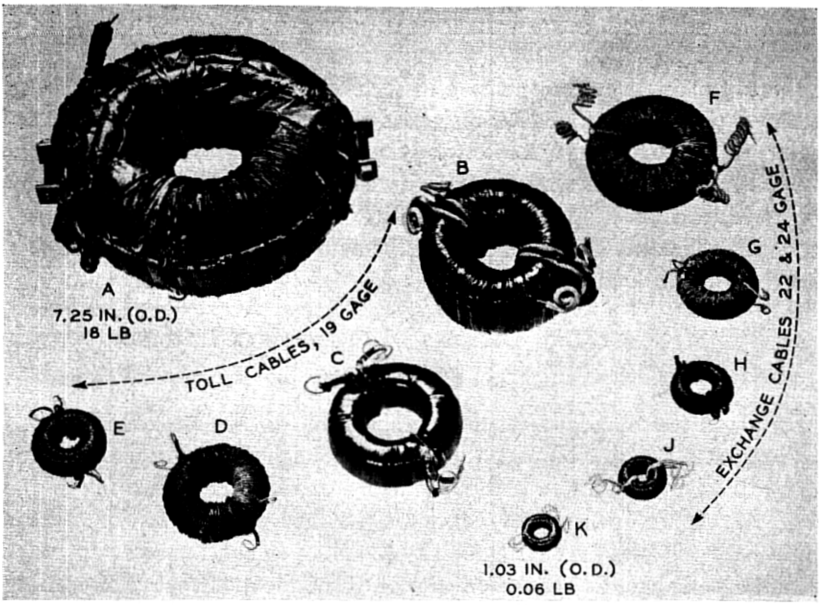

Headpiece.—A panorama of loading coils 1904–1948.

The Evolution of Inductive Loading for Bell System Telephone Facilities

By THOMAS SHAW

(Continued from January 1951 issue)

PART III. LOADING FOR EXCHANGE AREA CABLES

THIS portion of the present review is primarily concerned with non-phantom type of loading on non-repeatered non-quadded cables, since the evolution of exchange area loading has been almost entirely in terms of these facilities.

Phantom working has not been extensively practiced because in general it is not economical on exchange cables. In the occasional long cables where phantoming is economical, the phantom group loading makes use of loading apparatus developed for short-haul, two-wire type toll cable facilities.

The very wide range of impedance characteristics of the many different types of exchange cables (with and without loading, and as influenced by the terminal impedances provided by the many different kinds of subscriber loops and station sets) is such that telephone repeaters are necessarily limited to low gains when used at exchange area switching points. Moreover, it has not been generally feasible to use intermediate repeaters in the lines. Furthermore, the conventional two-wire type of telephone repeater used in the toll plant is quite expensive in relation to the feasible gains in the exchange plant. Consequently, there has not been an extensive use of repeaters in the exchange plant. Looking towards the future, however, the use of a low-cost telephone repeater of an entirely new design (Type E1) is expected to result in a much more extensive use of repeaters, and in consequence some considerable reduction in the demand for the heaviest weights of exchange area loading.

(15) First Two Decades of Commercial Loading

15.1 *General*

For about two decades after the establishment of the first standard cable loading systems (Table II, page 156), medium-weight loading was by far the most extensively used standard on exchange cables. However, a few of the longest exchange cables used heavy-weight loading. Also in some areas there was a moderate use of light-weight loading on short cables.

In the period under discussion almost all of the exchange area loading was installed on 19 ga. cables in situations where, without loading, the circuit lengths and the transmission requirements would have forced the use of much more expensive 13 ga. or 16 ga. cables. Twenty-two gauge cable was available for subscriber cables and for short inter-office trunks. Nineteen gauge non-loaded cable was used on short inter-office trunk cables, however, as it was then more economical than loaded 22 ga. cable, and had a greater supervision and signaling range. In the larger metropolitan areas, loading was much more generally used on trunks to tandem-switching office and on connecting-trunks between local and toll offices, than on the direct inter-office trunks, because of the much more severe transmission limits imposed on the tandem and toll office trunks. In occasional instances, these requirements made it necessary to use loaded 16-ga. circuits. There was also a large use of loading on trunk cables between city tandem offices and suburban local offices. By avoiding the need for 13-ga. cable and by greatly reducing the need for 16-ga. cable in these important fields of use, the introduction of loading made possible very large savings in the first costs of additions to the rapidly expanding new plant, and in the subsequent annual charges.

15.2 *Partial Loading*

In the course of the expansion of exchange area loading a practice of "partial loading" evolved. This is exemplified by the loading of a part of a trunk circuit when it exceeds by a moderate amount the length that would be satisfactory from the transmission standpoint without loading, instead of applying loading to the entire length of the circuit. In effect the partially loaded circuit is a tandem combination of loaded and non-loaded circuits, with the loaded part preferably located near the center. The purpose is to reduce plant cost by restricting the use of loading in individual circuits to about the minimum amount that would be necessary to meet the transmission limits set up as objectives in plant design. In these practices, certain minimum limits regarding the number of loads per circuit were worked to on the basis of engineering experience, different limits being applied in different operating areas.

15.3 *Compressed Iron-Powder Core Loading Coils*

The first important change in loading coil standards for exchange area loading occurred during 1916, immediately following the successful development of the compressed annealed, powdered-iron core-material[13] described on pages 167–170. In general, the coils that used this new core-material were much better suited to the requirements of exchange facilities than to those of toll cables. The old standard 95-permeability iron-wire core coils, Codes 506, 507, and 508, were superseded as standards for new plant by the new Nos. 573, 575, and 574 loading coils, respectively. The new coils had closely similar over-all dimensions to those of the superseded coils, and were substantially equivalent, or slightly better, with respect to steady-state transmission properties. They were greatly superior with respect to their resistance to permanent or quasi-permanent magnetization by strong currents that might flow through their windings in consequence of accidental grounds on d-c signaling circuits, or from other external causes, including power-line crosses and lightning surges.

For a period of several years, the loading practices with the new coils followed those which had evolved in the use of the older coils.

