Permalloy in Audio Transformers

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THE use of permalloy for transformer cores has been a highly important contribution toward the high quality of the transmission now obtained in audio frequency transformers, both input and output. Although available for only a few years, this material has been used to a rapidly increasing degree. Since manufacturing information was issued on the first coded transformer using a permalloy core, other designs have been added continually so that now there are available manufacturing specifications for dozens of audio frequency transformers of that type, for use under different conditions. Several hundred special designs have been developed as well, for use in the Laboratories in circuits and apparatus where transmission of high quality is desired.

So rapidly has its use grown that permalloy is the core material in a large majority of the audio frequency transformers designed today. There are two principal reasons for its choice—desire for the best available transmission characteristic, and for reduction in size. Improvement of transmission quality has been the more influential of the two, but there have been a number of occasions where extreme compactness, such as could not be attained with a core of silicon steel, has been the primary consideration. Due to the high nickel content, however, permalloy costs considerably more than silicon steel.

The first commercially important demand for audio-frequency transformers whose frequency range exceeded the ordinary talking range of about 200 to 3000 cycles came in connection with the design of amplifiers for the Western Electric Public Address System a number of years ago. Although transmission requirements were not unusually severe according to present standards, the occasion marked the beginning of a rapidly increasing demand for many types of audio-frquency transformers possessing transmission qualities higher than had previously been necessary. Since then, the rapid increase in the development of loud speaking equipment, radio circuits and special amplifiers has made the electrical requirements for transformers constantly more rigorous with respect to the frequency range to be transmitted and to the uniformity of transmission over that range. One of the most exacting commercial demands has been met in transformers used in amplifiers for talking moving pictures apparatus, where there is demanded as nearly uniform transmission as possible between the frequencies of 40 and 6000 cycles. In addition there have been numerous special developments for which it has been necessary to design transformers giving uniform transmission over an even wider range; notable among these is the television system recently demonstrated, for which transformers were required to transmit currents whose freqencies ranged from 10 to 20,000 cycles.

Importance of the core material in improving transmission at the lower frequencies is shown by the diagram of an input transformer the secondary of which is connected to a vacuum tube. Figure 1 is a schematic diagram, and Figure 2 the equivalent "T" network, where the condenser represents the input capacity of the tube and the distributed capacity of the transformer. The series arms a and b represent the primary and secondary resistances and leakage reactances, and M the mutual impedance between the windings. At low frequencies b can be neglected, and only the resistance component of a need be considered; this may be added to R, the resistance from which the transformer is working. It can readily be seen from this circuit that for the applied voltage to be transmitted without serious loss in the resistance R, the mutual impedance M must be large with respect to R. The value of M depends in turn principally on its reactive component, $2\pi fL$, where L is the mutual inductance of the transformer and f the frequency. As the frequency decreases, the impedance M obviously decreases as well; if it is to be kept high with respect to R, the important consideration is that L be made high. Thus the change from silicon steel to permalloy, by giving a core of higher permeability, raises L and M and so maintains the voltage amplification at frequencies where otherwise it would fall off badly. This merit of considerably higher permeability than that of silicon steel is confined however to low flux densities such as are ordinarily present in audio-frequency transformers.

