June 10, 1930. A. G. GANZ 1,762,775

INDUCTANCE DEVICE

Filed Sept. 19, 1928

FIG. 1

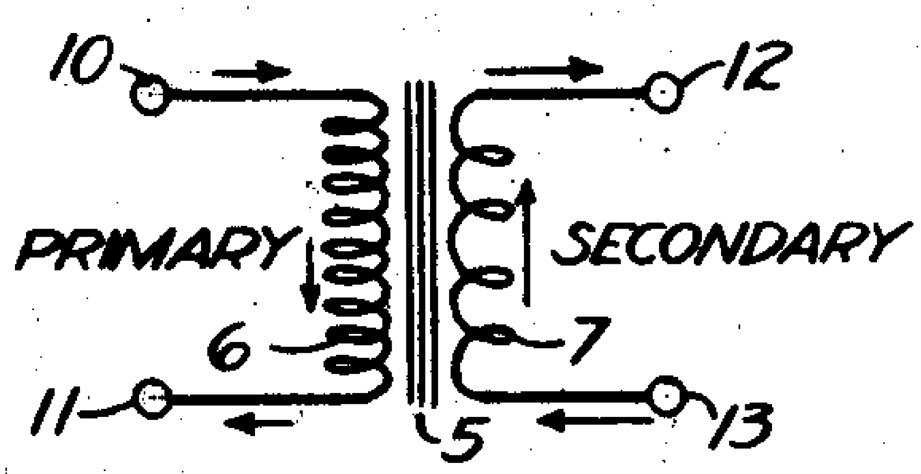