(16) Development of Cheaper Cables for Exchange Areas and Standardization of New Loading Systems for Them

16.1 *The New Cables*

During the early 1920's new, cheaper types of non-quadded cable began to be used extensively in the exchange area plant. These resulted from the continuing development work to reduce plant costs. By including design features that made them suitable from the crosstalk standpoint for the application of loading, the economies inherent in the use of loading substantially augmented the large economies that directly resulted from the lower costs of the cables. These design improvements included the staggered pair-twist construction and other features previously applied to the 0.066

mf/mi 19 and 16-gauge cables, Codes TB and TH, respectively, for which the early loading standards had been originally established.

With respect to the use of loading the most important of the new cables, above referred to, were: (a) a 455-pair,[q] 19 ga. cable, Code BNB, having a mutual capacitance of about 0.085 mf/mi, and (b) a 909-pair,[q] 22 ga. cable, Code SA, having a mutual capacitance of about 0.083 mf/mi. Also there was a 1212-pair 24 ga. cable having a mutual capacitance of about 0.079 mf/mi. Fractional-size cables having these properties became available subsequently. The 24 ga. cable did not become an important field for the economical use of loading until the late 1920's, following the development of the low-cost, compressed, permalloy-powder core loading coils described in Section 19.

Table VII
Loaded High-Capacitance Cables

Type of[1] Cable	Weight[2] of Loading (ohms)	Theoretical Cut-off Frequency (cycles)	Attenuation Loss at 800 cycles (db/mi)	Nominal Impedance (ohms)
19BNB	Medium-Heavy[2]	2450	0.31	1350
	Heavy	2050	0.29	1600
	Light-Medium[2]	2300	0.45	980
	Medium	2025	0.41	1110
	(Non-Loaded)		(1.15)	
22SA	Light-Medium	2320	0.77	980
	Medium	2040	0.68	1120
	(Non-Loaded)		(1.63)	

[1] In the tabulated data, the capacitance of 19BNB and 22SA cables are assumed to be 0.085 and 0.083 mf/mi, respectively, and their resistance 85 and 170 ohms per loop mile at 68° F.
[2] The first word in the compound designations applies to the coil inductance ("Medium" = .175 mh; and "Light" = 0.135 mh). The second word in the compound designation applies to the coil spacing ("Heavy" = 1.14 mi; and "Medium" = 1.66 mi).

16.2 *New Loading Arrangements*

In order to avoid an objectionable degradation in transmission service, new loading systems were standardized during 1922 for use on the high-capacitance 19 ga. and 22 ga. cables, above mentioned. These involved the use of the standard medium loading coil (Code 574, inductance 175 mh) at "heavy" spacing, and of the standard light loading coil (Code 575, inductance 135 mh) at "medium" loading spacing. Initially, these new loading systems were known as "medium-heavy" and "light-medium" loading.

[q] The largest number of pairs previously available in 19 and 22 ga. cables were 303 and 606, respectively.

Their installed costs were about the same as those of standard heavy and medium loading, respectively. The special importance and significance of these new loading systems was that their use on the higher capacitance cables avoided a degradation in the loading cut-off standards and the objectionable impairments in transmission intelligibility that would otherwise have resulted. The use of lower inductances at standard spacing, in order to comply with the cut-off standards without raising costs, resulted in a reduction of nominal impedance which was desirable and an increase in the attenuation which was accepted as tolerable, under the circumstances. This decision on the new loading systems was largely influenced by certain fundamental transmission-studies then under way which indicated that it would eventually be desirable to adopt much higher cut-off frequency standards, subsequently described.

Table VII compares certain transmission properties of "medium-heavy" and "light-medium" loading on the high-capacitance cables with those which would have resulted from the use of standard medium and heavy loading.

(17) First Increase in Minimum Cut-Off Frequency for Loaded Exchange Area Cables

17.1 *General*

During 1924 there occurred the first major improvement in loading standards for exchange area cables, consisting of an increase in the minimum cut-off frequency from about 2300 cycles to about 2800 cycles per second. This decision implemented the conclusions reached in comprehensive fundamental theoretical and experimental studies of exchange area transmission that got well under way during the early 1920's. The improved loading systems initially involved the use of available types of 135 and 175 mh loading coils at spacings shorter than those previously used with these coils, and the use of new 88 mh loading coils much smaller in dimension and much lower in cost than the 135 and 175 mh loading coils. The new 88 mh loading inductance eventually became the most extensively used inductance value in exchange area loading.

17.2 *New Technique for Computing Intelligibility Indices for Complete Circuits*

In the theoretical aspects of the fundamental study, above referred to, use was made of a new technique developed by Dr. Harvey Fletcher for computing the articulation index of complete telephone transmission systems, taking into account the effects of attenuation loss and circuit distortion in the line, the subscriber loops and station sets, the effects of sidetone in the station sets, and allowing for the masking effects of line noise and room noise.[r] The new technique was based on fundamental studies of speech and hearing, including a very extensive series of articulation tests on different combinations of lines and loops and telephone sets, in which the line portions were modified by electric wave filters to transmit various frequency-band widths, and distortionless attenuators controlled the line loss. Different representative types of subscriber loops were included in the tests. The then standard deskset telephones were used (No. 337 transmitter, No. 144 receiver, and 46 induction coil) and also special telephone sets using experimental types of transmitters and receivers having ideal, flat, frequency-response characteristics. In comparing complete systems having different types of lines, but otherwise similar, the computed articulation-ratings agreed sufficiently closely with the ratings determined from tests to warrant substantial confidence in the experimental use of the computation technique in the exploratory loading development studies.

17.3 *New Higher Cut-off Loading Systems*

The theoretical studies as applied to an exchange plant using the standard deskset telephones showed that a desirable improvement in the transmission intelligibility of complete connections could be obtained by using the new higher cut-off loading systems which are described in general terms in Table VIII. As discussed later, large economies also resulted in the design of new plant, and in the rearrangement of old plant. The loading designations used in the table are in accordance with a simplified system of designations which was adopted in 1923. The letter-component is a symbol for the spacing, and the number signifies the inductance. Prior to the introduction of these new loading standards, medium loading-spacing (M) was about 8775 ft. It was changed to 9000 ft. to facilitate coordination with the other types of loading in the layout of the cable plant. The "D" spacing was an entirely new spacing.

