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The Evolution of the Input Transformer

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INPUT transformers started their history but not their present characteristic name with the commercial installation in 1904 of telephone repeaters of the electromagnetic type. Transformers of various kinds and for different purposes had been in use in the telephone system for some years. In general their function was to insulate one portion of a telephone circuit from another. Thus, a toll line would be terminated by one winding of a transformer, the other winding of which could be connected to the local circuit. The local and long distance portions were thus insulated, but the speech currents in either portion were, by induction, repeated in the other, and hence, the name of "repeating coil" for such a transformer. The ratio of the turns in the two sets of windings was, of course, chosen with reference to the impedances of the lines between which the coil was to repeat.

When the mechanical repeater was inserted in a stretch of long distance circuit, a transformer called a repeating coil was used between the line and the input side: i.e., the receiving element of the repeater. Its function was to connect line and repeater without excessive transmission loss of voice currents due to unmatched impedances, and to prevent transmission of low frequencies incident to the use of the repeater on composited lines carrying telegraph signals. This repeating coil had a low ratio and a low impedance.

When a vacuum tube, suitable as an amplifier of voice frequencies, had been developed a need arose for a repeating coil with ratios and impedances previously not required in the telephone plant. And with this need there was a new emphasis upon the word "input" and the introduction of the term "input transformer" to describe the coil used to connect the line and the receiving side of the repeater element.

The input impedance of a vacuum tube—that is, the impedance between the grid and the filament—is very high, approaching infinity under certain conditions; and a transformer was required to transform—i.e., "step up"—the low impedance of the line to match the high impedance of the tube. Development work by E. O. Scriven was started in February, 1913, toward the production of one with as high a step-up ratio as could be obtained with satisfactory transmission of voice frequencies. The design then developed had a straight silicon-steel core and was wound in a number of sections to minimize the distributed capacity, as shown in Figure 1. Before assembly in the repeater equipment it was mounted in a wooden box filled with moisture-proofing compound. Its voltage-amplification — frequency characteristic is shown in Figure 2, and indicates a range of transmitted frequencies wide enough for intelligible speech.

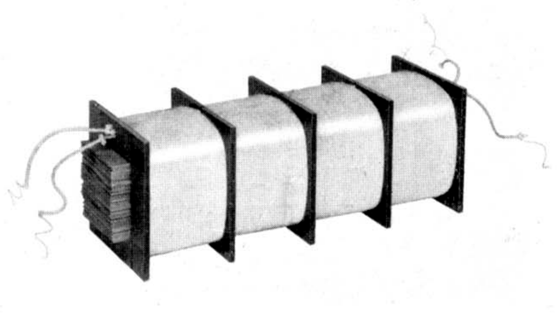

Fig. 1—Design of 1913; size 9 by 3 inches

This type of transformer had a very large external magnetic field which proved troublesome in the operation of the repeater. An entirely different type, therefore, was designed by R. L. Jones in the early part of 1914. That transformer, shown in Figure 3, was of the shell type. It had less distributed capacity than the straight-core type and there was some improvement in the range of transmitted frequencies, as is shown in Figure 2 by the characteristic dated 1914. This type of transformer was used in the first demonstration of the Transcontinental Telephone Line.

A considerable number of transformers of this type were built for use in the early vacuum-tube repeaters. Difficulty was experienced, however, in their manufacture, particularly in the winding. With the increasing demand for input transformers it was soon desirable to redesign for commercial production. The type of structure shown in Figure 4 was, therefore, evolved by W. L. Casper, and the first model of a transformer of this design was built in March, 1915. It was later known as the 203-type input transformer. Its construction is well suited to commercial production; the spools and windings are readily made and the assembly of the core with the spool involves very much less labor than the assembly of the earlier design.

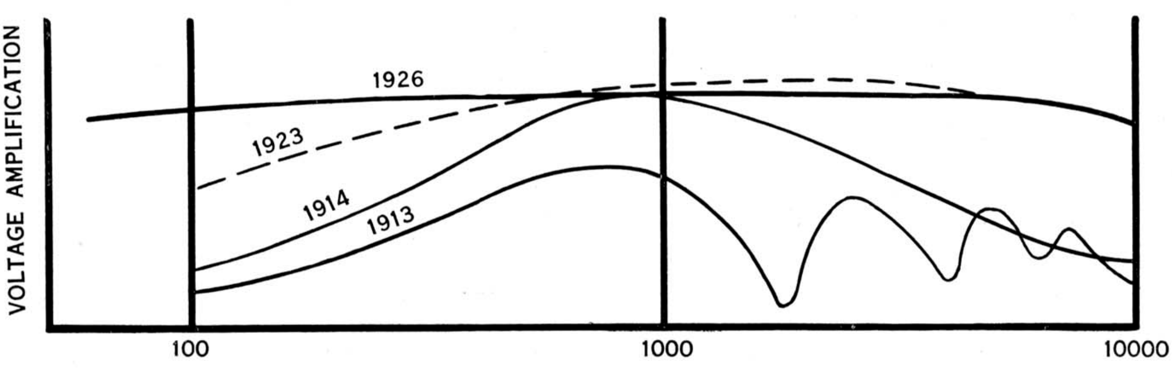

Fig. 2—How the voltage-amplification characteristics of our transformers have been improved in thirteen years

