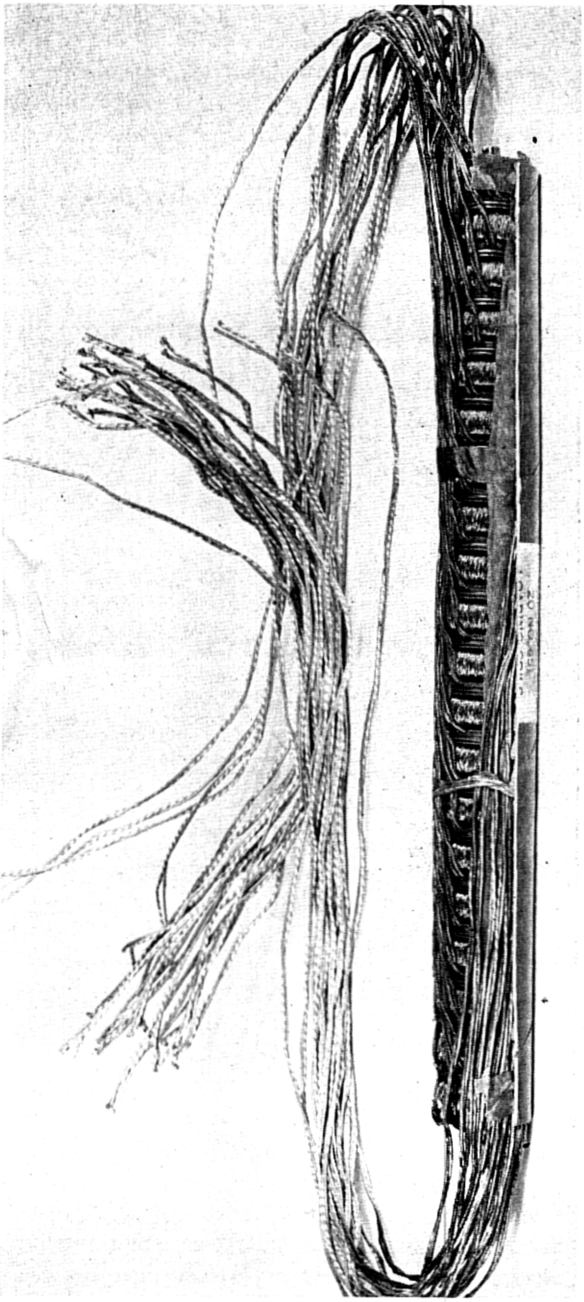

Fig. 22—20-Coil spindle assembly of No. 651 coils. Cable splice installations—long subscriber loops. View of assembly after impregnation, with part of plastic case removed to show the coils. The IN terminal pairs are bunched at one end, and the OUT pairs at the opposite end.

require stub cables, for office rack-installations, for submarine cables, and for buried, insulated wire. The splice-loading designs include individual cardboard containers for small exchange area (Fig. 21) and toll cable coils (Fig. 20), and baked varnish impregnated spindle-assemblies of coils for coaxial cable order-wire circuits, and for small exchange area cables (Fig. 22).

Case Sizes and Shapes

Where involved, the case size and shape limitations have generally been imposed by underground cable installation conditions. The circular tops of the cast iron cases and the rectangular tops of the welded steel cases had to be small enough to permit lowering the cases through the circular manhole openings in the loading manholes and loading vaults. In the early applications of loading, 26 and 27-inch manhole openings were very common; later on, 30-inch openings became standard for loading manholes. In recent years, in redesigning the large, thick-steel cases that required 30-inch manhole openings for their installation, the superseding thin-steel designs were proportioned to permit installation in line manholes having 27-inch openings.

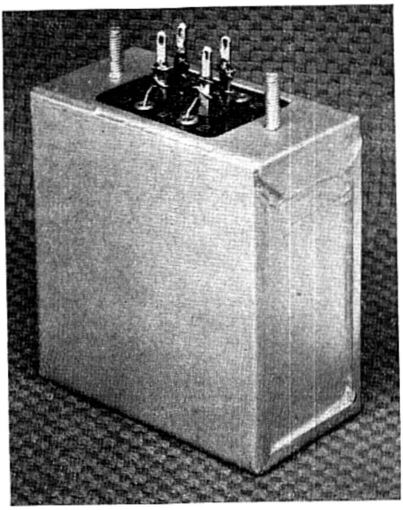

Fig. 23—Office type loading coil case for installation on office mounting plates. Designed for potting molybdenum-permalloy core program circuit loading coils.

The case bodies of the cast iron cases were approximately circular in cross-section with scallop-shaped contours corresponding to the compartments in which the coil spindle-assemblies were mounted. These ranged from 3 to 7 in number. In the rectangular cross-section, welded steel designs, there

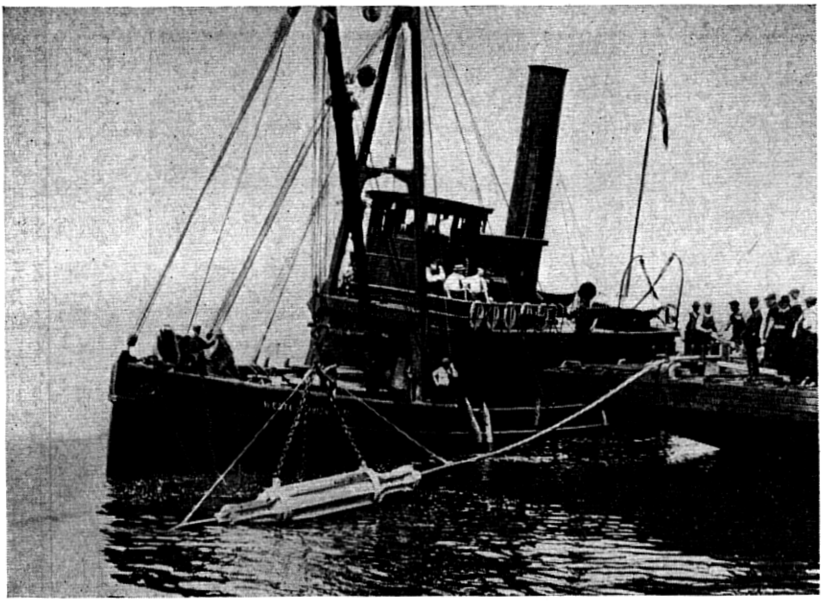

Fig. 24—Installation of submarine cable loading. An early type of cast iron case ready for lowering into water.

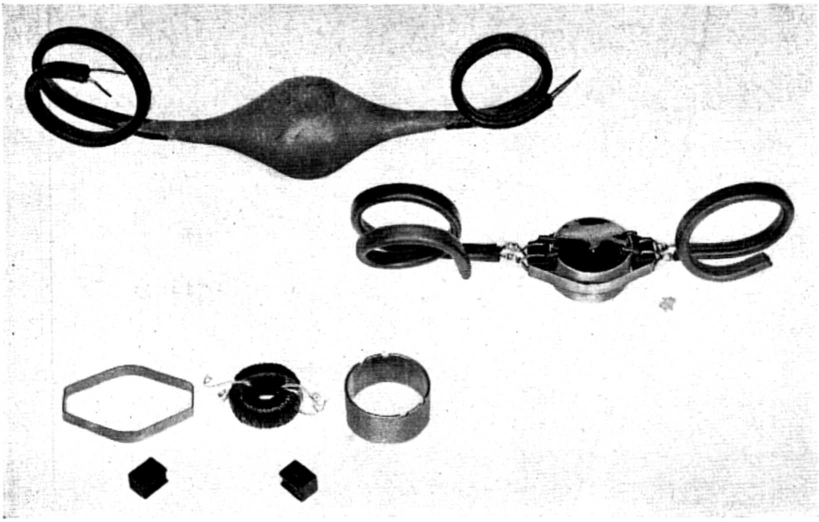

Fig. 25—Moulded rubber loading coil case for buried wire loading installations. Views of piece parts, partial assembly, and potted coil ready for installation.

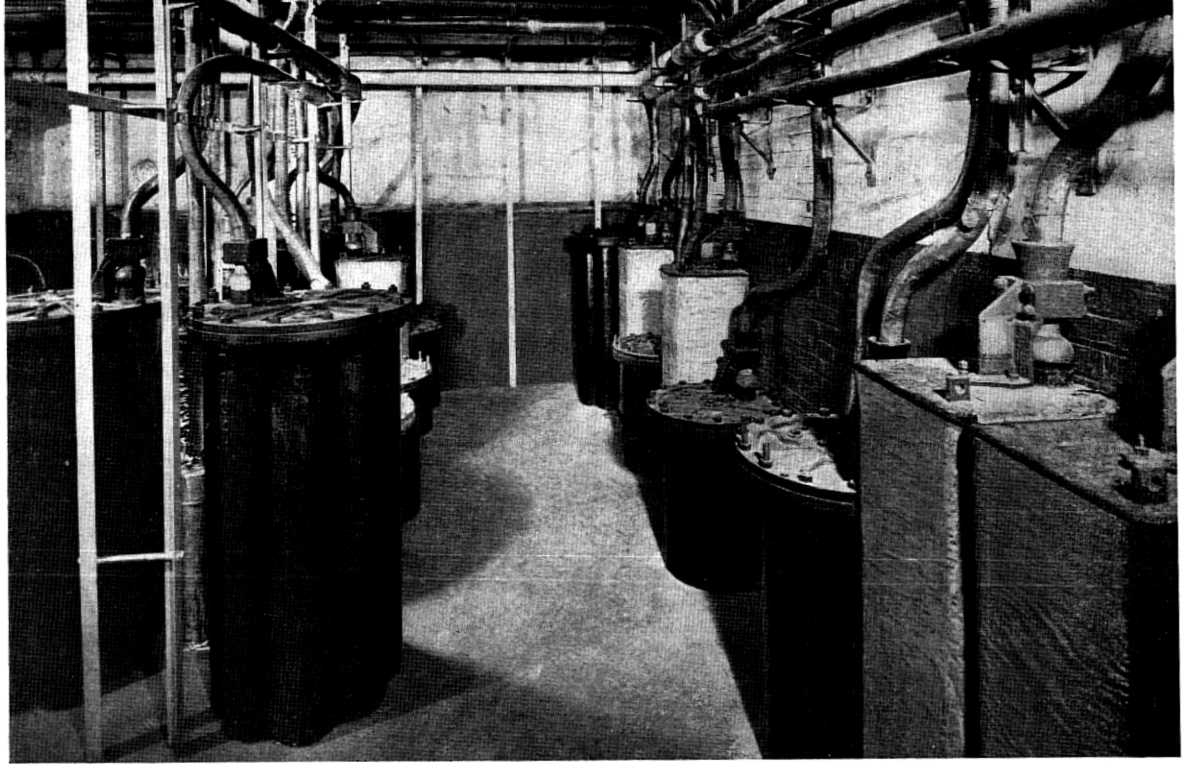

Fig. 26—Office vault installation of exchange area trunk cable loading. This vault is in the basement of a Manhattan office, close to the East River. The coils are used for loading trunks between Brooklyn and Manhattan offices routed through cables which cross the river in a rapid transit tunnel where space restrictions prevent the installation of loading coil cases. At time of photograph, a total of 36 cases containing a total of 11,404 coils were installed in this vault. The 36 cases comprise 20 cast iron, 9 rectangular welded steel, and 7 tubular thin steel designs. The view shows 17 cases; the other cases are hidden in background or are out of camera range. One case contains 456 coils; in the others the complement ranges from 303 to 306 coils. The individual coil codes are 601, 602, 603, 612, 613, 614 and 632. About 13% have iron dust cores, 63%

usually was design flexibility in proportioning the case heights and the cross-section dimensions to be approximately optimum for most efficient use of the available mounting and splicing-space in the loading manholes, subject of course to the manhole-opening limitations previously mentioned.