The decision to standardize the particular loading systems of Table VIII naturally involved extensive plant cost-transmission studies. These were directed to determining the maximum utilization of the new cheaper cables previously mentioned, and the most advantageous ultimate uses of the higher-grade, more expensive cables already in use. Practical considerations of economy dictated that the new series of loading standards should include systems which could use available loading coils and existing loading vaults in the important underground cable plant. These matters were also of great importance in the gradual rearrangement of the existing exchange area loading at a minimum expense to comply with the new cut-off standards.

While the improvement in intelligibility was one of the factors influenc-

[r] Comprehensive information on Dr. Fletcher's researches is given in Reference (33).

ing the design of the new loading systems, the engineering of the exchange cable plant continued for some time on the customary volume-efficiency basis, and the standards of over-all attenuation in the trunks were the same as before, in the use of the older loading systems. The improvement in intelligibility previously stressed was directly due to the ability of the new loading systems to transmit efficiently a band of important high-frequency overtones which were suppressed by the old standard loading systems. The subscriber services directly benefited from the improved transmission quality.

Used in the foregoing manner, the new loading systems also yielded large economies in the first costs of new plant by extending the transmission range of the cheaper types of cables. In this respect, the M88 system was by far the most important of the new standards, since it made feasible the use of loaded 22 ga. cable for short trunks, in place of non-loaded 19 ga.

TABLE VIII
IMPROVED EXCHANGE AREA LOADING STANDARDS

Loading Designation	Loading Spacing (feet)	Coil Inductance (mh)	Approximate Cut-off Frequency*	
			High-Capacitance Cables (cycles)	Low-Capacitance Cables (cycles)
M88	9000	88	2900	3200
H135	6000	135	2800	3200
H175	6000	175	Not recommended	2800
D175	4500	175	2900	3200

* These particular figures take 0.083 mf/mi and 0.066 mf/mi as representative values for high-capacitance and low-capacitance cables, respectively.

cable, and the aggregate length of the short trunks is a large fraction of the total exchange trunk mileage. The special economic importance of 22 ga. cable loading received recognition in the development of much cheaper loading coils which are described later on.

The more expensive new H-spaced loading was advantageous on the longer cables, and in shorter cables when lower transmission equivalents were necessary. H175 loading was important because of its suitability for use on low-capacitance cables.

The D175 system provided a field for the reuse of 175 mh loading coils that were displaced in the course of the plant rearrangements, previously mentioned. Also, it facilitated the conversion of old M175 facilities to meet the new cut-off standards, and with decreased attenuation. This conversion procedure involved the introduction of additional 175 mh loading coils, at or near the electrical centers of the old medium loading sections.

Some typical performance characteristics of the new loading systems on exchange area cables are given in Table IX. The tabulation, in general, is in the sequence of ascending costs. Although loaded 24 ga. cable is superior to non-loaded 22 ga. cable from the transmission standpoint, it was not sufficiently cheaper (when using iron-dust core loading coils) to warrant its general use. However, under some special circumstances involving large complements of the new coils, loaded 24 ga. cable could be proved in.

In the design of the cable plant, the signaling characteristics of the facilities of course had to be taken into account along with the transmission characteristics. In some situations the total costs could be reduced by using

TABLE IX
TRANSMISSION CHARACTERISTICS OF TYPICAL EXCHANGE AREA TRUNKS

Cable		Loading System	Theoretical Cut-off Freq. (cycles)	Nominal Impedance (ohms)	Attenuation at 100 cycles (db/mi)
Conductor Gauge	Capacitance (mf/mi)				
24	0.084	M88	2900	900	1.42
22	0.082	M88	2900	990	0.92
"	"	H135	2800	1300	0.63
"	"	D175	2900	1690	0.51
22	0.073	M88	3000	950	0.87
19	0.084	M88	2900	860	0.49
"	"	H135	2800	1280	0.34
"	"	D175	2800	1680	0.28
19	0.066	M88	3200	950	0.44
"	"	H135	3200	1420	0.30
"	"	H175	2800	1640	0.27
"	"	D175	3200	1860	0.25
16	0.066	M88	3200	960	0.24

a more expensive grade of circuit that allows the use of less expensive signaling equipment.

(18) LOADING COILS FOR HIGHER CUT-OFF LOADING SYSTEMS

18.1 *New Small-Size Coils for M88 Loading*

Preliminary design studies of cheaper and smaller loading coils for use on 22 ga. cables started well in advance of the decision to standardize M88 loading. It was realized that the maximum possible economies would result from a two-stage development plan, in which the first stage would consist of an improvised "stop-gap" design using available standard core-rings and simple modifications of existing standard loading coil cases, and the second step would be an entirely new design, having approximately optimum proportions as regards transmission and cost features in the expected wide use on 22 ga. cables. For optimum economies in potting and installation, entirely new types of loading coil cases would be required for this design.

In conformity with this plan, the temporary standard 88 mh loading coil, Code 601, became commercially available late in 1924, and its successor design, Code 602, approximately nine months later.

The 601 coil used a 2-ring core of compressed, unannealed, powdered iron. The over-all coil dimensions were such that 200 coils could be potted in the largest size of exchange area loading coil case then standard, which had originally been developed for potting 98 coils of the 574 and 575 coil-size. A larger size of case which potted toll cable loading coils was modified to pot 300 No. 601 coils. During 1924 and 1925, while the production of the 602 coil was being built up to meet the large demand for H88 loading, over 80,000 No. 601 coils were manufactured.

The 602 coil also used compressed, unannealed, powdered-iron cores, and it had much better proportions of axial length to diameter. Similar sizes of potting complements were standardized in the new cases. Coil F in the headpiece is a 602 coil. (Coil F in relation to Coil B shows the size difference for the contemporary standard coils designed for 22 ga. and 19 ga. cables, respectively.)

Because of their smaller size, the 601 and 602 coils had a higher ratio of resistance to inductance than the older coils which had been developed for use on lower resistance cables.

Making more efficient use of core material and copper, and using smaller-size, higher-speed winding machines, the 602 coil was substantially cheaper than the 601 coil, which in turn was considerably cheaper than the prior standard cable loading coils. In both instances, substantial economies in potting and installation costs also resulted.