From an electrical standpoint the new transformer was practically the equivalent of the preceding design and was entirely satisfactory for the transmission of speech.

The 203-type transformer, however, was large, heavy and expensive. To obtain the desired transmission for voice frequencies a very high impedance was required and that meant many thousands of turns of fine insulated wire. Since the Manufacturing Department had not at that time developed the technique of winding No. 40 black-enamel insulated wire it was necessary to use much larger wire insulated with enamel and silk. The amount and kind of wire required, therefore, were directly responsible for the size and weight and much of the cost.

In 1916 the problem of designing smaller and cheaper repeater equipment placed upon the coil development group the necessity of developing corresponding transformers. In this development the use of standard parts and standard methods of construction were adhered to as far as possible in order to secure a low cost. The toroidal construction of Figure 5 was selected. The number of turns of wire, however, which could be wound on the core was limited by the size of the shuttle on the winding machine. Also, the inertia of the moving parts of the winding machines then in use was so large that wire smaller than No. 31 could not be used without an excessive number of breakages. Due to these limitations on the windings, an amplification as large as was desired could be obtained only at a sacrifice of the low frequencies. It was not desirable, however, to impair the quality of the repeater operation in this manner.

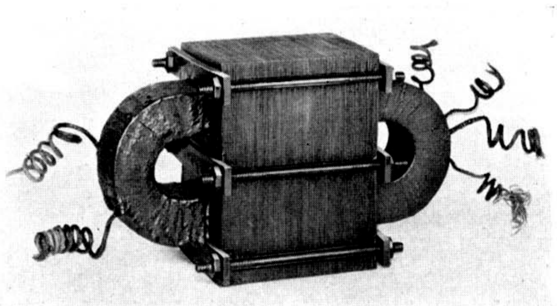

Fig. 3—Shell-type design of 1914; *size* 6⅝ *by* 4 *inches*

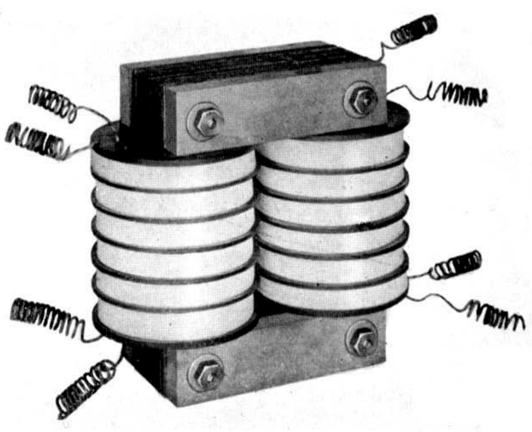

Fig. 4—*Design of* 1915; *size* 6¾ *by* 4⅝ *inches*

Up to that time (1916) the use for input transformers had been confined practically to telephone repeaters. In these, the amplification of frequencies below 135 cycles and above 2300 cycles was not desirable; in fact, it was decidedly objectionable, and means were provided elsewhere in the repeater to reduce the amplification of these frequencies. The band of frequencies which the transformer was required to transmit was therefore defined at about 200 cycles to 2300 cycles and the trend of the development had been along the lines of producing smaller and cheaper transformers rather than in attempting to extend the range of transmitted frequencies.