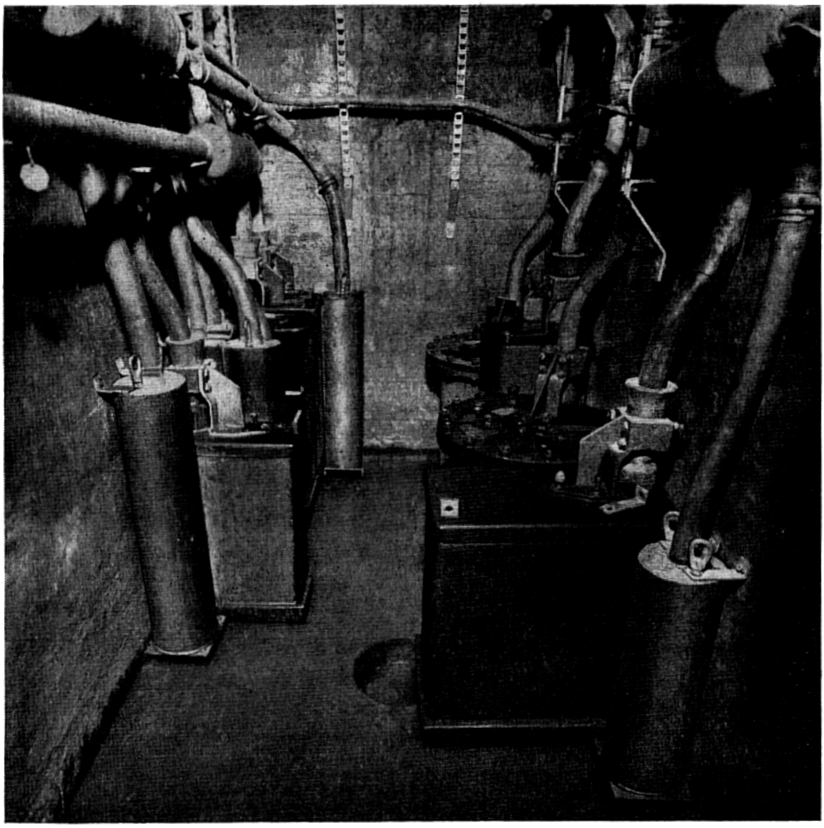

Fig. 27—Exchange area loading installation in side street auxiliary loading vault. In congested areas, space limitations frequently require the installation of underground cable loading coils in an auxiliary loading vault located in a side street near its intersection with the street under which the main cable conduit system is laid. Extensions of the case stub cables carry the coil terminal leads to the main cable splices. At time of photograph, a total of 18 cases containing a total of 7283 coils were installed in this auxiliary vault. Six cases had 303 or 304 coils, and 12 cases had 455 or 456 coils. The 18 cases include 2 cast iron cases, 5 rectangular welded steel cases, and 11 tubular, thin steel cases. The individual coil codes are Nos. 612, 632 and 643; 92% have 88 mh inductance, the remainder being 135 mh coils. 27% have permalloy cores; the remaining 73% have molybdenum-permalloy cores and formex insulated windings. This figure shows the far end of the loading vault where 14 cases are placed. Several tubular steel cases are hidden by larger cases in foreground.

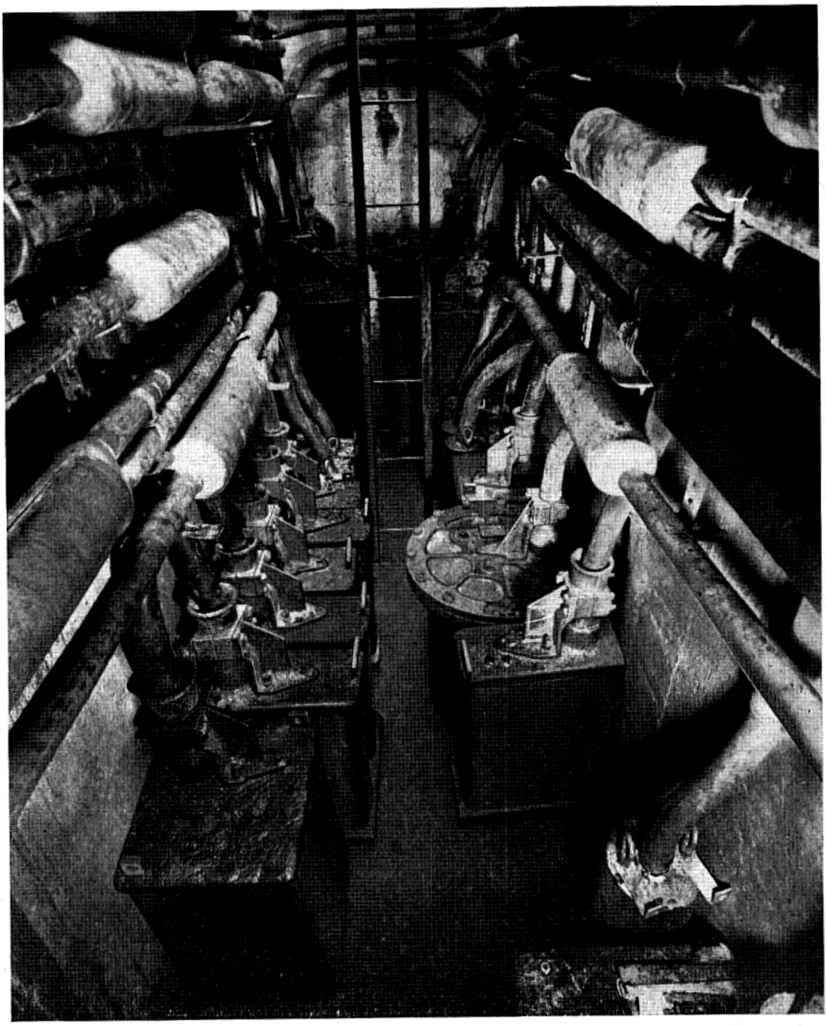

Fig. 28A—Another auxiliary vault installation of exchange area loading. One end of vault. At time of photograph, 33 cases containing a total of 11,241 coils were installed in this vault. A majority of the cases appear both in this view and in the view of Fig. 28B. 25 cases have 303, 304 or 305-coil complements, each of the other 8 cases have 455 or 456 coils. The total complement comprises 2 cast iron cases, 17 rectangular welded steel cases, and 14 tubular thin steel cases. The individual coil codes are 612, 613, 614, 622, 623, and 643. The coil inductances are: 88 mh, 70%; 135, 27% and 175 mh, 2.7%. 35% of coils have permalloy cores; the others have molybdenum-permalloy cores. 57% of coils have formex insulated windings.

Many of the individual designs were relatively tall, with cross sections requiring small amounts of floor space. The recent trend in case design (1948,

1949) revolves about two requirements: (1) the cases shall be capable of being installed in manholes having 27-inch openings, and (2) the vertical

Fig. 28B—Other end of vault in Fig. 28A.

dimensions shall be as short as possible while meeting requirement (1). The primary purpose of these changes is to reduce the cost of manhole construction in new conduits.

The submarine cable loading cases previously mentioned are cylindrical in shape, designed and installed so that the axis of the cylinder is in line with the axis of the submarine cable. A stub cable extends from each end, one having the IN leads to the coils, and the other the OUT leads. (Refer to Fig. 24, page 727.)

Potting Complement Sizes

Usually, the initial traffic requirements and estimated rate of traffic growth are the most important factors in determining the potting complement sizes for particular projects. Frequently the initial loading complement is greater than subsequent complements. In some situations, two or more cases may be installed at the same time, because of the case-design size limitations.

Non-Phantom Coils: In the early loading applications of non-phantom coils, the most common potting complements were of the order of about 50 coils. The maximum complements prior to the development of inexpensive loading for 22 ga. exchange cables ranged up to 98 coils. Complements of 200 and 300 coils became quite common with the Nos. 601 and 602 coils. With the introduction of the No. 612 (permalloy-core) coils, complements of 450 and 600 coils became common, and occasionally a 900-coil complement was used. The maximum complements of the much smaller molybdenum-permalloy core coils have been held to about 450 coils. The foregoing is an interesting manifestation of the stubborn limits upon case-design cost-reduction that come into play as the coils become smaller and smaller. The labor-cost component is dominant and little saving in materials can be achieved. In consequence, it is frequently preferable to use two medium-size complements, rather than one over-size complement having the same total number of coils, especially if the second complement can be deferred for some time.

Side and Phantom Coils: In the early applications of loading to quadded 19 and 16 ga. toll cables, the side circuit coils and the phantom coils were some times potted in separate cases. In such applications, the side circuit coil complements ranged up to 98 coils, and the phantom coil complements ranged up to 48 coils, but the average-size complements were substantially smaller. Soon it became the common practice to pot associated side circuit and phantom circuit coils together in the same case, and in such instances loading complements for 24 cable quads were common. To help meet the increasing demand for toll cable loading in the early 1920's, maximum complements for loading 36 cable quads became available. When the phantom coils were reduced to side circuit coil-size (1923), the maximum potting complement was increased to 45 loading units. The large coil-size reduction that resulted from the use of compressed permalloy-powder cores made practicable during the late 1920's and early 1930's a further, very substantial, increase in the range of standard potting complements covering up to

84 phantom loading units of the P-type, and up to 108 loading units of the PB-type. These very large loading complements had an interesting economic significance. At the time they became available the demand for additional toll cable facilities was increasing by leaps and bounds, and it was not uncommon for standard-size and over-size cables to be fully loaded at the time of the installation of the cables. In this connection, full loading for a 50% over-size, quadded, composite 19 and 16 ga. cable could be provided with two of the maximum-size potting complements of phantom loading units. This contrasts with fairly common experience in early installations of full-size cables, where four, five or six cases were used to provide complete loading.

The further size-reductions in toll cable loading coils that were achieved with the standardization of the M-type phantom loading units and later with the MF-type units occurred during a period of greatly reduced demand for toll cable loading, influenced by the exploitation of carrier systems on conductors from which loading was removed and on new non-loaded cables. The maximum potting complements were accordingly held to 80-unit and 48-unit sizes for the M-type and MF-type loading units, respectively.