18.2 *Coils for H135 Loading*

Further consideration of the transmission economics of the new H135 loading led, about the middle of 1925, to a decision to develop a new 135 mh loading coil using the same core and the same types of loading coil cases as for the 602 coil. Under the code No. 603, this coil became available for commercial service during 1926.

The 603 coil was intended for use on 22 ga. and 19 ga. cables, and yielded large economies during 1926–27 in these fields. The larger-size 575 coil was temporarily continued as a standard design, for use on long 19 and 16 ga. trunks where a better coil than the 603 coil could be justified. With this coil, the attentuation was about 0.03 db/mi better than that obtainable with the 603 coil.

18.3 *Coils for H175 and D175 Loading*

Because of the small relative demand for new coils for these types of loading, and because the 574 coil was fairly satisfactory in transmission-cost relations for the relatively expensive types of facilities involved, the 574 coil was temporarily continued as standard for the 175 mh loading system. *General:* Looking backwards, the classification "temporary standard" for the 574 and 575 coils as used in the higher cut-off loading systems is appropriate, and would also be appropriate for the 602 and 603 coils, by virtue of the fact that all of these coils were superseded as standard during 1927 by the new series of compressed, permalloy-powder core loading coils which are described below. A brief summary of some electrical and dimensional characteristics of the "iron-dust" core coils is given in Table X, prior to undertaking the discussion of the very much more important permalloy-

TABLE X
IRON DUST CORE LOADING COILS USED IN HIGHER CUT-OFF LOADING SYSTEMS

Coil Code No.	Nominal Inductance (mh)	Resistances—Ohms		Approx. Over-all Dimensions—Inches	
		d-c	1000 cycles	Diam.	Ax. Height
601	88	9.1	10.2	4.5	1
602	88	8.4	9.5	3.5	1.12
603	135	12.8	14.0	"	"
575	135	3.7	5.5	4.5	2.1
574	175	4.5	7.0	"	"

core coil development. The resistance values include 0.5 ohm for the 22 ga stub cables for the loading coil cases in which the 601, 602, and 603 coils were potted, and 0.2 ohm for the 19 ga. stubs used with the older coils.

(19) COMPRESSED PERMALLOY-POWDER CORE EXCHANGE AREA CABLE LOADING COILS

19.1 *General*

Since the general characteristics of the improved magnetic core-material[24] and the circumstances attending its development were briefly described on page 183, it is unnecessary to repeat this discussion as a part of the review of the evolution of exchange area loading. It is desirable, however, to call attention to the fact that the exchange area loading coils were given priority over the toll cable coils in the commercial exploitation of the greatly improved core-material, for two important reasons. In the first place, the service requirements in exchange area cables were much less complex and much less severe than those in the long distance toll cables and, in consequence of the smaller amount of development effort required, the large economies inherent in the use of the improved core-material could begin to be realized at a much earlier date. This was important because of the rapidly increasing demand for loading during the late 1920's. Secondly, by starting quantity production of the core material for use in the exchange area coils, the factory built up experience in the control of the many complicated new processes that were essential to the performance results which were particularly desirable in the toll cable coils. Also, knowing what could be expected from the commercial production of the core-material, the design engineers were in a better position to specify the most advantageous core-proportions in the final toll cable designs.

The large demand for M88 loading, relative to that for the heavier weights of exchange area loading, resulted in the concentration of the early development work on smaller 88 mh loading coils.

A comparison of the electrical and dimensional characteristics of the new permalloy-core coils is given in Table XI (page 460), following the general description of the new designs.

19.2 *612 Coil for M88 Loading*

The new permalloy-core 612 coil became available for a trial installation late in 1926 and quantity production built up to a new high level for exchange area coils during 1927.

The size reduction made possible by the favorable permalloy characteristics of high permeability in combination with low losses was carried to a greater degree in the 612 coil than was feasible in the toll cable designs. It was somewhat less than one-fourth as large as the 602 coil in volume and weight. Coil G in the headpiece is a 612 coil.

The careful cost-equilibrium study that was made to determine the commercial design requirements resulted in the 612 coil having a slightly smaller d-c resistance than the 602 coil. The resistance-frequency characteristics were sufficiently close to those of the 602 coil to warrant the acceptance of the new coil as an "equivalent" design, with respect to plant engineering.

The development of the 612 coil involved new design and manufacturing problems beyond those encountered in the design and manufacture of the improved core-material. To make feasible the small size of the toroidal core, an entirely new type of winding machine suitable for high-speed winding to an inner diameter of about 0.75 inch had to be made available. The use of small cores also made it desirable to have a better space-factor in the copper winding. This was achieved by using a composite (conductor) insulation of black enamel and single cotton, instead of the double serving of cotton employed in previous, much larger, designs. Subsequently this change was incorporated in the designs of all small loading coils.

The large size-reduction relative to the 602 coil resulted in substantial reductions in coil costs, notwithstanding the higher (per unit volume) cost of the improved core-material due to the more complicated processes and the high cost ratio of nickel to iron. The cost reduction in the coils was accompanied by a large reduction in the potting and installation costs. When the coils were first standardized, the potting complements were similar to those for the 602 coils but the cases were much smaller. Later on, larger-

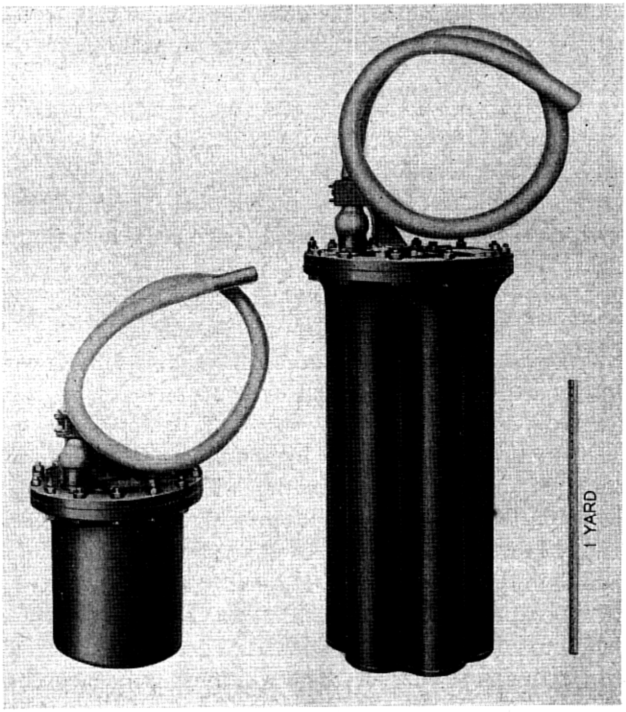

Fig. 16—Case size reduction resulting from coil size reduction. Cast iron cases containing 200 88-mh. coils. At left: No. 612 (permalloy core) coils; total weight potted coils, 725 lbs. At right: No. 602 (hard iron dust core) coils; total weight potted coils, 1750 lbs.