Furthermore, since it was desirable

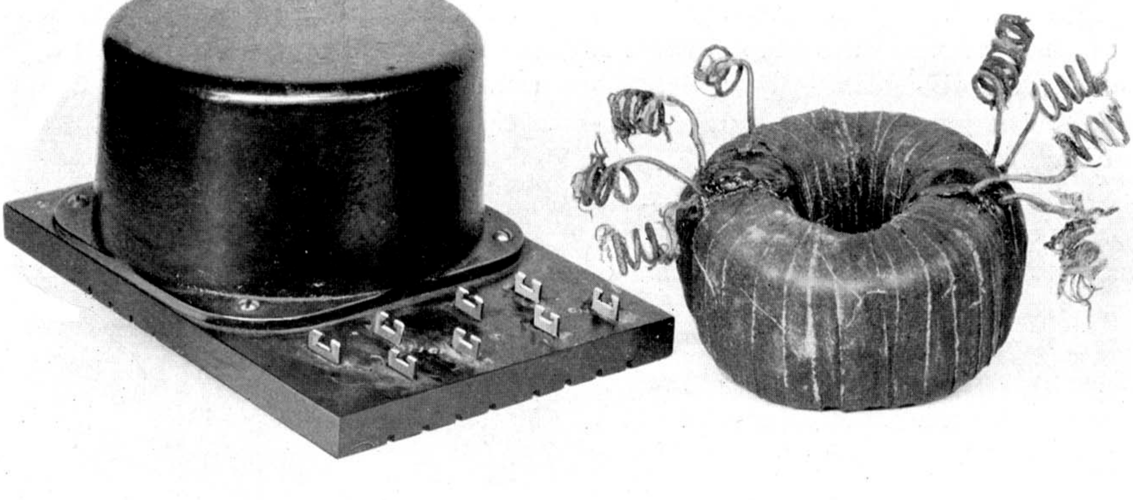

Fig. 5—Toroidal transformer, mounted on a block 6 x 4⅝ *inches*

to maintain the input impedance of telephone repeaters approximately constant over the transmitted frequency-range, each of the transformers so far mentioned was designed to be used with a non-inductive resistance shunt across its windings and the characteristics shown were taken under that condition. The resistance also served to flatten out the amplification characteristic, producing a more uniform amplification over the frequency range.

Soon after the United States entered the World War the demand for amplifiers of various kinds added a great stimulus to the development of input transformers, especially of the smaller and lighter types. Their development required not only the solution of many theoretical problems of design but also the development in the Manufacturing Department of the technique of winding small sizes of insulated wires. This accomplishment at Hawthorne was one of the principal contributions to the realization of small, highly-efficient input-transformers.

A number of designs were produced in the years 1916-1918, but only two of them combined advantages of cheapness and efficiency which enabled them to survive. They are the 201 and 213 types shown in Figure 6. Many of the amplifiers transmitted frequencies below and above the previously adopted range of 200 to 2300 cycles, for considerable progress was made in extending the frequency range.

The progress in amplifier design made during these years led to the decision in 1918 to improve the quality of the repeaters on the transcontinental telephone circuit. Since the quality of the transmission of the voice frequencies depended largely on the input transformer, that part of the repeater was selected as affording the greatest possibility of improvement. Naturally the types of transformer which were investigated were those recently developed for small amplifiers. Of these the 201 type was selected, since it was small, inexpensive and readily adaptable to quantity production. Furthermore, the Manufacturing Department had had experience in making this type and had developed methods of winding.

It was next evident that very little more could be done in reducing the size of the input transformer and that any further improvement would have to be in extending the frequency range or reducing the cost. Attention was given to the amplification of the higher frequencies and means were found whereby the amplification of the frequencies from 3000 to 5000 cycles, and even higher if necessary, could be controlled by the use of certain methods of constructing the windings. By these means it is possible to produce, in the frequency range above 1000 cycles, an amplification characteristic of practically any shape desired and hence to obtain the approximately flat characteristic necessary for faithful and accurate reproduction. An input transformer with such a characteristic is the 234-type shown in Figure 7. It has a silicon-steel core and an improved mechanical structure; and it is highly efficient as well as inexpensive. Its amplification characteristic is shown in Figure 2 under the date, 1923. This transformer, as well as those mentioned later, is designed to be used without any shunt resistance and the characteristics shown for it were taken under that condition.

Further development in the design of transformers, with the object of improving the amplification at the lower frequencies, led to the use of permalloy as a core material. Also, a further study of methods of winding resulted in the extension of the high-frequency range considerably above 5000 cycles. These developments have resulted in transformers with almost uniform amplification over a wide band of frequencies. This characteristic, very necessary in the high-quality amplifiers of the present day, is shown under date of 1926 in Figure 2. A transformer of this type is the 226-type, which is mechanically similar to the 234-type shown in Figure 7, except that it has a permalloy core.