Assembly Methods and Stub Cables

General: From the beginning of commercial manufacture, multi-coil complements of cable loading were coaxially assembled on spindles which were held in fixed positions in the cases. Preceding this operation, the accumulated moisture was expelled from the coil windings and the coils were dipped in a moisture-resisting compound. In the multi-spindle cases, the different spindle-assemblies were mounted in separate compartments of the cases, with the compartment partitions providing shielding to control crosstalk among the spindle-assemblies. On the individual spindle-assemblies, crosstalk was controlled by using steel washers between adjacent coils and mounting the coils so that their small, external, magnetic fields would be substantially non-interfering. The winding ends of the coils were connected to textile-insulated twisted-pair leads in spindle unit-cables, treated with wax for moisture protection.

After the spindle-assemblies had been fixed in position in the case compartments, the spindle unit-cables were formed by hand into a stub cable core over which a somewhat loose-fitting lead sheath was drawn. A color code on the conductor insulation provided identification for "wire" and "mate" conductors, and for IN and OUT coil terminals. The final assembly operations included filling the case compartments with a viscous rosin-oil compound, and a top layer of asphalt compound; and the stub cable sheath was soldered to a nipple in the case cover. At various stages in the assembly operations, suitable inspection tests were made to assure satisfactory conformation to specification requirements. After the final inspection tests, the outer end of the stub cable sheath was sealed to prevent entry of moisture.

When phantom loading started, the phantom coils were much larger than the side circuit coils. To conserve potting space in cases containing both types of coils, the individual spindle-assemblies consisted of only one type of coil. The phantom unit cross-connections between the phantom coils and their associated pairs of side circuit coils were made at the top of the case between quadded spindle unit-cables containing the OUT terminal leads of the phantom coils and the IN terminal leads of the side circuit coils. The quadded IN terminal leads of the phantom coils and the OUT terminal leads of the side circuit coils constituted the main line terminals of the complete loading units.

In general, all of the stub cable leads to the IN and OUT terminals of non-phantom type coils, and to the main line terminals of phantom unit combinations of side circuit and phantom circuit loading coils, were contained in a single stub cable sheath. Necessary exceptions to this practice occurred, however, in the submarine cable loading coil cases (which had two stub cables extending from opposite ends) and in the underground and aerial cable cases containing very large complements of P-B type loading units.

The first important change from the original potting practices followed soon after the introduction of phantom group loading. The original wax-dipped textile-insulated stub cables were found to be seriously objectionable sources of phantom-to-side and side-to-side crosstalk. To reduce crosstalk, and also to improve transmission, the practice started of using strip-paper insulated quadded conductors in a machine-stranded stub cable. This required a splice to be made inside the case, at the top, between the paper-insulated stub and the textile-insulated spindle unit-cables.

Apparatus Group-Segregation, Four-Wire Circuits: Several years later, when the development work on long-distance four-wire repeatered circuits got well under way, the assembly arrangements in the loading coil pots and the stub cable designs were changed to provide crosstalk segregation between the groups of coils used on the opposite-direction branches of the four-wire circuits. The segregation arrangements in the stub cables included shielding between the groups of terminal quads associated with the opposite-direction circuit groups. These loading coil case and stub segregation-arrangements were details of a fundamental plan for complete group-segregation between the opposite-direction branches of four-wire transmission systems (including the main cables themselves and the repeater office circuits) in order to control the intergroup near-end crosstalk coupling and prevent it from being a serious factor in the over-all crosstalk. (The relatively high amplification in the four-wire repeaters made very desirable the rigorous control of this type of crosstalk coupling.) Initially, the loading apparatus and associated stub cable quads intended for use on two-wire repeatered circuits were segregated in the coil cases from the two opposite-direction groups of four-wire circuit apparatus. Later on, this apparatus segregation between two-wire circuit coils and four-wire circuit coils was discontinued.

In mixtures of the two types of coils, the two-wire circuit apparatus was divided into approximately equal groups, each of which was combined with one of the four-wire opposite-direction groups. In order to simplify potting practices, the two-group segregation plan became the standard plan for all toll cable loading cases and was used in loading complements containing mixtures of two-wire circuit and four-wire circuit loading apparatus, and for complements consisting wholly of two-wire circuit coils, or of four-wire circuit coils.

In the most recent (1948–1949) general redesign of toll cable cases and stub cables, the segregation arrangements just described have been simplified, largely because of the present very small demand for additional H44-25 four-wire circuits. Group segregation of the apparatus within the cases is used only when four-wire H44-25 loading is involved. The use of shielding and of group-segregation arrangements in the stub cables has been discontinued. In complements of units for H44-25 loading, one of the opposite-direction groups is connected to a group of terminal quads having contiguous "quad counts" at the low end of the quad counting scheme described on page 737, and the other group is connected to the quads having "quad counts" at the high end of the quad counting scheme. When two-wire circuit coils are included in a loading complement containing four-wire circuit coils, the terminal quads of the two-wire coils use terminal quads having "quad counts" intermediate between those of the two opposite-direction groups of four-wire coils.

Phantom Coil Size-Reduction: The next important potting-practice change resulted from the size-reduction of the phantom coils to side circuit coil-size. From then on, the phantom coils were mounted on the same spindles as the side circuit coils, with each phantom coil immediately adjacent to its associated pair of side circuit coils. This permitted a more efficient use of potting space and made unnecessary the use of spindle-unit cabling for the cross connections between the coil components of the phantom loading units. The miniature inductance coils used in the loading-unit crosstalk adjustments were mounted on a frame located at the top of the coil spindle-assemblies and were connected in the circuit at the splices made between the stub cable and the spindle unit-cables leading to the coil line terminals.

Assembly Redesign, Exchange Area Coils: The first major change in the assembly and case-wiring arrangements for non-phantom exchange area coils was made during the middle 1920's in solving difficult problems that arose in the design of cases for 200-coil, 300-coil, and larger complements of the new small-size loading coils. The spindle-assemblies of coils were fastened to a skeleton frame to which the case pot-cover and the machine-stranded textile-insulated stub cable were attached. The part of the stub cable that extended within the case was subdivided into unit cables which were associated with the individual spindle-assemblies, to which the coil leads were connected, thus eliminating the intermediate spindle cables. After these connections had been made, the complete coil-assembly, with stub cable, was lowered into the coil casing. The case cover was then fastened to the coil casing, and the case filling-compound was poured through a small temporary opening in the cover.

Assembly and Cabling Changes; Beginning of Use of Loading Units in Individual Shielding Containers: Some of the improved assembly-arrangements, above described, were made available for phantom loading units soon after the permalloy-core toll cable coils became available, along with the standardization of the P-B type loading units. Certain differences were necessary, however, in order to permit the assembly of the 3-coil loading units in individual, cylindrical, shielding containers, having one end open. The associated three coils of a unit were mounted on a short hollow dowel, at one end of which was mounted a frame supporting terminal posts for all of the line terminals of the individual coils and the crosstalk adjustment-elements (small inductances and resistances, preselected to meet crosstalk requirements). The cross-connections between the phantom and side circuit coils were made between appropriate terminal posts, and the loading unit main-line terminals were connected to the stub cable conductors at this point, after the crosstalk adjustment-elements were connected in the circuit. The individual loading units in their shielding containers were fastened to a vertical frame by bolts extending through the hollow spindles. This frame was attached to the case cover. The stub cable was a machine-stranded, single piece of paper-insulated cable having the part below the case cover separated into unit cables for the connections to horizontal rows of loading units.

The loading unit and potting assembly methods are illustrated in Figs. 10 and 11 (pages 186 and 188, respectively). Generally similar arrangements were used with the M-type and SM-type loading units. With the standardization of the MF-type loading units, the adoption of cylindrical steel case bodies resulted in some potting assembly changes which are illustrated in Figs. 12, 13, and 14 (pages 192, 193 and 194, respectively). In the medium and large size potting complements, the individual loading units are mounted near the outer periphery of circular mounting plates, and the inner end of the stub cable extends through a circular opening at the center of these plates, (Fig. 13). In the very small complements, the MF units are stacked one above the other as shown in Fig. 14.

The concentric layer-type stub cables, used with new cases potting P-B type loading units and subsequently with the M-type, SM-type, and MF-type loading units, had an improved color-code for the conductors of the terminal quads which provided a counting-scheme type of identification for each of the individual loading units potted in a given case. To facilitate this full-scale identification of the individual units, it was necessary to have a precise wiring coordination between the positions of the individual units on the case assembly frames and the positions of their terminal quads in the stub cable (which were identifiable in terms of the quad-count color-code). This permitted the necessary coordination of the coil-grouping arrangements which were desirable for crosstalk reasons in complements of four-wire circuit loading (as previously discussed) with the group segregation and shielding arrangements of the associated stub cable terminal quads. A simplifying factor was the use of adjacent quads for the IN and OUT terminals of same loading unit.

The improved stub designs greatly simplified the manufacturing problems involved in providing, (a) full flexibility as regards loading complement sizes, and (b) full flexibility for desirable combinations of different types of loading units.

(a) Using a relatively small number of case sizes, provision was made for obtaining any total-complement size, ranging from one up to the maximum-complement size, in steps of one loading unit. A different size of stub cable was used for each different size of case. When less than a full complement was desired in a particular size of case, the unused terminal quads were left open at the inner end of the stub cable and were tagged at the outer end. In terms of "quad counts" these non-used quads had contiguous numbers at the "high" end of the quad counting-scheme, and were readily identified by means of the quad-count color-code and the tags previously mentioned. (A name-plate on each case recorded the number and the code types of loading units potted in the case.) In the prior art, different stub cables had been provided for fitting the different partial and full potting-complements in particular sizes of cases.

(b) For several years prior to the standardization of the improved assembly and stub design it had been a common practice to use mixed potting complements of different types of loading units, in order to realize the maximum potting and installation economies inherent in the use of larger-size loading complements made practicable by size-reduction of the loading coils. These mixtures usually comprised combinations of coils for four-wire long-haul circuits with one or two types of coils for short-haul or medium-haul two-wire circuits. When this practice of mixed potting complements started, it was customary to use different stub cables for each different potting-mixture, even when the same total number of loading units were involved. In these stub cables, each of the different types of loading units had its own individual color-code identification. In the new set-up, the relatively simple color-code counting-scheme provided full flexibility for all desirable combinations of different types of loading units.

Loading units of a given type made use of terminal quads having *contiguous numbers* in the quad counting-scheme. In mixtures involving two types of loading units, for example P1B and P11B units, the units having the lower-number component in their code-designation used the low-numbered terminal quads, and the units having the higher code-number used the high-numbered terminal quads. In mixtures involving three different types of loading units, the units having the intermediate code-number in their code designation used a contiguous group of terminals which were intermediate in position between the low-numbered quads and the high-numbered quads which were respectively associated with the loading units having the lowest and the highest code numbers. These procedures were followed in each of the two segregated groups of opposite-direction loading units previously mentioned.