size cases potting complements of 450, 600, and 900 coils were standardized. Using cases no larger than the previous maximum-size cases, potting complements ranging up to about 2000 coils could have been made available, if a demand for them should have arisen. Incidentally, the demand for the 900-coil cases was small. The extensively used complements in the range 300–600 coils proved to have a large value in relieving serious congestion in the underground loading-vaults in metropolitan areas, notably New York, and in general made it feasible to provide smaller-sized loading vaults for new installations.

It is important to note that the small size and reduced cost of potted 612 coils led to a general use of M88 loading on non-quadded 24 ga. cables, thus permitting additional cost-reductions in the cable plant. Such facilities were cheaper than non-loaded 22 ga. cables, and had a greater transmission range—subject in some instances to signaling restrictions.

It is also of interest that the 612 coil was the first standard loading coil sufficiently small to be placeable within loading splice-sleeves. When only a few coils were required at a particular point, this method of installation permitted worthwhile economies as compared with the use of conventional types of loading coil cases and stub cables.

The 612 coil remained standard for about 10 years, during which period more than a million of them were manufactured. It had a much greater economic impact on the fundamental design of the exchange area plant than any other individual loading coil, notwithstanding the fact that the present standard 88 mh loading coil, subsequently described, has already been used in much larger quantities.

19.3 { *623 Coils for H135 Loading* / *624 Coils for H175 and D175 Loading* }

During the development of the 603 (135 mh) iron-dust core coil described in subdivision 18.2, it was fully appreciated from the transmission cost equilibrium standpoint that a higher grade design would be warranted if it could be obtained at a moderate increase in cost. Since this would have meant a new coil-size intermediate between that of the 603 (and 602) coil and the much larger 575 coil, a decision was made to use the 602 core, thereby obtaining quick savings.

It was appreciated also that a less efficient loading coil than the 574 (175 mh) coil would be good enough for H175 and D175 loading, if it could be obtained with a sufficiently large cost-reduction.

These objectives were carefully considered from the cost-equilibrium standpoint. It turned out that the use of a permalloy core of the same size as the iron-dust core of the 602 and 603 coils would come close to an ideal economic solution of the service requirements for the heavier weights of exchange area loading, and accordingly the use of this size of core and coil was decided upon. An important additional, immediate, economic advantage was that the new coils could be potted in the cases originally developed for the 602 and 603 coils, thus minimizing new potting developments. The demand for the heavier weights of loading could be met with smaller-sized complements than those frequently required for M88 loading, and consequently no new larger sizes of cases were necessary.

Compared with the 603 coil, the new 613 (135 mh) loading coil gave a material improvement in transmission, the value of which was large relative to the small cost-increase involved. On the other hand, the 613 coil was nearly as good from the transmission standpoint as the much larger 575 coil and the cost per potted coil was about one-third lower. A substantially similar comparison applied between the new 614 (175 mh) coil and the old standard 574 coil.

During the late 1920's the high demands for new facilities and the plant rearrangements to meet the higher cut-off loading standards combined to require a somewhat larger total quantity of 613 and 614 than 612 coils. The importance of the higher inductance coils dropped substantially after 1930, especially that for the 175 mh loading.

19.4 *618 (44 mh) and 619 (22 mh) Loading Coils*

These low-inductance coils, using the same core as the 612 coil and the same types of cases, became available during 1931, primarily for use in correcting spacing irregularities in loaded exchange area trunks.

TABLE XI

COMPRESSED PERMALLOY-POWDER CORE EXCHANGE AREA LOADING COILS

Coil Code No.	Nominal Inductance (mh)	Resistances—Ohms		Approx. Over-all Dimensions—Inches	
		d-c	1000 cycles	Diam.	Ax. Height
612	88	8.5	9.3	2.0	0.75
618	44	4.9	5.2	"	"
619	22	2.5	2.7	"	"
613	135	5.5	6.8	3.5	1.10
614	175	8.0	9.7	"	"
615	250	12.0	14.0	"	"

19.5 *Subscriber-Loop Loading*

During 1933 the practice of using the 618 (44 mh) coil at M or H-spacing got a good start on long subscriber loops. This new field for loading had been under study for some time, and has greatly increased in importance during the intervening years. In many instances, this practice makes it feasible to meet the transmission limits on long loops in available 19 or 22 ga. subscriber cables, when otherwise it would be necessary to use local battery telephone sets, or install more expensive cable plant, or use relatively expensive telephone repeaters. Under some conditions, the 612 (88 mh) coil was also used for loading long loops.

19.6 *Coil Data*

Some detailed data regarding the new coils above described are given in Table XI. The resistance data include 0.5 ohm for 22 ga. stub cables. The 615 coil was made available primarily for emergency replacement use in old plant using 250 mh loading.

(20) Second Increase in Minimum Cut-Off Frequency For Loaded Exchange Cables

20.1 *General*

During 1932 there became effective a second increase in the minimum cut-off frequency standards for loaded exchange trunks, which in terms of frequency ratio was about as large as the first change that was decided upon in 1924, the successive (minimum) standards being 2300, 2800, and 3500 cycles.

The new cut-off frequency standard was implemented by the standardization of a graded series of higher-impedance, lower-attenuation loading systems described below. These made it possible to secure a substantial reduction in the over-all costs of the exchange area trunks by permitting a more extensive use of the cheaper types of cables, even though the cost of the loading per mile became greater in consequence of the closer coil spacing. The improved transmission characteristics, i.e., lower attenuation and reduced frequency-distortion, resulted from the use of standard coils at substantially closer spacings.