Our progress of approximately thirteen years in the development of input transformers is well symbolized by Figure 2, to which reference has previously been made. There has been a steady improvement in trans-

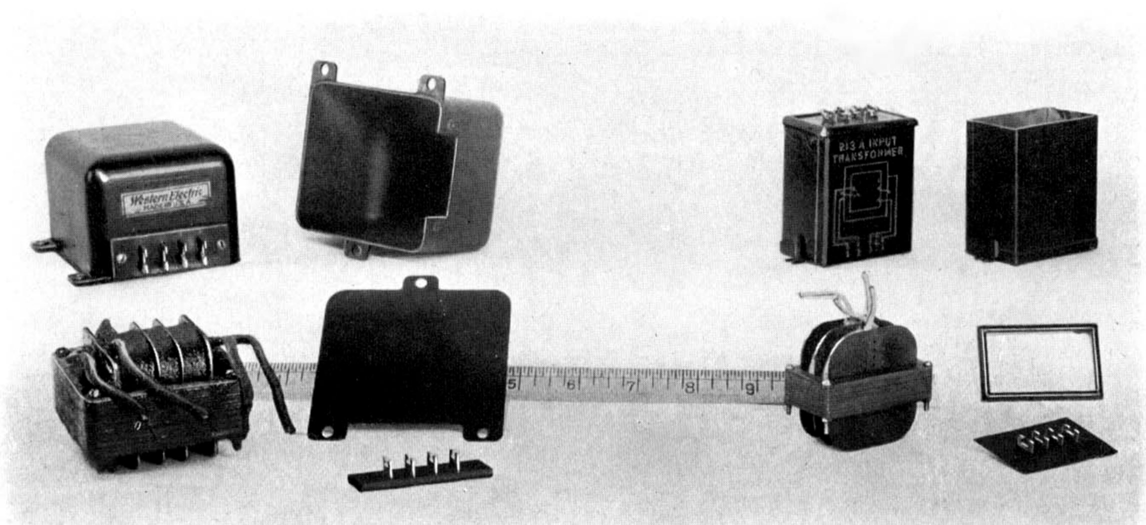

Fig. 6—"War babies"; 201-type on the left and 213-type on the right

mission characteristic, both in frequency range and in voltage-amplification ratio. Commensurate improvements in cost, in reliability, and in reduction of size have accompanied the gains in transmission. Of the engineers concerned with coil development whose studies and designs have been responsible for these advances many names ought to be mentioned, particularly H. Whittle and E. L. Schwartz, but space limitations preclude telling the complete history.

The developments have resulted in input transformers which are about as small as can easily be handled for manufacturing purposes, with a range of transmitted frequencies adequate to present-day requirements, and producible at relatively low cost. Further progress will demand attention particularly to extending the range and further reducing the cost. The method and technique which has been evolved will prove of value also in other related developments.

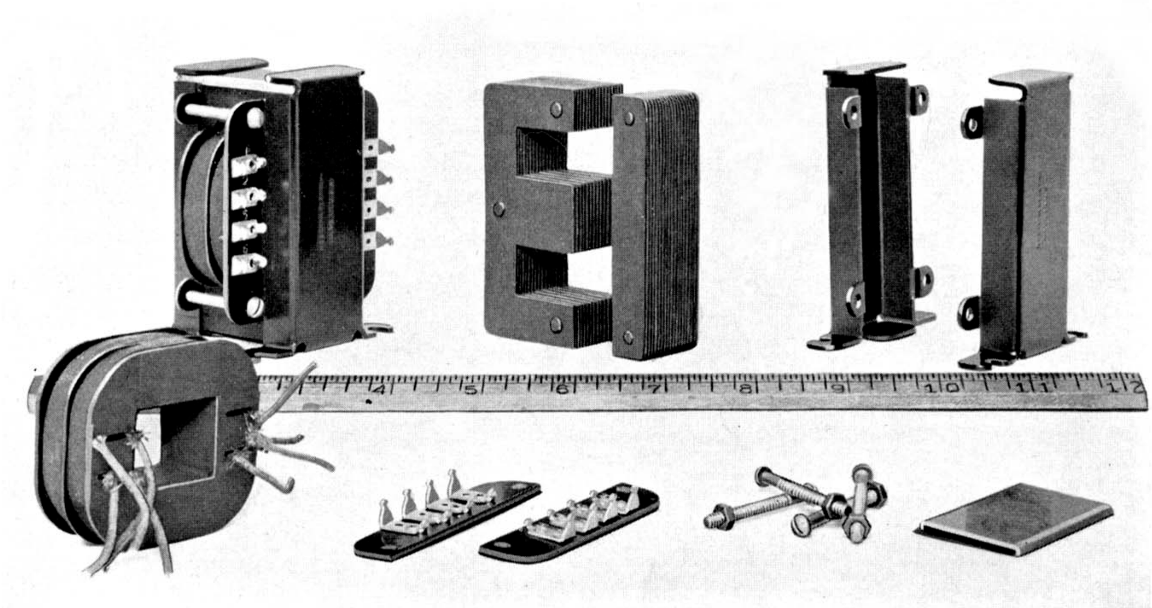

Fig. 7—234-type input transformer; an example of present-day small, economical, and efficient design