Quadded Stub Cables for Non-Phantom Coils: During the 1930's, the practice of using quadded stub cables for cases potting non-phantom type exchange area and program circuit loading coils was started. One pair of each terminal quad was connected to the IN terminals of a coil, and the associated pair was connected to the OUT terminals of the same coil. Previously, the IN and OUT terminals had been grouped in different unit cables. The close association of IN and OUT terminals in the new quadded stub cables reduced the factory testing-time, and simplified the preparatory phases of the field splicing of the stub cables to the main cables. Other subsequent improvements included the use of paper-pulp insulation on the stub cable conductors, in place of textile insulation. By this time it had become a common practice to terminate the coil windings on terminal clips mounted in close proximity to the coils. The inner ends of the stub cable conductors were soldered directly to these clips.

Stub Cable Conductor Sizes: Since the case stub cables are extensions of the main cables, transmission considerations have generally led to the use of about the same sizes of conductors. However, notable exceptions to this rule have been accepted in situations where conformation to the rule would have made the stub cable unduly expensive, or unduly large and difficult to handle at the factory or during installation. The stub cable conductor sizes have ranged from 13-gauge in the cases containing coils designed for composite coarse-gauge toll cables to 24-gauge in the standard cases for the coils used principally on 22 and 24-gauge non-quadded exchange cables. For several decades, 19-gauge stub cables were used for the toll cable loading cases. The most recent case designs are using 22-gauge conductors.

Fig. 29—Buried coaxial cable installation of voice-frequency loading on outer layer quads. View of installation after completion of the splicing work, and prior to filling in the excavation. The loading coils are potted in two tubular, thin steel, cases. Each of black boxes near center covers a cable splice, and furnishes protection against mechanical injury. At each splice, connections are made to the stub cable conductors of a single loading coil case. Splicing difficulties prevent all of the connections from being concentrated at a single cable splice.

Dielectric Strength

From the beginning of the use of cable loading, a fundamental design requirement has been that the insulation of the loading coils and of the associated stub cable and pot wiring should have a dielectric breakdown-strength as high as that of the cables for which the loading was intended, and preferably somewhat higher, to assure that the loading apparatus would not be dielectrically weak points in the loaded cable systems.

When dielectric-strength improvements in toll cable design started during the late 1930's in order to reduce damage by lightning, especially on buried and aerial cables, equivalent improvements were also made in the loading apparatus. These cable and apparatus improvements were primarily concerned with raising the dielectric strength of the insulation between core and sheath.

During recent years, the extensive installation of buried toll cables in areas where the ground resistance is high has led to the use of cables having very much higher dielectric strength (wire to ground) than those used during the 1930's. The development of the copper-jacketed toll cable having a thermoplastic protective covering between the lead sheath and the jacket, which was capable of withstanding a dielectric-strength test of 10,000 volts d-c, between the sheath and the jacket, made it necessary to apply an equivalent insulation to the exterior of the buried loading coil cases. The more recent development of the "Lepeth" sheathed toll cable has made it possible to approach a dielectric breakdown-strength of the order of 25,000 volts d-c between cable core and sheath. This is achieved by extruding a sheath of polyethylene of suitable thickness over the cable core, and over this a thin lead sheath. Loading coil cases were redesigned to match this construction, using an *inner lining* of thermoplastic insulation to provide equivalent insulation between the coils and the case. The stub cables have dielectric design-features corresponding with those of the Lepeth toll cable.

Potting Costs

The potting cost per coil, or loading unit, varies considerably with the potting complement-size, and is a maximum in small complements. These general relations apply for all types of coils.

In the early designs, the average potting cost per coil was much smaller than the coil costs. Over the years, the case cost-reduction that has resulted from coil size-reductions, increased complement-size, and other design changes, has been smaller on a percentage basis so that in the present designs the average per coil potting costs are somewhat greater than those of the coils. Notwithstanding the changes in cost relations just mentioned, the direct and indirect savings that have resulted from the potting development work constitute a substantial fraction of the aggregate plant cost-reduction which has been achieved by the use of coil loading.

PART V: LOADING FOR INCIDENTAL CABLES IN OPEN-WIRE LINES

INTRODUCTION

From the earliest days of telephony, when it became necessary to use pieces of cable in long-distance lines to provide toll entrance facilities at toll centers or for other purposes at intermediate pionts, such cables have had more or less objectionable effects on the over-all transmission-system performance. These impairments resulted from the much greater transmission loss per unit length in the inserted cable, and from reflection effects occurring at the cable junctions with the open-wire—these being due to the large differences between the cable and open-wire impedances.

Prior to the advent of loading, the losses in incidental cables could be reduced to low unit-length values only by using expensive coarse-gauge cables. Cable loading became available just in time to head off the installation of some very expensive coarse-gauge cables that had been proposed for unusually long entrance facilities in the New York and Boston areas. The use of loading on the open wires greatly increased the economic importance of attenuation reduction in the incidental cables occurring in such lines. By substantially raising the line impedance, loading also increased the magnitude of the reflection losses at junctions with non-loaded cables.

Standard "heavy" loading (Table II, page 156) came into general use on long entrance cables in the loaded lines. While this loading did not have a sufficiently high impedance to match that of the loaded line, it was close enough to reduce the junction reflection losses to acceptable values. A special light-weight loading found some use on incidental cables in non-loaded lines.

When satisfactory types of telephone repeaters became available for extensive use on loaded open wires, the cable junction impedance-irregularities, and other irregularities, had to be reduced to very small values so as to avoid repeater circuit unbalances that would objectionably restrict the repeater gains. These severe requirements put a high premium upon the use of an improved type of cable loading having impedance characteristics that matched closely those of the associated open-wire circuits. This "extra-high" impedance loading also had very satisfactory attenuation properties.

Subsequently, when the exploitation of the vacuum-tube repeater started on non-loaded open-wire lines it became necessary to use a new, low-impedance type of impedance-matching loading on their associated incidental cables. Because of the low impedance, the attenuation reduction was considerably less than that provided by the extra-high impedance loading just mentioned. This, however, was not a serious limitation in the non-loaded repeater circuits. After open-wire loading became obsolete, further improvements in telephone repeaters and in transmission standards led to progressive improvements and refinements in the loading used on cables in non-loaded lines.

Beginning around 1920, the rapidly increasing use of open-wire telephone and telegraph carrier systems made it necessary to use in the associated incidental cables improved loading systems that provided good impedance-matching and attenuation-reduction properties over the complete voice and carrier-frequency bands used by the carrier transmission systems. The use of several different carrier telephone systems employing materially different frequency-band widths made it economically desirable in due course to use several different types of loading to provide the necessary transmission bandwidth through the incidental cables.

The various types of cable loading mentioned above are separately considered under suitable headings in the following pages. The two principal subdivisions of Part V are devoted to voice-frequency loading and to carrier loading, respectively. A third subdivision briefly describes a special type of voice-frequency phantom loading which is used in coordinated phantom-group combinations with side-circuit carrier loading systems that provide 10-kc and 30-kc transmission bands.

The importance of the incidental cable loading described in Part V of this article is due to its substantial, beneficial contributions to the transmission service-performance of the relatively expensive open-wire facilities, rather than from the amount of loading so employed. This is quite small relative to that used in voice-frequency toll cables and exchange cables.

(V-A) Voice-Frequency Impedance-Matching Loading

Since the most important early uses of the vacuum-tube repeaters on open-wire facilities were on loaded lines, the first new impedance-matching loading system was developed for this particular use. As noted later, this had an important effect on the loading system subsequently developed for use on cables in non-loaded lines.

Loading for Cables in Loaded Open-Wire Lines

The new phantom-group loading for this use was designed to have closely the same values of nominal impedance and theoretical cut-off frequency as those of the loaded lines. The cable coil inductances had to be a little higher than the open-wire coil inductances, in consequence of the smaller amount of distributed inductance in the cable. A standard cable coil-spacing of about

5575 ft. (0.062 mf/mi cable) was adopted so as to have loading section capacitances close to those of the open-wire loading sections. This cable loading system originally known as "extra-heavy" loading, and later designated E248-154, was used on coarse-gauge cable conductors and had a slightly lower attenuation loss than that of the then standard "heavy" loading for coarse-gauge toll cables. (In the loading designation, *E* is the symbol for 5575-ft. spacing.)

The loading coils used 65-permeability iron-wire cores with two short, series air-gaps, to secure good magnetic stability.

The long obsolescence of open-wire loading makes further description of the E248-154 cable loading unimportant.

Loading for Cables in Non-Loaded Open-Wire Lines

When open-wire repeaters first came into general use, it was a common situation for entrance and intermediate cables to have one group of circuits associated with loaded open-wire pairs, and another group connected to non-loaded pairs. In such situations, it was obviously very desirable that the different types of cable loading associated with the loaded and the non-loaded lines should be installed at the same cable loading points.

Early Standard Loading Systems

E28-16 Loading: It was found that a satisfactory, low-impedance type of impedance-matching loading could be obtained by using 28 mh side circuit coils and 16 mh phantom coils at the spacing used for E248-154 loading. Some quantitative data regarding this low-impedance loading, designated E28-16, are included in Table XV (page 746) along with corresponding data on other voice-frequency loading systems subsequently standardized for cables in non-loaded lines.

M44-25 Loading: In many situations where the impedance-matching requirements were not so severe, and where loaded open-wire lines were not involved in the incidental cables along with the non-loaded lines, a somewhat cheaper type of low-impedance loading using a longer coil-spacing was utilized. Data regarding this loading, designated M44-25, are included in Table XV. (It is of interest that this type of loading had been used on a small scale prior to the extensive utilization of telephone repeaters.)

From Table XV it will be noted that the two loading systems had the same nominal impedance and that the better system, E28-16, had much higher cut-off frequencies. A brief digression regarding the important part which the cut-off frequency plays in the impedance-matching problem in the upper speech-frequency band is appropriate at this piont.

Importance of Cut-Off Frequency

Basically, the general impedance-matching problem under discussion is complicated by the fact that the non-loaded line is a "smooth," i.e., a uniform, line, whereas the loaded cable is a "lumpy" line. On the one hand, the sending-end impedance of the non-loaded line is substantially a constant resistance with negligible reactance over the frequency range above about 1 kc. On the other hand, the high-frequency impedance of the loaded cable may vary substantially in its resistance and reactance components with rising frequency, depending upon the type of loading termination employed. "Half-coil" and "mid-section" terminations have the important advantage of substantially negligible reactance, for which reason one or the other of them was used in the early applications of impedance-matching loading.(w) With these particular loading terminations, the resistance component of the loaded cable impedance changes with rising frequency, at a rapidly accelerating rate as the cut-off frequency is approached. The reference impedance in these changes is the nominal impedance of the loaded cable, which for optimum impedance-matching should be equal to that of the non-loaded line. (Numerically, the nominal impedance in ohms is equal to the square root of the ratio of the total circuit inductance, in henrys, to the total mutual capacitance, in farads, per unit length.) The resistance changes with rising frequency go up when mid-section termination is used, and drop down when half-coil termination is used.

The important practical significance of the foregoing is that the high-frequency impedance irregularities at the open-wire cable junction become progressively smaller as the loading cut-off frequency is raised (provided that the nominal impedances of the line and cable are closely alike). With the simple types of loading terminations above described, the requirements for good impedance-matching make it desirable to have much higher cut-off frequencies than those which are necessary from the standpoint of attenuation-frequency distortion in entrance and intermediate cables.