The above mentioned change in the relations between cable costs and loading costs recognized a considerable departure from plant cost equilibrium that came about during the late 1920's and early 1930's in consequence of the substantial reduction in loading costs that was realized by extensive use of the permalloy-core coils previously described. Moreover, the prospect of further savings was an encouraging factor in the adoption of the new standards.

20.2 *The New Loading Systems*

The general characteristics of the new standard loading systems are given in Table XII. The letters H and B in the loading designations signify 6000 and 3000-ft. spacings. In the cable designations, "high" and "low" capacitance have the same significance as in Table VIII.

Some typical attenuation data are given in Table XIII, for comparison with attenuation data given in Table IX. The attenuation comparison by itself, however, is not a completely adequate comparison since it ignores the distortion-reduction advantage of the wider frequency-band transmitted by standards of transmission-service performance. On the other hand, the penalty ratings for trunks using the old standard types of loading having lower cut-off frequencies range from nearly 1 db to 4 db or more, depending primarily upon the theoretical cut-off frequency.

From the foregoing, it can be understood that the distortion penalty in old cables having old types of low cut-off loading may be a substantial fraction of the total allowable effective transmission loss in the trunk.

(21) Compressed Molybdenum-Permalloy Powder Core Exchange Area Loading Coils

21.1 *The Improved Core Material*[26]

A brief general description of the new compressed molybdenum-permalloy powder core-material is given under this heading in Section 11.1.

The low-inductance exchange area loading coils described below were given priority in the commercial exploitation of the improved core-material in message circuit loading.

21.2 *622 (88 mh), 628 (44 mh), and 629 (22 mh) Loading Coils*

The preliminary development-activity was in terms of 88 mh loading, on account of the added importance of this loading which resulted from the adoption of the higher cut-off loading-standards, described in the preceding pages.

The transmission engineering studies and the cost-equilibrium design studies resulted in a decision to reduce the coil size as much as possible, without degrading transmission performance.

A size reduction of about 60%, relative to the 612 permalloy-core coil, proved to be feasible. The new coil, Code 622, was closely equivalent to the 612 coil. Actually it had somewhat better frequency-resistance characteristics, because of the superior eddy-current loss characteristics of the improved core-material. On the other hand it was not quite so good as the 612 coil with respect to susceptibility to magnetization by superposed d-c signaling currents. Coil H in the headpiece is a 622 coil (Coil G being its standard predecessor, the 612).

The ability to make so small a molybdenum-permalloy core coil as the 622 coil, without degrading transmission, was principally due to the ingenuity of the factory engineers in devising an entirely new, high-speed, winding machine capable of winding a small toroidal core to a finished inside diameter of 0.5″—an achievement which seemed impossible a decade earlier when the 612 coil was developed. The use of an enamel-film insulation on the core ring, in place of the overlapping fabric-tape employed on larger and older designs, was a favorable factor in the more efficient utilization of the core winding-space. Although the percentage cost-reduction was not large, the aggregate savings were large in consequence of the substantial amount of new loading required. The reductions in potting costs of the new smaller-size loading coil cases, and the savings in installation costs were important factors in the total savings.

The new 44 mh and 22 mh loading coils, Code 628 and 629 respectively, used the cores designed for the 622 coil. They were substantially equivalent in transmission performance to the 618 and 619 coils. The new 628 (44 mh) coil became quite important in subscriber-loop loading. Over the years during which they remained standard, the average annual production was about one-fourth that of the 622 coil. Relatively very few 629 coils were used.

21.3 *623 (135 mh), 624 (175 mh), and 625 (250 mh) Loading Coils*

The new 135 mh coil had about the same size and efficiency relations to the 613 coil, as those that existed between the new and old 88 mh loading coils (612 and 622). The entirely new size of core which was made available for it was also used in the relatively unimportant, new higher-inductance coils. The winding machine developed for the 612 coil was used in winding the coils under discussion.

The over-all dimensions of the new coils were intermediate between those of Coils H and G in the headpiece, being closer to H than to G. The expected demand for the 623, 624, and 625 coils was not large enough to warrant the development of an entirely new series of loading coil cases especially for these coils. As these non-phantom coils were being developed concurrently with the molybdenum-permalloy core side circuit and phantom circuit coils for toll cables, i.e., the M-type loading units described in Section 11.2, arrangements were made for potting them in the new cases that were developed for potting the loading units. However, different assembly arrangements and stub cables were required. Since the non-phantom coils were only about 20% smaller than the coil components of the loading units, this potting procedure was not unduly expensive for the non-phantom coils.

The percentage savings resulting from the development of the 623, 624, and 625 coils was larger than that yielded by the 622, 628, and 629 coils but the aggregate savings were much smaller in consequence of the much lower demand for the higher-inductance coils.

(22) Redesign of Exchange Area Loading Coils to Take Advantage of Use of Formex Insulation on Winding Conductors

22.1 *General*

During the late 1930's a greatly improved type of enamel insulation (developed by the General Electric Co.) known as "Formex" became commercially available for use on small copper wires. Studies of its application to telephone apparatus indicated that further, worth-while size-reductions in loading coils could be achieved by virtue of the greatly superior space-factor of this insulation, relative to that of the combination of cotton and enamel insulation that had been used for more than a decade in small loading coils. Another advantageous possibility was the reduction of the coil resistance by employing a larger size of conductor to utilize the winding space saved by the thinner conductor-insulation.

Although the better space efficiency of the Formex conductor insulation was a contributory factor in the further size reduction of the smallest loading coils, the size-reduction achievement under discussion was mainly dependent upon the development and use of a new type of winding machine.

The new non-phantom type coils that resulted from the redesign work are described below under appropriate headings. They all use compressed molybdenum-permalloy powder cores. Additional information regarding them is given in an A.I.E.E. paper,[30] previously referred to. In Table XIV (page 471) electrical and dimensional data are given on the individual coils, along with corresponding data on the designs which they superseded.