FIG. 4

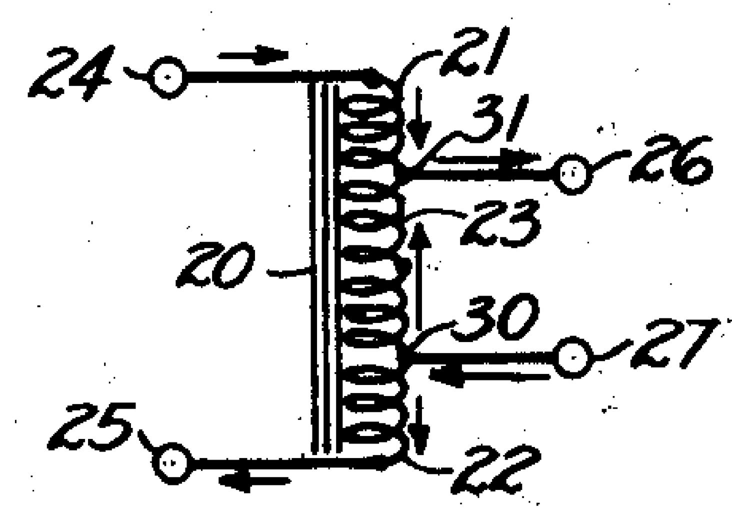


FIG. 2

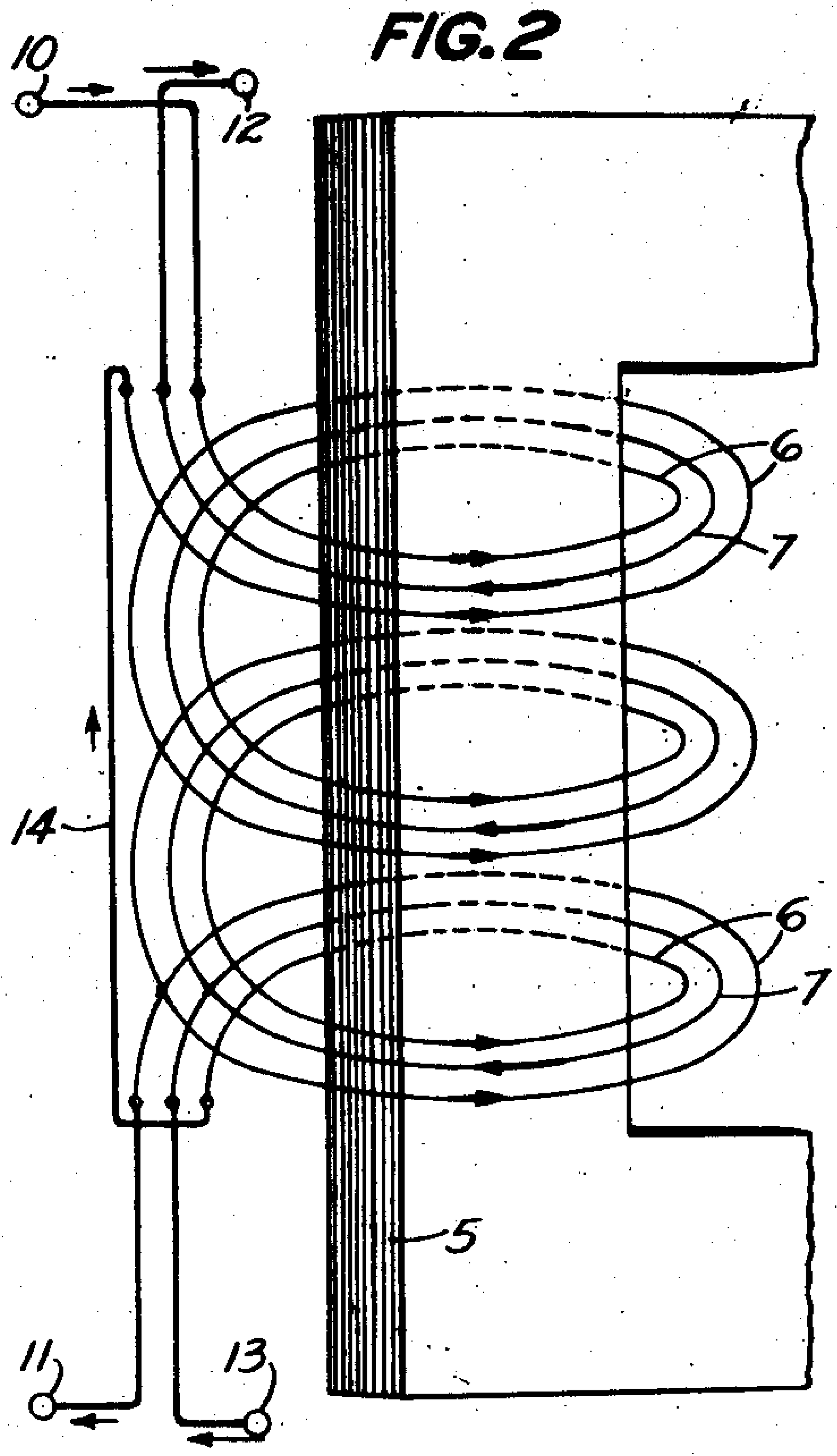


FIG. 5