H28-16 Loading

The discontinuance of the manufacture of open-wire loading coils about 1924, and the decreasing importance of open-wire loading, made it desirable to discontinue the use of the E-spaced loading solely for entrance and intermediate cables. Plant simplicity and flexibility requirements made it desirable to use H-spaced loading to permit coordination with the loading

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(w) Half-coil termination involves the use of coils having one-half of the regular "full-coil" inductance at the end of the cable, followed in regular periodic sequence by "full" loading sections and "full" loading coils. In "mid-section" termination, the first full-coil is located one-half of a full loading section away from the end of the cable.

used on toll cable circuits along the same routes. Studies of these coordination possibilities resulted in the standardization of H28-16 entrance cable loading during 1927. Referring to Table XV, it will be seen that the change from 5575-ft. spacing to 6000-ft. spacing, using the same loading inductance values, resulted in a small drop (about 4%) in nominal impedance and theoretical cut-off frequency. A contemporary allied development made available new types of balancing networks which simulated the iterative impedances of the H28-16 loaded cables. The use of these new networks with repeaters at the office ends of long H28-16 loaded cables gave considerably better repeater balances than those obtained with open-wire balancing networks at the office ends of long E28-16 loaded cables. Up to this time, balancing networks which simulated the impedances of the associated open-wire lines had been used with the open-wire repeaters. This early practice was continued on open-wire lines having short entrance cables with H28-16 loading.

H31-18 Loading

General: It was known prior to the standardization of H28-16 loading that the 28-16 mh loading inductances were not optimum from the impedance-matching standpoint for use at 6000-ft. spacing. However, it was appreciated that the concurrent development work on the compressed permalloy-powder core-material previously described (Section 9.1) was approaching completion and that a general size-reduction redesign of all toll cable and toll entrance loading coils would soon be undertaken. These considerations made it undesirable to develop for the H-spaced 28-18 loading new iron-dust core loading coils which would in all probability be superseded in a short time by permalloy-core coils. Thus it happened that the development work for the improved H31-18 loading system was coordinated with that on smaller-size, permalloy-core, loading coils having the necessary new inductance values for use in that system.

The H31-18 loading was designed to have a slightly higher nominal impedance than E28-16 loading, to make it more suitable for use on incidental cables in 104-mil open-wire lines, which were expected to be its principal field of use, since the more expensive, larger conductors (128 and 165-mil) were destined for use principally on a carrier basis and would require carrier loading on their incidental cables.

Improved Loading Terminations: It was also considered desirable to provide better impedance-matching characteristics at high voice-frequencies to assist in obtaining more satisfactory repeater operation on long-haul, multi-repeater, voice-frequency circuits which were becoming more common and more important in the rapid expansion of the open-wire plant. This requirement was met by providing improved loading terminations, which kept the resistance component of the cable impedance fairly close to the nominal impedance over the upper part of the frequency-band transmitted by the voice-frequency repeaters, and which also had satisfactory low reactance. Two different but equally satisfactory terminations[12] were developed, to provide flexibility and economy in the loading layouts. One of these was theoretically based on the mid-section termination previously described. This half-section termination was extended to about an 0.83-fractional section, followed at the open-wire junction by a terminal loading unit having inductance values about .36 of the full-weight loading inductances used in the loading designations. The other new loading termination was theoretically based on the mid-coil termination previously described. It used 0.86-fractional coils instead of half coils, and had a 0.36-fractional loading section adjacent to the open-wire side. These new loading terminations were known as "Fractional coil" or "Fractional section" terminations, depending on whether the fractional coil or the fractional section was the terminal element closest to the open-wire line. At the office ends of loaded entrance cables a mid-section loading termination was frequently used, and the repeater balancing network-circuits were adjusted to correspond with this situation in the line.

TABLE XV

VOICE-FREQUENCY LOADING FOR INCIDENTAL CABLES IN NON-LOADED OPEN-WIRE LINES

Loading Designations	Coil Spacing (ft.)	Type of Circuit	Nominal Impedance (ohms)	Theoretical Cut-off Frequency (cycles)
E28-16	5575	Side	650	7250
		Phantom	400	7650
M44-25	8750	Side	650	4600
		Phantom	400	4900
H28-16	6000	Side	630	7000
		Phantom	380	7400
H31-18	6000	Side	666	6700
		Phantom	403	7000

Note: The full-coil inductances in millihenrys are given in the loading designations. The first number applies to the side circuits and the second number to the phantom circuit.

The H31-18 loading system was standardized in 1928 and is still the standard voice-frequency loading system for incidental cables in open-wire circuits which are not arranged or used for carrier operation.

Loading Systems Data: General transmission data regarding the loading systems briefly described above are given in Table XV.

Attenuation Data: The relatively low cable impedances which are necessary for good impedance-matching limit the attenuation-loss reduction to smaller values than those obtained with the higher impedance loading systems used on toll cable facilities. The theoretical 1000-cycle attenuation values for H31-18 loading (on a db/mi basis) are 0.56, 0.30, and 0.16, respectively, for 19 ga., 16 ga., and 13 ga. cables. The phantom circuit attenuation is nearly 20% lower, being about 0.47, 0.24, and 0.13 db/mi.

The attenuation losses in the other loading systems of Table XV are close to those for H31-18 loading. This follows from the fact that their impedances are nearly the same in magnitude.

Low-Frequency Impedance Matching

Before ending the discussion of transmission system characteristics, it is important to note that the attainment of optimum impedance-matches at low voice-frequencies, with the types of loading under discussion, involves the use of the so-called "optimum" cable conductor sizes. This follows from the fact that at these low frequencies the circuit resistances are important factors in determining the open wire and cable impedances. The optimum conductor combinations are 13 ga. cable for use in association with 165-mil open-wire lines, 16 ga. cable with 128-mil lines, and 19 ga. cable with 104-mil lines. Allowing for the loading coil resistances, these combinations of cable and open-wire conductor-sizes closely conform to the fundamental theoretical requirement that the unit-length ratio of series resistance (ohms) to shunt capacitance (farads) to total linear inductance (henrys) in the loaded cables should be close to the corresponding linear ratio in the associated non-loaded lines.

Loading Coils and Cases for Incidental Cables

In their general design features, excepting inductance and effective resistance, the voice-frequency loading coils for incidental cables corresponded with those currently used in toll cable circuits. When the toll cable coils were redesigned to take advantage of new core-materials, or in other important features, the entrance cable coils were included in the general redesign work.

The first loading units developed for H31-18 loading were coded in the "P" series. The code designation P4 applied to the "full-weight" loading unit. The fractional-weight loading units developed for use in the "fractional section" and the "fractional coil" loading termination were coded P5 and P6, respectively. These numerical code components have been retained in the code designations of all standard replacement designs, namely the PB, M, SM, and MF series of loading units.

The potting practices used with the entrance cable coils were generally similar to those used with similar-sized toll cable coils. The potting complements for incidental cables, however, were small relative to the complements most generally used in the toll cables. Occasionally, in situations where toll entrance facilities and long-distance cable facilities shared the same cable for a short distance, the potting complements would include both types of loading. The color code used on the coil terminal quads in the stub cables of the loading coil cases facilitated identification of the different types of loading in the cable splicing-operations.

(V-B) CARRIER LOADING FOR INCIDENTAL CABLES IN OPEN-WIRE CARRIER SYSTEMS

Historical

The first open-wire carrier telephone system was installed late in 1918, and in the early 1920's general commercial use began to expand rapidly. A comprehensive account of the pioneering development work is given in a 1921 *A.I.E.E.* paper[36] by E. H. Colpitts and O. B. Blackwell.

Experimental types of carrier loading were made available for use on incidental cables in the open-wire lines on which the first carrier systems were installed. In general, these early carrier loading installations were engineered to specific job requirements.

C4.1 and C4.8 Loading: From this experience there evolved a quasi-standard loading treatment which served the current service needs, pending completion of the development of the first standard carrier loading systems, C4.1 and C4.8, late in 1923. These were designed to provide good impedance-matching up to a top frequency of about 30 kc. During the intervening years this loading has remained standard for incidental cables in carrier systems using this frequency-band, even though important changes have been made in the carrier systems themselves, notably the first Type C carrier systems[37] during the middle 1920's, and the improved Type C systems[38] during the late 1930's.

B15 Loading: During the late 1920's a lower cut-off carrier loading system designated B15 was designed especially for use with carrier facilities operating below a top frequency of about 10 kc. This loading served a double purpose. It was suitable for use with the old standard Type B carrier telegraph system[36] and with the new standard, single-channel, Type D carrier telephone system.[39] (In many of its early applications the Type B telegraph system used the frequency space between the voice circuit and the carrier telephone channels.) The B15 loading system is still in good standing. When an improved single-channel telephone system, Type H[40], was developed during the late 1930's, its frequency allocation was chosen so that it could use "spare" B15 circuits which had become available on a substantial mileage of incidental cables.

A2.7 and 3.0 Loading: During the late 1920's the rapid expansion of carrier working led to extensive studies of the practicability of obtaining a larger number of telephone channels in long-haul carrier systems. These studies indicated a good prospect of using a wider frequency-band extending up to a top frequency of about 50 kc. In order to secure a much better control of intersystem crosstalk over the wider frequency-band, plans were made for spacing the wires of individual pairs much closer together, and for spacing adjacent pairs at greater distances apart. Also, improved transposition systems were designed for these new open-wire arrangements. In the period of interest, the open-wire plant was expanding very rapidly, and as a part of this expansion several entirely new pole lines were required for important long-haul service. These lines incorporated the improved construction features above mentioned. Even though the proposed new broader-band carrier systems were still in the "discussion stage" of development, it seemed desirable that a new type of broader-band loading should be installed on the incidental cables in the new pole lines, in order to avoid the larger expense of eventually replacing the 30-kc Type C loading, if it should be used initially. These considerations resulted in the rush development of the Types A2.7 and A3 carrier loading systems specifically to meet the impedance-matching requirements over the proposed 50-kc band. This loading was duly installed according to plan, but fate decreed that it should never be used for its originally intended purpose. Type C carrier telephone systems were immediately installed on the new lines, in the expectation of removal when broader-band systems became available, and the Type A loading was actually used only for 30-kc transmission.

The explanation for this turn of events was that before the final development requirements could be established for the proposed new 4 or 5-channel systems, some entirely new factors(x) entered the continuing studies and eventually resulted in a decision to develop a 12-channel system.[41] This was designed for placement above a Type C system on the same open-wire pair, making a total of 15 carrier channels above the voice-frequency circuit. The new broad-band carrier telephone system was coded in the "J" series. Its top working-frequency was about 143 kc.

Type J Loading: In due course, the development of new carrier loading was coordinated with the work on the new carrier telephone system. Three loading systems, designated J-0.72, J-0.85, and J-0.94, became available during 1937–1938 and are still in good standing, although they are not extensively used.