22.2 *632 (88 mh), 638 (44 mh), and 639 (22 mh) Formex Insulated Coils*

The large current and expected future demand for the low-inductance exchange area coils, relative to that for all other types of loading coils, resulted in the concentration of the initial redesign efforts on these types of coils.

In the redesign of the low-inductance coils, it was decided to reduce the coil size as far as possible without degrading transmission performance. An important secondary requirement was that the new design should not be more susceptible to magnetization by superposed signaling currents than the current standard coils, previously described.

Before these transmission requirements were finally set, the experimental design studies had shown that worth-while cost-reductions could probably be secured by using improved winding machines capable of winding the coils to a new size-limit of 0.35-inch finished inside diameter. In due course, the very difficult winding-machine design problem was solved by the factory engineers. The above stated transmission requirements made it necessary to use the same amount of core material (molybdenum-permalloy) as that used in the 622, 628, and 629 coils, previously described. The coil design problem was solved by a redesign of the core to obtain a shorter magnetic circuit having a larger cross-section, keeping the same volume. (The inside and outside diameters were reduced and the axial height increased.) This permitted about a 20% reduction in the over-all volume and weight of the wound coils, without appreciable degradation in transmission performance.

Altogether, this was a remarkable achievement of the apparatus development and factory engineers.

The new coils had code designations 10 digits higher than those of the coils which they superseded, beginning on a quantity production basis during 1942. The very extensively used 632 coil became widely known as the "wedding-ring" coil. It appears as Coil J in the headpiece.

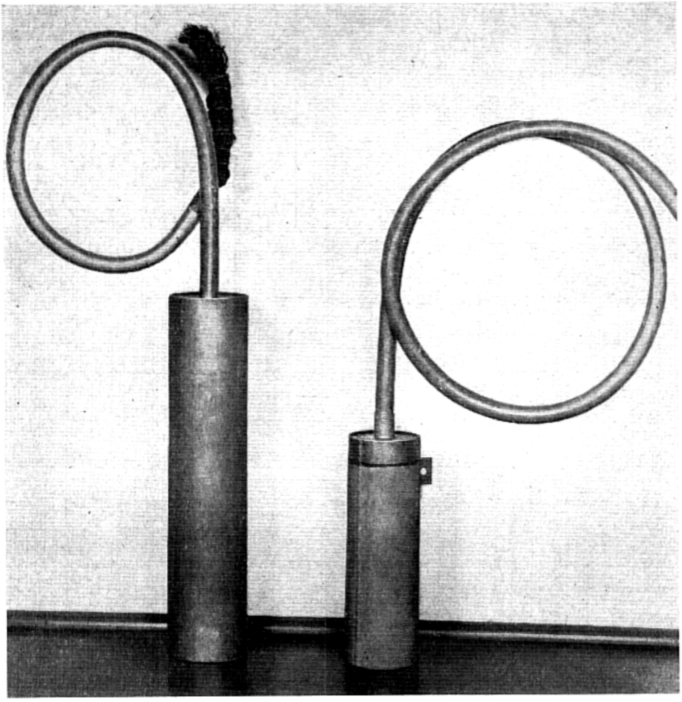

Fig. 17—Case size reduction 100-coil complements 88 mh. coils. At left: Lead sleeve case containing No. 622, molybdenum-permalloy core, coils. At right: Welded steel case containing No. 632 coils having Formex insulated windings on molybdenum-permalloy cores.

To provide the most economical potting arrangements for the new coils an entirely new series of loading coil cases was developed.

The economies that have resulted from these coil and case developments in the post-war period are large relative to the development cost, and are large in the aggregate, even though the savings per potted coil are small. The current demand for this series of coils greatly exceeds the aggregate demand for all other types of loading coils.

At this point it is of interest to present Fig. 18, which illustrates the progressive size reduction in loading coil cases for exchange area loading which resulted from the coil size reduction, starting with the 602 coil (1925) and including the 612 coil (1927), the 622 coil (1937) and 632 coil (1942). These 88-mh loading coils are equivalent to one another in transmission performance.

Fig. 18—Progressive case size reduction 1925–1942 200-coil complements—88 mh. loading coils. Left to right: No. 602 (hard iron-wire core) coils in cast iron case; No. 612 (permalloy core) coils in "thick" steel cases, welded joints; No. 622 (molybdenum-permalloy core) coils in "thick" steel cases; No. 632 (molybdenum-permalloy core) coils in tubular "thin" steel cases.

22.3 *Special Loading Coil for Signal Corps Spiral-Four Cable*[27]

A digression from the main line of the story is appropriate and permissible at this point, since the special coils used in loading the very important spiral-four cable carrier systems that were extensively used by the army during World War II were made possible by the development work that led to the standardization of the 632 coils, and by the development of the 60-permeability molybdenum-permalloy powder core-material, described in Section 11.1. These 6 mh "army" loading coils used 60-permeability cores having the same dimensions as the 125-permeability cores of the 632 coils. The small over-all dimensions of the coils made it practical to mount them within the "connectors" that terminated each quarter mile length of spiral-four cable, without requiring the connectors to be appreciably larger than otherwise would have been necessary. Thus, in effect, the loading was built into the cables at the factory, thereby simplifying installation. Another remarkable feature of the loading was that it had a cut-off frequency of about 22 kc and provided satisfactory transmission for cable carrier systems using a frequency-band extending to 12 kc. One indication of the importance of the coil under discussion was that nearly two million of them were manufactured for the United States Signal Corps before VJ day.

22.4 *Impact of Strategic Material Scarcities on Loading Coil Design*

Before the redesign of other loading coils could be undertaken to take advantage of the space-saving possibilities inherent in the use of Formex-enamel insulation, a new design factor suddenly became controlling. Nickel had become a strategic war material, and accordingly severe restrictions were placed upon its use, including all magnetic alloys in which nickel was a constituent. Molybdenum-permalloy was in this category.

This made it necessary to redesign the toll cable phantom loading units, as mentioned in the description of the "SM" type loading units (Section 11.3), the high-inductance exchange area loading coils, and certain non-phantom type toll cable loading coils used principally for "order-wire" circuits in coaxial cables.