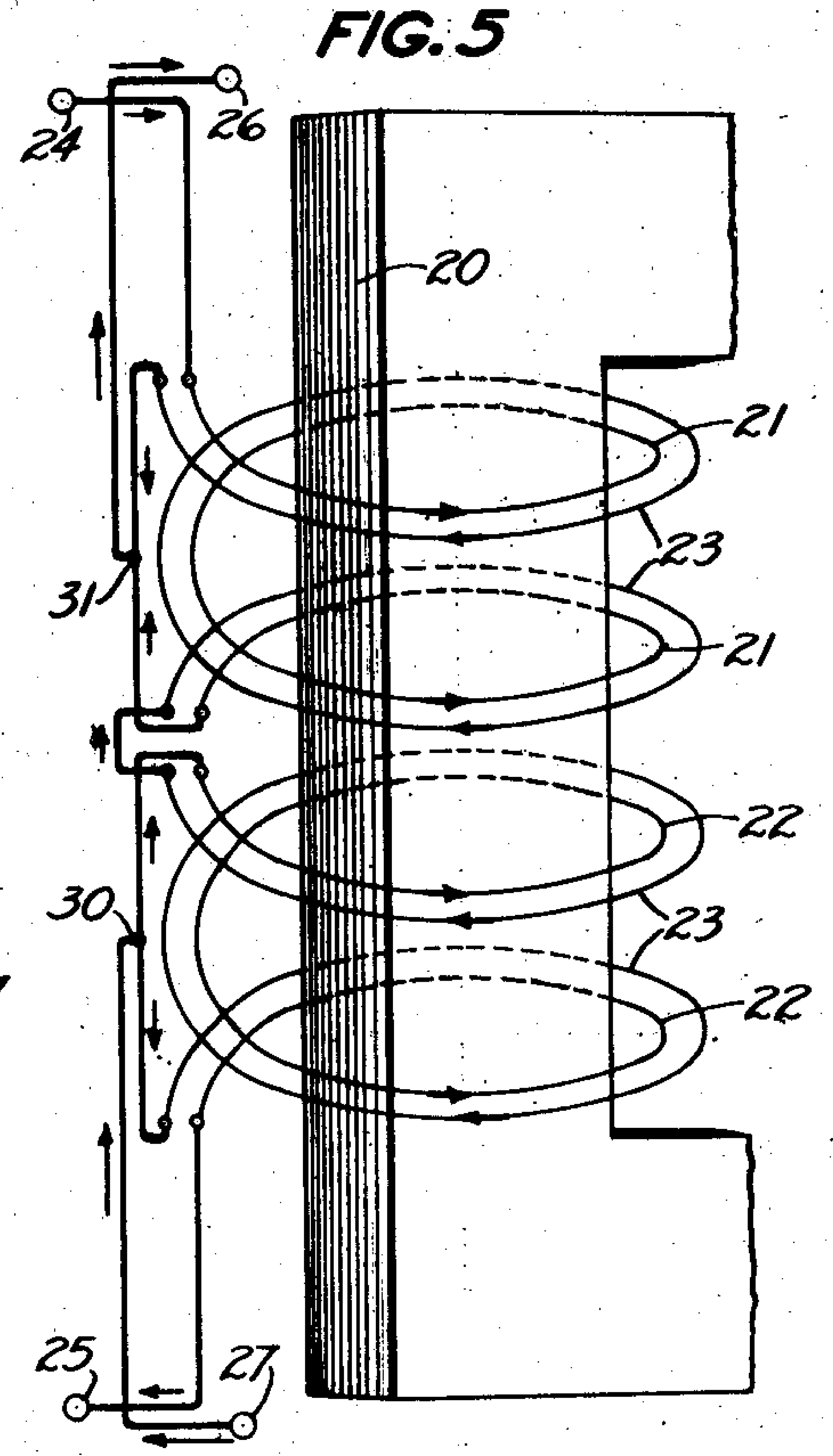


FIG. 3

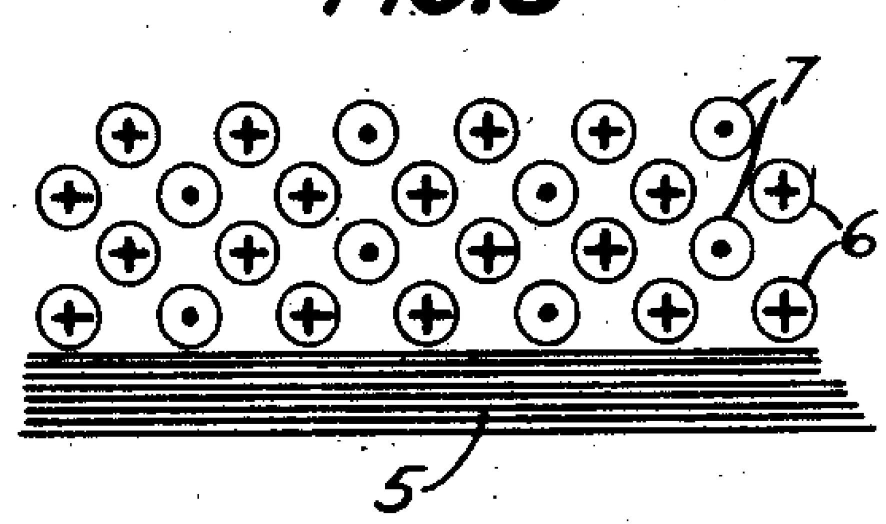
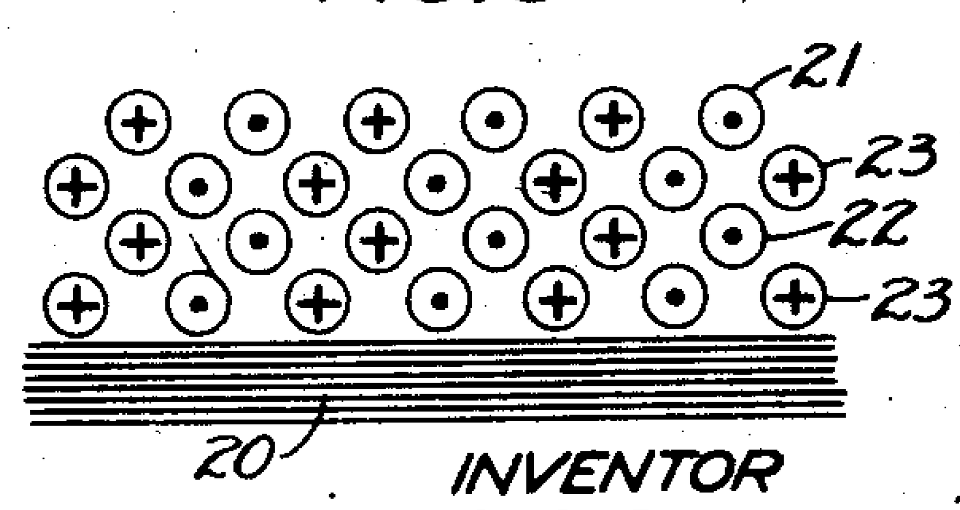