In the following pages, the general transmission characteristics of the Type C, B, and J loading systems are described, and some general informa-

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(x) Including high-gain, high-stability, negative-feedback repeaters, and crystal filters.

tion is given regarding the loading apparatus and the building-out apparatus. The Type A systems are not included.

Loading Systems Characteristics

General: A summary of loading systems characteristics is given in Table XVI, below. Attenuation data are given in Table XVII.

Compensated Loading Terminations: These loading systems are commonly known as compensated loading by virtue of their use of compensated loading terminations[12] to provide the desired impedance-matching characteristics at about the minimum cost. Over the working carrier-band the impedances of these compensated circuits closely approximate the non-reactive, flat, frequency-resistance characteristic of their "corresponding smooth lines"; that is to say, the "lumpiness-of-loading" effects on the loaded cable impedance are reduced to tolerable low values over a predetermined frequency-band. By also having the nominal impedance of the loaded cable close to that of the associated open-wire line, satisfactory impedance-matches are obtained up to a much higher fraction of the loading cut-off than is possible with the more simple loading terminations used with the voice-frequency loading. In some carrier loading designs, this impedance-matching band extends up to about 0.75 of the cut-off frequency, or a little higher. An extension to still higher frequencies, relative to the cut-off frequency, would tend to result in objectionable "lumpiness-of-loading" attenuation impairments. The compensated loading terminations achieve substantial economies in the loading costs by permitting the use of much lower cut-off frequencies than would otherwise be feasible, thus allowing the full-weight coils to be spaced at much longer intervals.

TABLE XVI
CARRIER LOADING FOR INCIDENTAL CABLES IN OPEN-WIRE CARRIER TELEPHONE SYSTEMS

Loading Designation	Approx. Top Working Freq. (kc.)	Theoretical Cut-off Freq. (kc.)	Nominal Impedance (ohms)	Theoretical Total Loading Section Capacitance (mmf.)	Theoretical Coil Spacing (ft.)	Representative Coil Spacing (ft.)	Full-Coil Inductance (mh.)
C4.1	30	45	590	12100	929*	740	4.09
C4.8	30	41.5	640	12100	929*	740	4.78
B15	10	13.5	640	36850	3000*	2800	14.7
J-0.72	142	208	542	3027	633†	500	0.72
J-0.85	142	190	575	3105	648†	500	0.85
J-0.94	142	181	600	3105	648†	500	0.94

Notes: * In ordinary quadded cable having 0.062 mf/mi side circuit capacitance.
† In special 16 ga. disc insulated cable having 0.025 mf/mi capacitance.

Additional information regarding the loading terminations is given in the description of the terminal loading units which are used in these terminations.

Control of Impedance Irregularities; Loading Layouts: The carrier loading systems are engineered and installed to meet unusually severe limits on impedance irregularity among the individual loading sections and at the terminals. In installations involving more than one carrier system, it is especially desirable to restrict the individual impedance irregularities in order to control intersystem reflection crosstalk. The significance of this is understandable when one appreciates that usually the dominating reason for using carrier loading on the incidental cable is to avoid the objectionable reflection crosstalk that would result from the impedance irregularities caused by non-loaded cables. An additional important reason for the control of impedance irregularities is to avoid large humps in the insertion loss-frequency characteristics which might cause objectionable frequency-distortion within the individual channels.

TABLE XVII
CARRIER LOADING ATTENUATION DATA

Loading Designation	Cable Conductor Gauge	Cable Capacitance (mf/mi)	Attenuation—db/mi				
			1 kc	10 kc	30 kc	80 kc	140 kc
C4.1	13	0.062	0.28	0.39	0.92	—	—
	16	0.062	0.42	0.52	1.04	—	—
C4.8	16	0.062	0.40	0.50	1.14	—	—
	19	0.062	0.67	0.78	1.37	—	—
B15	16	0.062	0.35	0.54	—	—	—
	19	0.062	0.62	0.80	—	—	—
J-0.85	16	0.025	0.41	0.51	0.64	0.93	1.36

The procedure for controlling impedance irregularities in the loaded incidental cables involves the adjustment of the total capacitances of the individual loading sections to values close to the theoretical design values by means of adjustable building-out condensers. Ordinarily, a precision limit of about ±1% is involved. To make these limits economically practicable, precision types of capacitance measuring-instruments have been made available, along with low cost building-out devices capable of simple precision adjustments.

The theoretical total loading capacitances for the different carrier loading systems are given in Table XVI, along with theoretical values of coil spacing in terms of the "nominal capacitance" of the usual type of cable involved. The actual geographical coil-spacing is usually well below this theoretical spacing because of the unavoidable capacitance deviations that occur in commercial paper-insulated cables. The loading layout procedure is such that the highest-capacitance cable pairs in the individual loading sections will not have too much capacitance. When the loading is installed, the capacitances of the various pairs in the individual loading sections are measured, as also are the mutual capacitances of the loading coils and their associated stub cables, and then enough shunt capacitance is added to obtain the desired theoretical total capacitance, per loading section.

In many installations, especially in underground cables, the theoretically best loading points for the carrier loading coils (after engineering allowances have been made for cable-capacitance deviations) frequently occur at points where it would be unduly expensive to install the loading. In such instances, shortened spacings are used, and the building-out adjustments are increased to correct for the geographical spacing-deficiency along with the cable-capacitance deviations.

For reasons above mentioned, the individual coil-spacings may vary considerably in the same project, and the average coil-spacing may be quite different on different projects involving the same type of loading. The "representative coil-spacings" given in Table XVI are representative job averages.

As with the voice-frequency loading, the choice of cable conductor-gauge is important in the impedance-matching performance of the C4.1, C4.8, and B15 loaded cables at low voice-frequencies. The optimum resistance relations between the cable conductors and the open-wire conductors are the same as in voice-frequency loading. In the use of the Type J loading as practiced on short cables, this resistance-ratio question is unimportant because such loaded cables are substantially "transparent" at voice frequencies.

The loading terminations are unimportant factors in voice-frequency impedance-matching. This follows from the fact that the voice frequencies are low relative to the loading cut-off, for which reason the carrier loaded circuits act as electrically smooth lines in this range.

Type C Loading: These loading systems were designed for use on cable pairs connected to 12-inch spaced open-wire pairs. The impedances of the open-wire pairs vary substantially with the conductor size and because of this a single cable-loading system would not be satisfactory as regards carrier-frequency impedance-matching for all types of open-wire. The C4.1 system is used on cable pairs connected to 165-mil open-wire pairs. The C4.8 is a compromise system for use on cables connected to the less important and less expensive 128-mil and 104-mil open-wire pairs.

It is of interest that the theoretical coil-spacing for Type C loading is one-sixth of that of the E-spacing described in the discussion of voice-frequency impedance-matching loading.

Considerable Type C loading has been used on cables associated with open-wire pairs which have their conductors spaced 8 inches apart. The closer wire-spacing reduced the open-wire impedances below the values for which the carrier loading was originally designed. To obtain better impedance-matches when used with these lower-impedance lines, the Type C carrier loading was *"modified"* to have lower impedances by systematically building-out each loading section to have a higher total loading-section capacitance. This procedure also reduced the loading cut-off by an amount proportional to the impedance reduction, which effect limited the allowable impedance reduction. The "standard" modification of C4.1 loading dropped the nominal impedance to 558 ohms, and the cut-off to 42.5 kc. The "modification" of C4.8 loading dropped the nominal impedance to 625 ohms, and the cut-off frequency to 40.5 kc. The standard Type C loading apparatus was used in these installations.

B15 Loading: The single-channel open-wire carrier system with which this type of incidental cable loading is associated is a short-haul transmission system, principally used on 104-mil open-wire pairs. Since the impedance-matching requirements are much more lenient than those for loaded cables in the multi-channel systems a single weight of loading is sufficient.

The cable-capacitance deviations tend to be considerably smaller than with Type C loading, because of "random" splicing at a considerably larger number of intermediate cable splices within the individual loading sections. In consequence, the average amount of capacitance building-out is much smaller (on a percentage basis).

Type J Loading: Because of the higher frequencies involved in the Type J carrier systems the impedance-matching requirements are even more severe than those for the Type C systems. For this reason, a series of three Type J loading systems were made available, as noted in Table XVI.

To make carrier loading economically feasible for 140-kc transmission it was necessary to develop an entirely new type of low-capacitance cable for use with the loading. The new cable makes use of shielded, "spiral-four" units of 16 ga. conductors. The conductors are supported by means of insulating discs at the corners of a square, and the diagonally opposite conductors are associated as working pairs. The spacing between these wires and between them and the quad shields is such as to obtain a mutual capacitance very close to 0.025 mf/mi in the individual carrier pairs. The structural relations between the associated pairs of the individual units are such as to minimize crosstalk coupling. The over-all dimensions of the shielded units are such that not more than 7 or 8 units can be provided in a single cable without using an over-size sheath. In consequence the cable cost per carrier pair is high.

The low-capacitance construction, above described, also results in a much higher ratio of distributed inductance to distributed capacitance than that of paper insulated cables. This makes it necessary to build out the series inductance in a proper ratio to shunt capacitance, when geographical spacing-deviations require the use of corrective building-out adjustments. These capacitance-inductance adjustment devices are considerably more expensive than the relatively simple condensers used in the adjustments on Type C and B loaded circuits. Closer coil-spacing also makes the Type J loading more expensive. All in all, the total cost of the Type J loaded cable pairs is very high relative to that of the Type C loading. Furthermore, the attenuation-reduction feature of the loading, although it is substantial in magnitude per unit length, does not have a large economic value in reducing the number and cost of repeaters required in a complete carrier system. These considerations have limited the use of Type J loading to short cables, seldom more than 0.5 mile long.

In entrance-cable installations of greater length it is common practice to use line filters at the outer end of the cable to separate the "J" frequencies from the lower frequencies. The "J" frequencies are then transmitted to the office over non-loaded pairs terminated at each end in impedance modifying transformers. Separate cable pairs having Type C loading transmit the "C" carrier channels and the voice frequencies.

In such installations a special type of adjustable loading is used on the short "lead-in" cables from the bare open wire to the line filters, when they are installed in "filter huts" at the outer end of the cable. At the filter hut, this loading uses a continuously variable air-core inductance coil of the solenoidal, inductometer type, with which adjustable condensers are associated, one on each side of the coil. This provides a variable impedance loading which is adjustable for a predetermined range of impedances and for a predetermined range of lengths of lead-in cable. Long lead-in cables also require a (non-adjustable) loading unit at their open-wire end. The adjustments for optimum impedance-matching are made in terms of return-losses measured at the open-wire end of the lead-in cable.

Carrier Loading Apparatus

General: The initial, experimental designs used large-size, toroidal-shaped, non-magnetic cores, and finely stranded copper conductors. These coils were nearly as large as the biggest coil shown in the headpiece, (page 149). Their construction made it possible to secure lower effective resistances at the high carrier-frequencies than could be obtained for the same total cost using the best magnetic materials then available. An additional advantage was that their non-magnetic cores could not cause non-linear distortion. This particular advantage assumed critical importance in later years when it became necessary to work to stringent over-all limits of non-linear distortion in the long-haul carrier facilities. As an example of the importance of controlling non-linear distortion, it became necessary during the late 1920's to mount the carrier loading coils in individual, shielding containers in order to prevent the small leakage fields of the toroidal air-core coils from penetrating nearby magnetic parts of the loading coil cases, thereby causing objectionable inter-channel modulation interference.