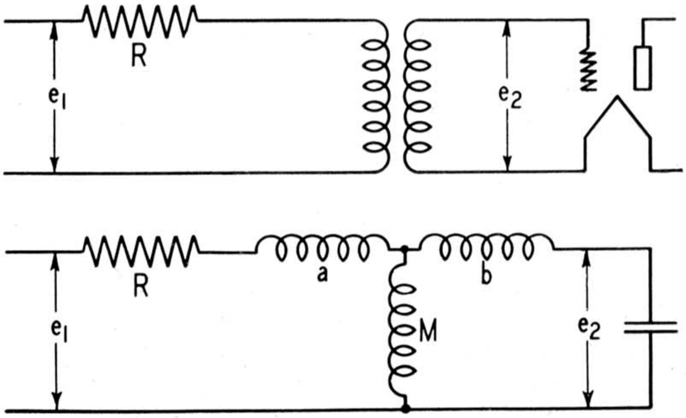


Figure 1, above, and 2, below

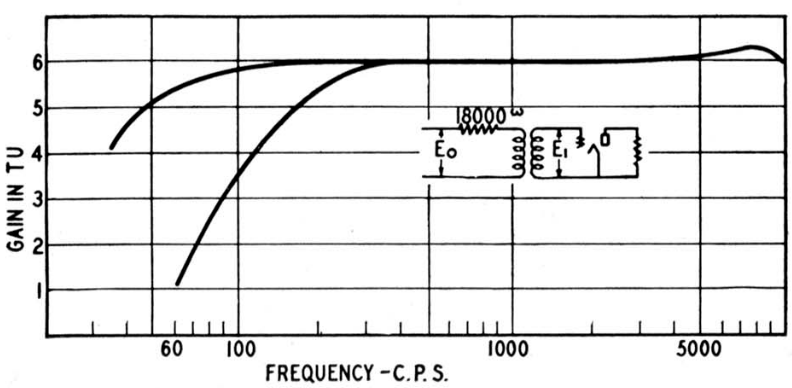
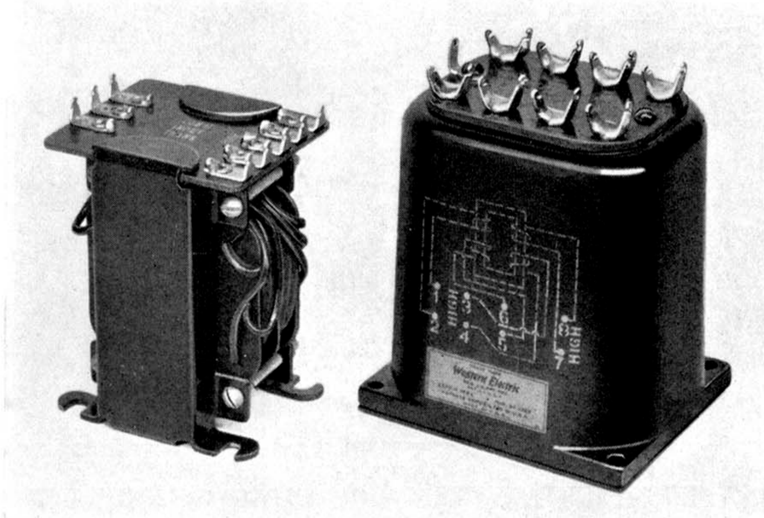


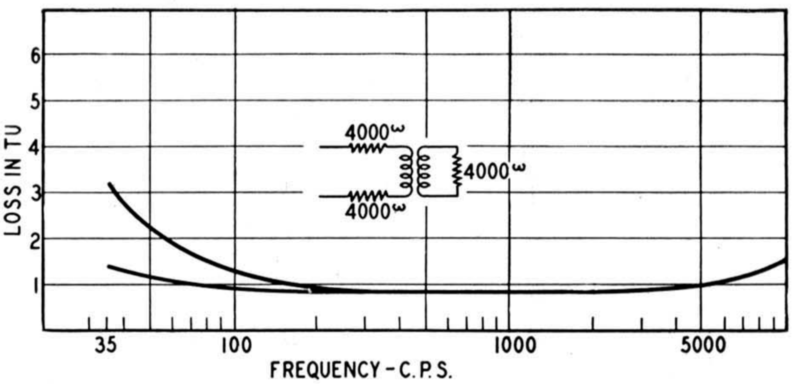
Fig. 3—Effect of the core material on the voltage amplification characteristics of two input transformers. Upper curve, permalloy core; lower, silicon steel core. These curves, and those of Figs. 4 and 5, were taken with a superimposed direct current of 0.002 amperes through the primary winding

The marked improvement in transmission quality of audio-frequency transformers which comes from the use of permalloy is readily seen from comparison of the voltage-amplification characteristics of two input transformers differing only in the magnetic materials used for their cores. These characteristics are recorded on the curves of Figure 3. It should be borne in mind that the transformer used does not embody the highest amplification quality available, but was chosen rather to indicate the improvement which can be made in the amplification of the lower frequencies by a change of core material. The same windings were used for both curves, and the cores themselves, the same in dimensions and construction, differed only in material; one was of silicon steel, and the other of permalloy. Each core was separable, and so after measurements had been made using one core it was removed from the windings and replaced by the other. In Figure 3, the lower curve represents measurements taken when the core laminations were of silicon steel, the material formerly used almost universally, and the upper curve represents data with laminations of permalloy. At frequencies as high as 300 the improvement from change of core material is noticeable, and at 60 cycles it is more than 4 TU. It will be noted that there is no noticeable change in amplification at the higher frequencies. Above 3000 or 4000 cycles the voltage-amplification characteristic is determined principally by design of the windings and is affected by change of the core material only to the extent that such a change permits modification of the winding design.

In the design of output transformers marked improvement in transmission at the lower frequencies, comparable to that for input transformers, can also be made under most conditions by the use of permalloy cores. Consideration must usually be given, however, to the necessity of carrying direct current of relatively large value from the plate circuit of the vacuum tube. Susceptibility of permalloy to the magnetizing effect of direct current is far greater than that of silicon steel. With input transformers, ordinarily, direct current is so small that if it cannot be neglected the design can be arranged to take care of its presence, but for output transformers the direct current usually must be kept out of the transformer windings or its effect must be balanced out by some such circuit arrangement as push-pull con-