FIG. 6



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Patented June 10, 1930 **1,762,775**

UNITED STATES PATENT OFFICE

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INDUCTANCE DEVICE

Application filed September 19, 1928. Serial No. 306,877.

This invention relates to inductance apparatus for connecting electrical circuits and particularly to transformers.

An object of this invention is to provide a transformer which will transfer waves between two circuits with low energy loss and small distortion.

In the case of connecting two circuits of different impedances such as cable telephone circuits and open wire telephone circuits, transformers are commonly used to step the impedances up or down between the circuits. Since telephone circuits transmit a range of frequencies, changes in the impedance of any transmission element due to frequency variation may be of considerable importance. These changes may cause a mismatching of the impedances of the circuits at various frequencies which may cause reflection losses and distortion.

In the case of the joining of two carrier circuits of different characteristics, it was found that as the frequency increased the effective series resistance of the windings of the connecting transformer also increased, disturbing the matched impedance condition of the joined circuits, and causing excessive reflection losses and poor transmission at the higher frequencies. One reason for this increase in effective series resistance of the windings of the transformer with frequency was found to be that the unbalanced flux of the load currents cutting the turns of the windings set up eddy currents in the wires of the transformer windings.

To illustrate briefly, the portion of the load flux, ϕ, cutting the cross-section of any wire produces a voltage, e, around a loop linking such flux in accordance with the equation $e=\frac{nd\phi}{dt}$. This voltage produces currents which flow in a plane parallel with the axis of the wire and result in an energy loss. As the load flux ϕ is proportional to the load current I_e, and e at any frequency is proportional to ϕ, the eddy current i is proportional I_e and the total energy loss $W=\Sigma ei$ is proportional to I^2. Where eddy current losses occur, therefore, they appear, at any frequency as an effective resistance in series with the load, since $\frac{W}{I^2}=\frac{I^2R}{I^2}=R$. As these losses are dependent on frequency, they change with variations in frequency causing changes in the impedance of devices in which they occur. This loss, of course, is not the loss due to skin effect which is present in an alternating current conductor regardless of surrounding flux and currents.

This invention provides for the construction of a transformer whose impedance modifying effect is substantially independent of frequency over a wide band of frequencies. This transformer has its windings so wound that no substantial accumulation of flux due to load currents is possible at any point within the windings. For instance, in a balanced auto-transformer each half of the shunt winding and the adjacent series winding may be wound as a parallel pair. In the case of a two-winding transformer, the primary and secondary windings may be wound as a parallel pair.