The satisfactory control of non-linear distortion has made it necessary to continue the use of non-magnetic cores in the carrier loading coils, notwithstanding the large improvements that have been made in magnetic core-materials during the last three decades. These improvements would make it possible to use much smaller coils without objectionably degrading the steady-state transmission performance. However, the hysteresis characteristics of the best available magnetic materials are such that if these materials should be employed it would be necessary to use coils larger and more expensive than the non-magnetic core coils, in order to meet present-day severe limits on allowable intermodulation interference in the Type C telephone systems.

Types C and B Loading

Full Coils: These loading systems use the same general types of full-weight loading coils and terminal loading units, except as regards their electrical parameters. The over-all dimensions of the full-weight coils are about 6⅜ inches in diameter and 2½ inches axial height. The shielding container has an over-all diameter of about 7¾ inches and an axial height of 3¼ inches.

Terminal Loading Units: The terminal loading units which provide the compensated loading terminations, previously mentioned, include a 0.82 fractional-weight series loading coil. This is shunted on the open-wire side (or office side) by a two-element network consisting of a condenser in series with an inductance coil, and located between the two half-windings of the coil. The complete terminal network may be regarded as an extension of half-coil termination. The portion beyond the half-coil point in the series (fractional) coil functions as an impedance corrective-network to produce the approximate "corresponding smooth line" impedance, previously described. The correct electrical proportioning of the elements of this corrective network is very important. The series loading coil is much smaller than the regular full-weight loading coil. Its size and those of the other network-elements are such as to allow the assembly of the complete terminal loading unit in the same size of shielding container as that used for the full-weight loading coils. The standard potting complements range up to 16 coils or terminal units. The loading units are installed at the ends of full-length terminal loading sections. When short cables have only one loading section, terminal loading units are used at each end.

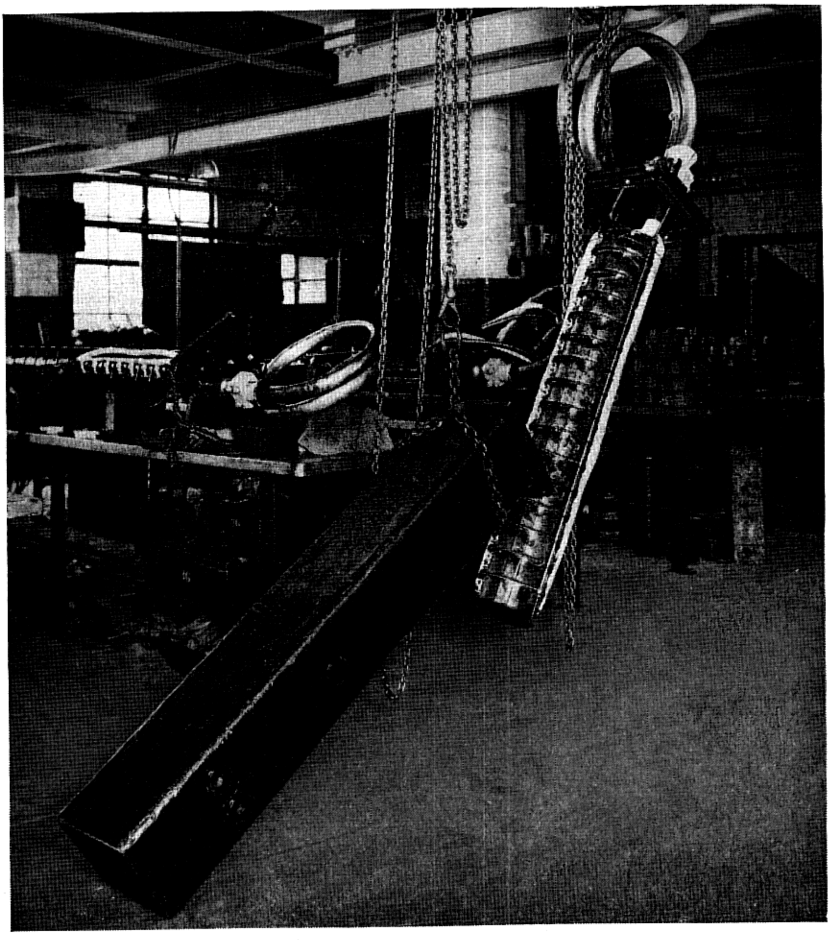

Fig. 30—Various stages in the assembly of toroidal type carrier loading coils. Several coils mounted in their shielding containers are piled on a bench at right center. On the bench at left center, an assembly of coils is being connected to the stub cable conductors. In diagonal center, a completely assembled and cabled complement of 16 coils is ready for placement in a tall, rectangular shaped, cast iron case.

Building-Out Condensers: As previously indicated, building-out capacitance adjustments are extensively required in the control of local impedance irregularities, especially in the installations of the Type C loading.

In the office adjustments of the capacitance of the terminal loading sections, multi-unit paper-insulated condensers are employed. These condensers consist of ten different unit-condensers having six different nominal capacitance values, the ratio between the highest and lowest being of the order of about 30 to 1. Parallel combinations of the individual units are selected by measurement to provide the total required building-out capacitance, with the required precision.

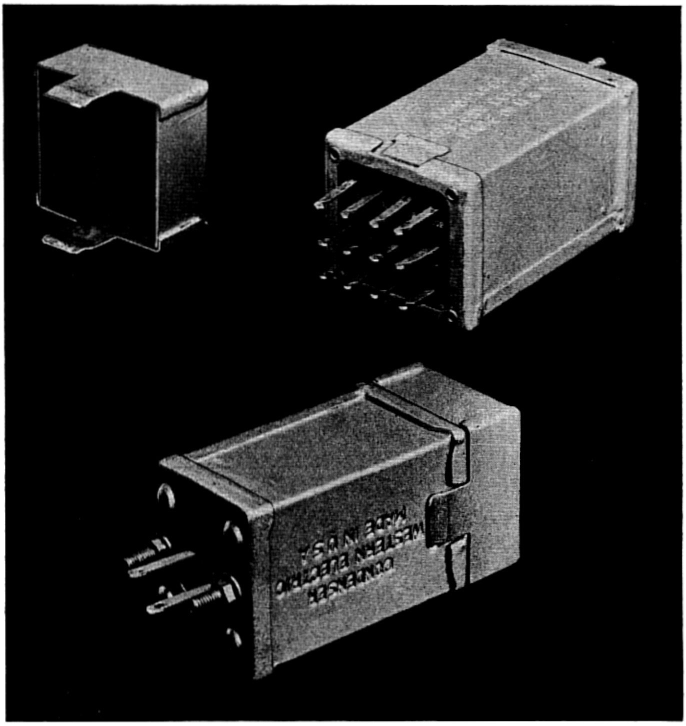

Fig. 31—Multi-unit, paper insulated building-out condenser for use in offices. Upper views show can cover for terminals of individual condensers removed to permit parallel cross connections, to obtain desired total capacitance. Lower view shows the complete assembly. The main terminals of the parallel connection of unit condensers appear at the left end in close proximity to the studs which are used in fastening the condenser case to the office mounting plates.

The intermediate and open-wire terminal loading sections make use of small wire-wound and small mica condensers in the capacitance building-out adjustments. These are usually installed at a cable loading point, placed within the sleeve of the loading splice. The wire-wound condensers consist of parallel, insulated conductors wound in layer formation around small ceramic spools, and impregnated with moisture-resisting compound. Their capacitances are continuously adjustable, by unwinding the outer end of the bifilar winding, and trimming off the excess length. The nominal capacitance values, prior to adjustment, range from 500 mmf to 3000 mmf. In occasional instances where the total required capacitance cannot be provided by the highest-capacitance wire-wound condenser, a non-adjustable mica condenser

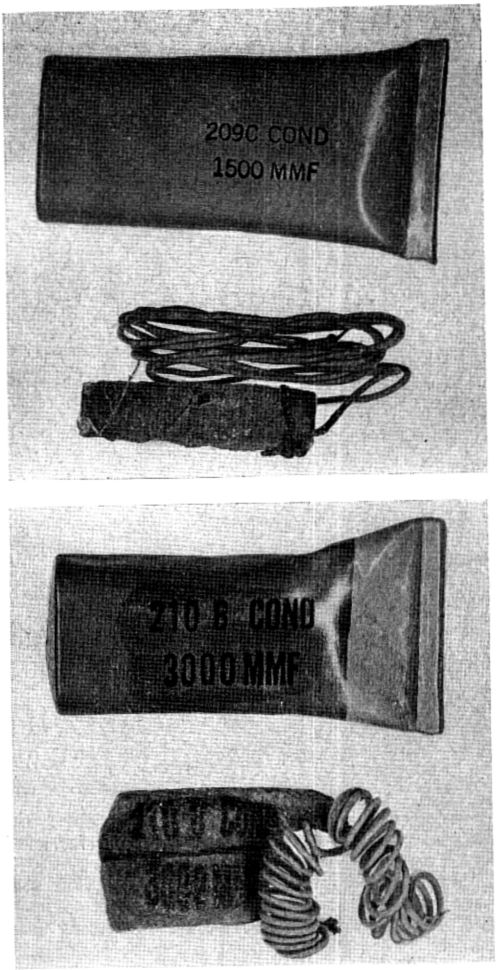

Fig. 32—Building-out condensers designed for installation within carrier loading splice sleeves. Upper view: Continuously adjustable, wire-wound condenser. Lower view: Non-adjustable, mica insulated condenser in small canvas bag. The upper part of each view shows the containers in which the condensers are placed, to protect them from moisture penetration and physical injury during the period intervening between manufacture and installation.

is used in parallel with a wire-wound condenser. In such combinations, the precision capacitance-adjustments are made with the wire-wound condenser. The nominal capacitances of the mica condensers range from 500 mmf to 4500 mmf.

Prior to the development of these small splice-installation types of building-out condensers (during the late 1930's), building-out stub cables were extensively used in the loading-section capacitance adjustments. Several pairs in these stubs were connected in parallel for use with an individual main cable pair. By varying the number of parallel pairs, and the length of the stub cable, the necessary wide range of building-out capacitance was obtained with the required degree of precision.