As the new low-inductance exchange area coils (632, 638, 639), previously described, used only a very small amount of nickel (about 0.9 oz. per coil), no further worth-while reductions in the core size could be obtained without objectionable reactions on transmission, and without undertaking extensive development work that would have interfered objectionably with much more important war jobs. Consequently, the new 632, 638, and 639 coils were continued as standard designs. Large quantities were used during the war, and very much larger quantities since VJ day.

22.5 *643 (135 mh), 644 (175 mh), and 645 (250 mh) Exchange Area Loading Coils*

Since the standard 623, 624, and 625 coils, previously described, used about four times as much nickel in their cores as the 622 (and 632) loading coils, their redesign became an important factor in the new development program to conserve nickel.

A relatively simple solution for this specific problem was worked out, namely to use Formex-insulated conductors on the cores developed for the 622 series of coils. This saved three-quarters of the nickel used in the

623 series of coils. By using the 622 core instead of the 632 core, a larger winding-space became available for the same savings in nickel, and a lower winding resistance was obtained. New loading coil cases were not required, since the redesigned coils could be potted in the cases developed for the 622 series of coils.

The use of the much smaller cores necessarily resulted in resistance values that were substantially higher than those of the 623 series of coils, notwithstanding the improved winding-space efficiency of the Formex-enamel conductor insulation. The increments in the d-c resistance (relative to the 623-coil series) were a little over 60%. The effective resistances at 1 kc were approximately 50% greater. The attenuation impairments that resulted from the increases in resistance were in the general range 0.01 to 0.02 db/mi at 1000 cycles, depending upon the type of cable and weight of loading, and were considered to be tolerable for war-emergency designs.

22.6 *641 (44 mh) and 642 (88 mh) Non-Phantom Toll Cable Coils*

These are briefly mentioned here because of their general similarity, except as regards inductance and resistance, to the 643, 644, and 645 exchange area coils described in the preceding paragraphs. They also make use of cores developed for the 622 coils and utilize Formex-insulated conductors.

These coils are replacement "nickel-saving" designs for pre-war standard, "toll-grade" non-phantom type of cable loading coils, which were of about the same size as the side-circuit loading coils used in the M-type loading units. During the war the new coils had a moderate use as substitutes for SM-type loading units on toll cables, thereby saving additional amounts of nickel. The 641 (44 mh) coil has about the same resistance characteristics as the side circuits of the SM-type 44-25 mh phantom group loading units. A similar general relation exists between the 642 (88 mh) coil and the side-circuit of the SM-type 88-50 mh loading units.

The present principal field of use for the 641 and 642 coils is on 4-wire type and 2-wire type "order-wire" circuits in coaxial cables for use in the operation and maintenance of coaxial cable systems. Some of these order-wire circuits are as long as or longer than the longest loaded commercial message circuits used prior to the general introduction of cable carrier systems into the toll cable plant. The 643 coil also is occasionally used on short-haul order-wire circuits in coaxial cable systems.

22.7 *651 (44 mh) Coil for Subscriber-Loop Loading*

This was a post-war development looking towards the reduction in cost of subscriber-loop loading.

During the war, the design of a radically new type of automatic winding machine made it feasible to apply fine-wire, high-inductance windings on a miniature toroidal core much smaller than the smallest loading coil core previously described. This eventually led to studies of the desirability of using the miniature core in loading coils. The initial study showed definitely that this miniature core would not be good enough for loading coils. Larger cores, about one-half as large as the 632 coil core, were then considered.

The transmission economic studies of this design showed it would not be suitable for general use in loading exchange area trunks, in consequence of the increased attenuation that would result.

Table XIV

Compressed Molybdenum-Permalloy Powder Core Loading Coils for Non-Quadded Cables

Coil Code No.	Nominal Inductance (mh)	Approximate Resistances—Ohms(1)		Approximate Over-all Dimensions—Inches	
		d-c	1000 cycles	Diameter	Ax. Height
622	88	9.0	9.8	1.6	0.63
628	44	4.7	5.1	"	"
629	22	2.5	2.7	"	"
623	135	5.7	6.8	2.25	0.91
624	175	8.1	9.5	"	"
625	250	11.9	14.0	"	"
632	88	9.0	9.8	1.25	0.63
638	44	5.1	5.5	"	"
639	22	2.6	2.8	"	"
641	44	3.5	4.1	1.60	0.63
642	88	5.9	7.4	"	"
643	135	9.3	10.6	"	"
644	175	13.0	14.7	"	"
645	250	19.3	21.9	"	"
651	44	7.5	8.1	1.06	0.43

(1) Resistance data include the resistance of $7\frac{1}{2}$ ft. of stub cable except for the 651 coil used only in loading splices and having low-resistance short leads.

The standard 632 and 641 series of coils have 24 ga. stub cables with 0.8 ohm resistance.

The superseded 622 and 623 series have 22 ga. stub cables with 0.5 ohm resistance, excepting the 622 coil when potted in lead-type cases or in its 450-coil case with 24 ga. stub cable.

A proposed new 44 mh coil, using this core, was, however, found to be good enough for use as a partial substitute for the standard 638 coil in loading long subscriber loops under conditions mentioned below.

This new "miniature" loading coil is coded 651. It appears in the headpiece as Coil K.

The very small size of this coil makes it especially suitable for potting in a plasticized-type "case" for installation in loading splices. These cases involve an assembly of coils on a common spindle. Under favorable conditions, by using one or more spindle units, loading complements ranging up to a total of about 60, or more, coils may be installed at a single loading splice. It is expected that a considerable fraction of new installations of subscriber-loop loading may be in terms of splice installations of 651 coils. In occasional instances where large complements are required, and the cable-splicing conditions are not favorable for splice loading, the larger sized 638 coils will be used, potted in conventional types of loading coil cases. This plan avoids the need for developing entirely new, conventional design, cases for the 651 coil.

Commercial production of the 651 coil and their new splice cases started during 1948. It is expected that the future savings in the cost of new plant (due to the cheaper coils, cases, and installation) will be large relative to the development cost.

22.8 *Summary of Coil Data*

Table XIV gives a summary of electrical and dimensional data on the molybdenum-permalloy core message-circuit coils described in the preceding pages.

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(*to be continued*)