A better understanding of the invention will be had from the following specification taken in connection with the drawings, in which:

Fig. 1 is a schematic representation of a two-winding transformer embodying the invention;

Fig. 2 is a diagrammatic view of a portion of the transformer of Fig. 1 showing the details of the winding;

Fig. 3 is a cross-sectional view showing the relative positions of the turns of the windings of the transformer of Fig. 1;

Fig. 4 is a schematic representation of an auto-transformer embodying the invention;

Fig. 5 shows a portion of the auto-transformer of Fig. 4 diagrammatically; and

Fig. 6 is a cross-sectional view showing the relative positions of the turns of the windings of the auto-transformer of Fig. 4.

Before taking up the detailed description of the drawings it might be well to consider briefly the action of a transformer, considering for simplicity a unity ratio transformer. It is well known that the impedance diagram of a transformer includes a shunt element corresponding to the mutual impedance and a series element corresponding to the leakage impedance. Corresponding fluxes are the magnetizing flux and the leakage flux. The magnetizing flux is produced by the magnetizing current in the primary which in a well constructed transformer is small in comparison with the primary load current and, as to phase, is substantially at right angles thereto. The load current in the secondary is substantially equal and opposite to the load current in the primary, and the secondary load flux within the core neutralizes the primary load flux.

Outside the core two regions are to be distinguished, first, the space occupied by the conductors and second the remaining space external to the core. If the secondary winding is spaced materially from the primary winding the load fluxes outside the core are not entirely neutralized. In particular, if we consider a primary turn which is surrounded at some distance away by a secondary turn it is found that in the space between these two turns the load fluxes are in the same direction and therefore add instead of neutralize. It is, of course, this failure of the two load fluxes to neutralize which accounts for the leakage flux and the leakage impedance.

Considering now the space occupied by the winding conductors themselves any leakage flux which interlinks a turn of the winding produces eddy-current losses in the copper. Applicant has found that in certain uses of a transformer, at least, these eddy-current losses in the windings themselves are appreciable as has been noted above.

The effects above described for a unity ratio transformer are, of course, present in a non-unity ratio transformer, except that in considering the magnitudes of the load currents the turns ratio must be taken into account.

The transformer structure now to be described in accordance with the invention reduces the leakage substantially to a minimum and also by the disposition of the primary and secondary conductors reduces the energy losses in the conductors which would be produced by the leakage flux.

In the description to follow the same elements in the different figures are given identical numbers while the arrows show by their lengths and directions a rough comparison of the magnitude of the load currents and the direction in which they flow at one particular instant in the windings of the transformers. It is to be understood that the magnetizing current has been arbitrarily omitted since its magnitude is small and any eddy current losses due to it appear as a small additional core loss which has no appreciable effect on the impedance characteristic.

The transformer of Figs. 1, 2 and 3 which is shown as a non-unity ratio transformer, comprises a core 5, a primary winding 6 with terminals 10 and 11 and a secondary winding 7 with terminals 12 and 13. (It will be understood that either winding can be considered the primary and the other the secondary).

Fig. 2 shows the primary winding 6, beginning at terminal 10, being wound first on the inside of the loops and then returning by conductor 14 and being wound on the outside of the loops ending at terminal 11. The secondary winding 7, beginning at terminal 13, is wound on the inside of the loops and terminates at terminal 12. Winding 6, being the high voltage, small current winding, is shown with twice the number of turns as the low voltage, large current winding 7, while the lengths of the arrows roughly indicate the comparative magnitude of the currents. The neutralization of the flux produced by the oppositely directioned load currents is substantially complete since the current flowing in winding 7 is approximately twice as large as that flowing in the winding 6, the winding 6, of course, having twice as many turns as winding 7. The arrangement of the turns is shown in Fig. 3 in cross-section with a turn of winding 6 on either side of a turn of winding 7. In this last figure the dots represent current flow toward the reader and the crosses represent current flow in the opposite direction in accordance with the well-known convention. The windings are shown in Fig. 2 as a group of three for clearness but this group may have as many turns as required for the desired voltages and loads.

The auto-transformer of Figs. 4, 5 and 6 comprises a core 20, a primary winding including the upper series winding 21 and lower series winding 22 together with shunt or bridge winding 23, having terminals 24 and 25, and a secondary winding including only the shunt winding 23 having terminals 26 and 27.