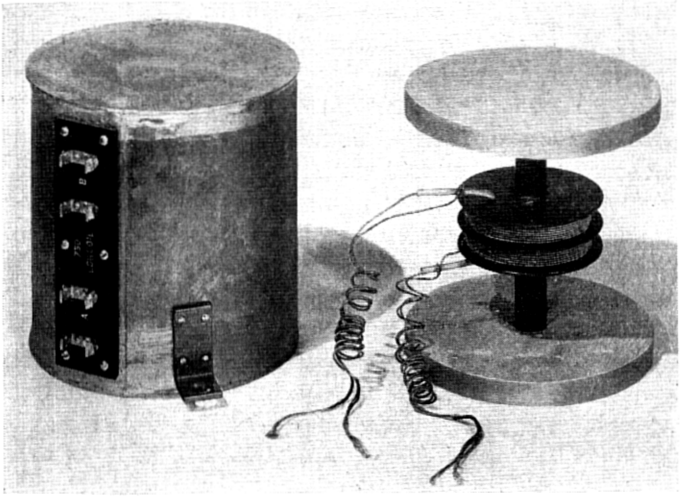

Fig. 33—Solenoidal type non-magnetic core loading coil used for type J carrier loading. At right: Internal coil structure and supports; At left: Copper shielding-container, with coil inside. This view shows the terminal strip on which the coil terminal clips are mounted, and also one of the brackets used in fastening the coil in position in the loading coil cases.

Type J Loading

Full-Weight Loading Coils: The full-weight loading coils are small solenoidal-type, air-core coils having a layer-type winding with a very finely stranded conductor, for control of coil resistance at the high "J" frequencies. The outside diameter and axial length are $2\frac{3}{4}$ inches and 0.5 inch, respectively. To contain the external magnetic field, and control modulation effects and intercoil crosstalk that would otherwise result, a relatively large shielding container is required. Its over-all diameter is about $5\frac{3}{8}$ inches and its axial length about 5$\frac{3}{4}$ inches. The container dimensions are such that the small energy losses in the container-material have unobjectionable reactions upon the frequency-resistance and inductance characteristics of the coils.

A comparison of the effective resistance characteristics of representative toroidal and solenoidal types of carrier loading coils is of interest at this point.

Referring to table XVIII, the more favorable resistance values of the solenoidal coils at 30 kc. and above are due to greater refinements in the stranding of the copper conductors. The relatively small coil size, however, penalizes the low-frequency resistance; this is tolerable in the Type J systems because of the relative unimportance of the voice-frequency circuit.

Terminal Loading Units: For engineering flexibility in the loading layouts, and to minimize the cost of building out the terminal loading sections, two different, equally satisfactory, types of compensated loading terminations[41] are provided for use with Type J carrier loading systems. One of these is electrically analogous to that used with the 30-kc. and 10-kc. loading systems, and is theoretically based on the half-coil termination previously described. Lower inductance and capacitance elements are used because of the much wider carrier frequency-band. The alternative type of loading termination is theoretically based on half-section termination. It involves an extension of the terminal loading section from half-section to about 0.8 full-section and the use of a terminal loading unit which employs a fractional-weight loading coil (approx. 0.32 full-coil inductance) in series with the cable, and which has equal-capacitance condensers connected in parallel across each of the two line windings of the fractional coil.

TABLE XVIII

EFFECTIVE RESISTANCE DATA—REPRESENTATIVE CARRIER LOADING COILS

Type of Coil	Nominal Inductance (mh)	Resistance in ohms per Millihenry at Specified Frequencies in Kilocycles				
		1	10	30	80	140
Toroidal	4.83	0.48	0.58	1.35	—	—
Toroidal	14.75	0.45	0.76	—	—	—
Solenoidal	0.85	0.95	0.95	1.1	1.3	2.0

At the junctions of cable and open wire, the cases which pot the shielded terminal units in pairs are mounted on crossarm fixtures in close proximity to the bare open wire. In office installations, the loading unit assemblies are mounted on individual panels for installation on an equipment bay in close proximity to the associated Type J system line filters.

Building-Out Units: The building-out apparatus used in conjunction with

Type J loading is radically different from that used with the Types C and B loading, primarily because it is usually desirable to include series inductance along with shunt capacitance, in proper proportions, because of the relatively high ratio of distributed inductance to distributed capacitance in the disc-insulated cable with which the loading is used (about 1.4 m.h. inductance and 0.025-mf capacitance, per mile).

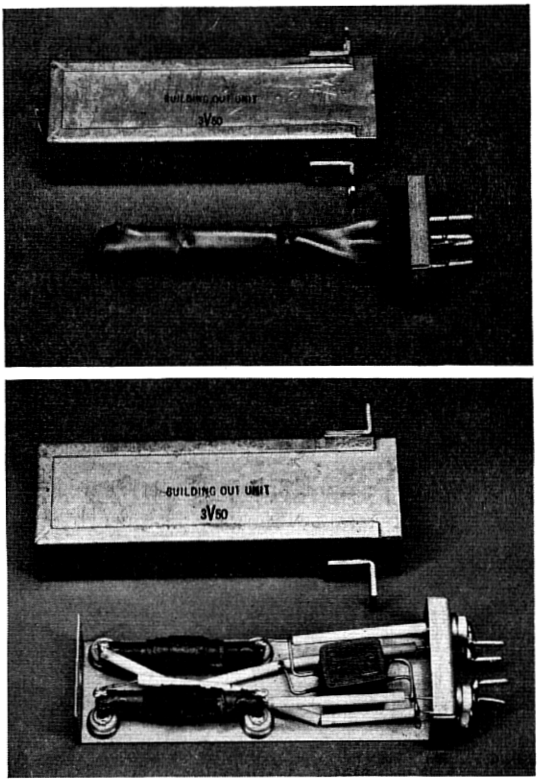

Fig. 34—Building-out units used in electrical adjustments of type J carrier loading sections. Upper View: Continuously-adjustable wire wound unit. Prior to adjustment it has a distributed shunt capacitance of about 275 mmf, and a series inductance of about 16.5 microhenrys; Lower View: Single section non-adjustable artificial line, providing a shunt capacitance of about 250 mmf (single condenser) and a total series inductance of about 15 microhenry (2-coils). This particular unit simulates a length of about 53 ft. of disc-insulated cable pair. Other (multi-section) artificial line units simulate longer lengths of cable pair.

Two types of building-out units are required, (1) a continuously adjustable, wire-wound unit which is used for making precision adjustments, and

(2) a graded series of non-adjustable artificial lines using lumped shunt condensers and lumped series inductances, these "lumps" being electrically small enough to avoid objectionable "lumpiness" effects. The required building-out units are connected in tandem with the loaded cable pair under adjustment.

The adjustable unit consists of a single-layer, bifilar winding on a non-magnetic spool about 4 inches long and $\frac{3}{8}$ inch in diameter. The wiring of the unit to its two pairs of line terminals is such as to provide a series inductive-aiding connection of its line windings when the unit is serially inserted in the cable pair according to plan. The diameter of the spool is chosen to provide the desired ratio of inductance to capacitance per bifilar turn, taking into account the increase of capacitance of the winding which is caused by a wax-dipping process.

The inductance coils used in the non-adjustable units are very small air-core solenoids. Their inductances are adjusted (in manufacture) to have the correct electrical relations with the associated very small, mica-type, shunt condensers.

The complete building-out adjustment for an individual loading section usually involves the use of one or more artificial-line units in tandem with an adjustable unit. The adjustments are made in terms of capacitance measurements, since this procedure automatically provides the required series inductance. Capacitance measurements of the cable pair to be adjusted and of preselected non-adjustable units precede the precision adjustment of the wire-wound unit. This latter is accomplished by removing an integral number of bifilar turns from the winding, to meet the capacitance requirements, after which the shortened winding is reconnected to its main line terminals.

Housing of Building-Out Units: For flexibility in installation, the different electrical sizes of building-out units are "potted" in individual containers of the same size. These are much too large for installation in the loading splice-sleeves. Accordingly, in the cable-type cases for full-weight loading coils, and in the open-wire terminal pole cases for terminal loading units, space is provided in compartments with removable covers for the installation of the cable building-out units. The connections to the main cable circuit are made to terminal strips mounted in these compartments. Thus the installation of the building-out units can be made after the loading coils and loading units have been spliced to the disc-insulated incidental cables. The terminal loading units used at office ends of loaded entrance cables also include space and wiring provision for the installation of building-out units which may be required on the cable side of the terminal loading unit.

(V-C) VOICE FREQUENCY PHANTOM LOADING FOR COMBINATION WITH SIDE CIRCUIT CARRIER LOADING

Voice-frequency, impedance-matching, phantom circuit loading is available for use in coordinated combinations with C4.1, C4.8, and B15 carrier loading in situations where the need for improving the phantom circuit transmission in an incidental cable warrants the use of loading. This brings up a factor not previously mentioned, namely, that the early applications of carrier telephone systems made use of the side circuits of open-wire phantom groups. This is still the general situation, especially with the short-haul, single-channel systems. On the other hand, a substantial fraction of the Type C systems installed since the late 1920's, including those that now work in the frequency-band below a Type J system, uses open-wire pairs that are not arranged for phantom working.

The phantom loading under consideration is limited to voice-frequency operation because of the serious technical difficulties and high costs that would be involved in the satisfactory operation of carrier systems simultaneously on open-wire side circuits and their associated phantoms, and through the incidental cables.

The phantom group full-weight loading units and terminal loading units, which provide the phantom circuit loading, also include carrier loading apparatus for the associated side circuits; i.e., the phantom loading apparatus is not separately available. Thus, when phantom loading is required, it is necessary to engineer and install the loading on a carefully coordinated phantom-group basis.

The "full-coil" inductance of the phantom loading used in association with 30-kc. side circuit loading is 12.8 mh. and the full loading-section capacitance corresponds to that of "E" spacing. Thus its loading designation is E12.8, and the complete phantom-group loading designations become CE4.1-12.8 and CE4.8-12.8. The corresponding phantom circuit loading for use in association with B15 side circuit loading is designated H15, and the phantom group loading is designated BH15-15.

There must be an integral number of side circuit carrier loading sections in each voice-frequency phantom loading section. This ratio is 2 to 1 with *BH* loading. With *CE* loading, it may be 7 or 8 or 9, to 1, depending upon the average amount of building-out in the side circuits. This numerical variability with CE loading results from the fact that the condensers which are used primarily for building out the (carrier) side circuits add negligible capacitance to the phantom. An adjustable four-wire type of condenser is available for capacitance building-out adjustments of the phantom circuit. Depending upon the amount of capacitance building-out used in the carrier side circuits, the average geographical spacing for the full-weight phantom loading units ranges from about one mile to nearly 6000 feet.

The voice-frequency attenuation in the loaded phantom circuits is appreciably lower than that in the associated side circuits. The small transmission impairments which the phantom loading apparatus introduces into the associated carrier side circuits are negligible. The voice-frequency impedance-matches between the loaded cable phantoms and the (non-loaded) open-wire phantoms are nearly as good as those obtained with voice-frequency phantom group loading.

An interesting feature of the phantom loading under discussion is that it uses a 2-coil scheme, with similar phantom coils in each side circuit at each phantom loading point. This scheme is one of several covered by the basic phantom loading patent (*U. S.* No. 980,921; Jan. 10, 1911) but was not used commercially in the Bell System until the late 1920's when very severe side-to-side crosstalk limits became necessary in phantom-group carrier installations for the control of high-frequency intersystem crosstalk. This control was strengthened by shielding the two associated phantom loading coils from one another.

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(*to be concluded*)