Typical permalloy-core input transformers, potted and unpotted, weighing 2 and 3¾ pounds. Departure from this type has been mainly for output transformers required to transmit relatively large power and presenting correspondingly severe insulation problems; a few of these weigh as much as fifty pounds nection of the vacuum tubes. Fortunately in many of the recent amplifier designs the tubes in the last stage are connected in push-pull to give the necessary power output; with this arrangement the direct currents from the two tubes pass through the windings in opposite directions, and so their magnetizing effects tend to neutralize each other. Of course perfect balance seldom results, but with tubes of average commercial quality the neutralizing effect is usually sufficient to assure a considerable part of the improved transmission characteristics made possible by the use of permalloy. In Figure 4, characteristics of output transformers are compared when the cores are of permalloy and of silicon steel. As before, there is no change in the windings, and the two cores are the same in size and shape, differing only in material. At the higher frequencies amplification is not changed, though an improvement could have been secured by change in design; the improvement would however have been at the expense of part of the gain at the lower frequencies.



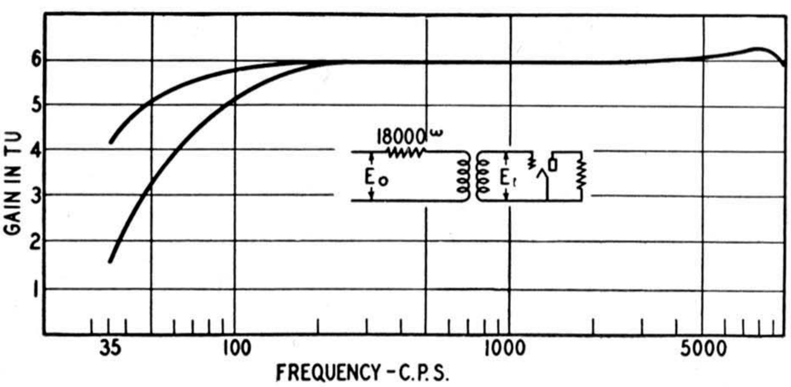


Fig. 4, above—Transmission loss characteristics of two output transformers. Lower curve, permalloy core; upper, silicon steel

Fig. 5, below—Voltage-amplification characteristics of input transformers with permalloy cores. Upper, core assembled with butt joints; lower, with interleaved construction

Use of a permalloy core is not of itself assurance of high-quality transmission at the lower frequencies; a substantial part of the improvement can be lost by use of a type of core assembly unsuitable for the conditions under which the transformer is to be operated. An example is illustrated in Figure 5. Two input transformers were used, with identical windings, and each with a permalloy core. The two cores in turn were made up of identical parts, but were assembled somewhat differently. In the first case, the laminations were assembled into two core units in the form of an E and I respectively. These were then placed together, with butt joints where they touched, imparting the effect of an extremely small air-gap. This gave the core sufficient stability to withstand the magnetizing effect of a small direct current in the windings. In the case of the other transformer, the same laminations were assembled individually into a complete core, with the E and I pieces interleaved. The joints were thus alternated from side to side, and the effect of the air gap eliminated as far as possible. The result was an unstable magnetic circuit, with inductance higher than given by butt joint construction when there was no direct current but much smaller under actual circuit conditions, when a relatively small direct current flowed through the windings. Change to interleaved construction increased the loss at 60 cycles from 0.5 TU to 2.0 TU; such a loss in each input transformer of a Public Address System or an amplifier for talking moving pictures would of course be most objectionable. In output transformers, where appreciable direct current is usually present, selection of proper core design is even more important. Use of any transformer with permalloy core should be restricted to circuit conditions for which it is suited, since presence of an unsuitable condition such as is illustrated above when direct current is present may counteract in large part the benefits which the core material would otherwise bring, and render its use of little value.

A French Appreciation of the Bell System

Monsieur Drouët, Inspector General of Posts and Telegraphs of France, in his preface to E. M. Deloraine's French translation of K. S. Johnson's "Transmission Circuits for Telephonic Communication," gracefully acknowledges the indebtedness of the world to the United States and particularly to the American Telephone and Telegraph Company for the development of telephonic communication.

"Un groupement industriel et financier très puissant s'y est progressivement constitué autour de l'American Telegraph and Telephone Co., qui exploite aux Etats-Unis les communications à grande distance. Ses services techniques, et ceux des Sociétés qui lui sont affiliées, comprennent un état-major d'ingénieurs de premier ordre, et certains d'entre eux sont des savants dont l'autorité s'est imposée dans tous les pays.

"De ce groupement d'hommes de valeur, qui mettent en commun leurs efforts pour le perfectionnement d'une même technique, on pourrait dire qu'il constitue une véritale confrérie intellectuelle qui développe et propage, en matière de communications électriques, une doctrine dont la valeur est hautement apprécipée par tous les spécialistes."

He speaks of their technical staff, in which he includes Bell Telephone Laboratories, as engineers of the first order who constitute an intellectual brotherhood for the development of matters pertaining to electrical communication.