Tracing the larger current circuit, or in this case, the secondary winding, starting at terminal 27, this circuit begins at point 30, Fig. 5, the current flowing through the shunt winding 23, the turns of which are on the outside of the loops, to point 31 and terminal 26. The current in the primary winding flows in series windings 21 and 22 in the opposite direction from the current in the circuit just traced. Starting at terminal 24 the inner conductor shown in the two upper loops of Fig. 5 is series winding 21 terminating at point 31, while the corresponding conductor starting at point 30 in the two lower loops forms the series winding 22 which terminates at terminal 25.

It is noted that the transformer is so wound that at any point within the windings there is substantially no accumulation of flux due to load currents, that is, the product of the number of turns and the load current in one direction tending to cause flux to link any point is equal to the product of the number of turns and the load current in the opposite direction causing flux to link the same point. As a result, there is an almost complete neutralization of load flux at all points.

In the actual winding of the transformer as described it is preferable to wind the series and shunt windings as parallel pairs, that is, in the transformer shown in Figs. 4, 5 and 6, winding 21 and the upper half of winding 23 are wound as one parallel pair, and winding 22 and the lower half of winding 23 are wound as another parallel pair, certain terminals being connected at points 30 and 31 as shown in Fig. 5.

The transformers described have been shown as having turns ratios of 2 to 1 but any turns ratio may be obtained by grouping as many wires as desired and in a manner to substantially neutralize the flux at any point within the windings due to load currents flowing in each wire.

Although the invention has been described embodied in two particular transformers it is to be understood that modifications may be made and that no limitations upon the invention are intended other than those imposed by the scope of the appended claims.

What is claimed is:

1. An inductance device for connecting two lines, comprising a core with a plurality of inductively coupled windings, each of said windings having its individual turns carrying current in one direction at a certain instant interleaved with the individual turns of another winding carrying current in the opposite direction at said instant and substantially preventing the flux within either of said windings from producing eddy currents in any of said turns.

2. An inductance device intermediate and connecting two lines having different impedances, comprising a core with a primary winding and a secondary winding thereon inductively coupled, said windings having a different number of turns respectively, said primary winding being conductively connected to one of said lines and said secondary winding being conductively connected to the other of said lines, said primary winding carrying current in one direction at a certain instant having each turn interleaved with the turns of said secondary winding carrying current in the opposite direction at said instant to reduce eddy current losses in said turns.

3. A non-unity ratio inductance device intermediate and connecting two lines having different impedances comprising a core, a primary winding on said core connected to one of said lines carrying current in one direction at one particular instant, and a secondary winding on said core connected to the other of said lines and inductively coupled to said primary winding carrying current in the opposite direction at said particular instant, the turns of said primary and secondary windings being wound respectively as parallel groups with the product of the current in one direction and the turns carrying said current tending to cause flux to link a particular point outside the core, substantially equal to the product of the current in the opposite direction and the turns carrying said oppositely flowing current tending to cause flux to link said point.

4. In combination, a multi-layer winding non-unity ratio inductance device having a core and a plurality of windings on said core, a source of currents of a band of frequencies to be transmitted through said device, and a receiving circuit, each turn of said windings connected to said source being wound adjacent a turn of said windings connected to said receiving circuit, the oppositely flowing load currents in the alternate turns preventing the flux within the device from causing substantial eddy current losses in said turns.

5. An auto-transformer comprising a plurality of series and shunt windings inductively coupled for connecting and matching the impedances of two electrical circuits having different impedances, each turn of said series windings paralleling and wound adjacent to at least one turn of said shunt windings to neutralize at any point within said windings the flux produced by the load currents in said auto-transformer.

6. An auto-transformer intermediate and connecting two lines having different impedances, comprising a core, a primary winding on said core connected to one of said lines having a plurality of series and shunt portions, and a secondary winding on said core connected to the other of said lines composed of said shunt portions of said primary winding, said series portions of said windings carrying current in the opposite direction to the current flowing in said shunt portions, the product of the current in one direction and the turns carrying said current tending to cause flux to link a particular point being substantially equal to the product of the current in the opposite direction and the turns carrying said oppositely flowing current tending to cause flux to link said point.

In witness whereof, I hereunto subscribe my name this 15th day of September, 1928.

ALBERT G. GANZ.