

May 15, 1951

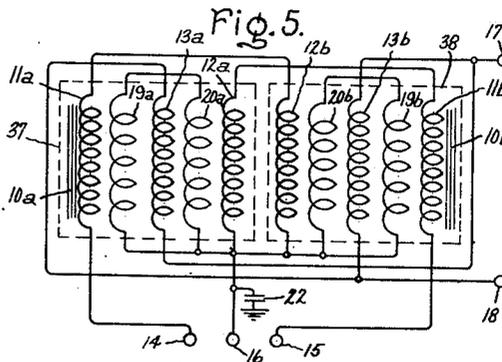
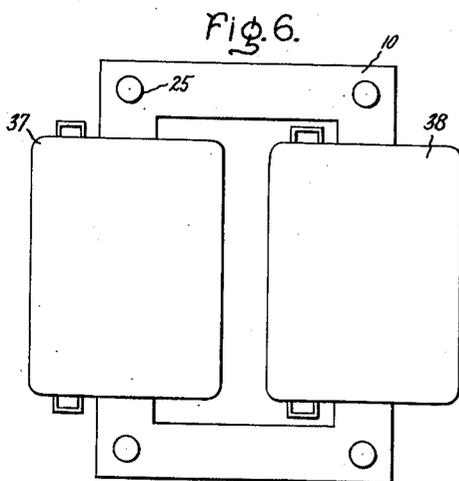
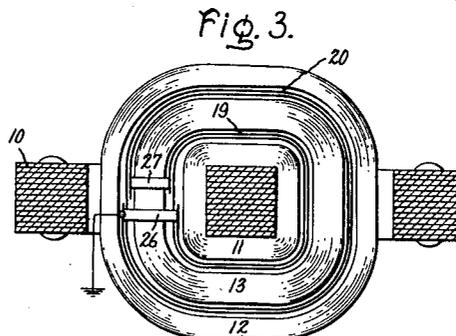
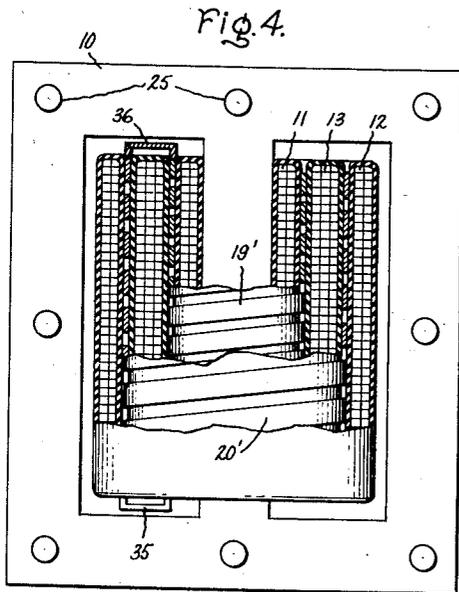
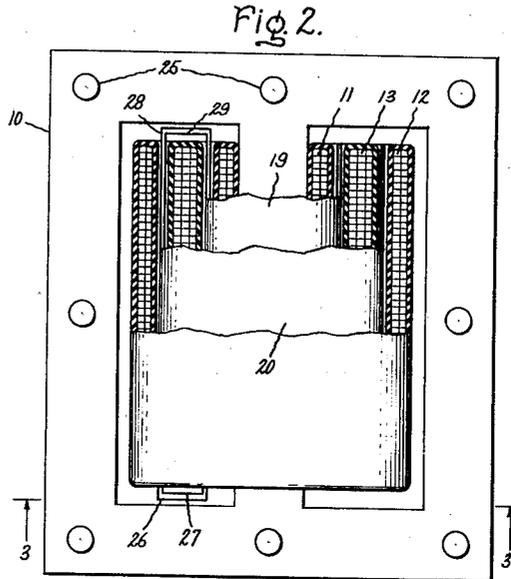
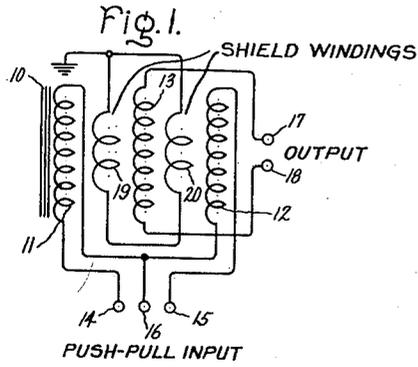
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2,553,324

WIDE BAND AUDIO AND VIDEO TRANSFORMER

Filed July 27, 1949

2 Sheets-Sheet 1



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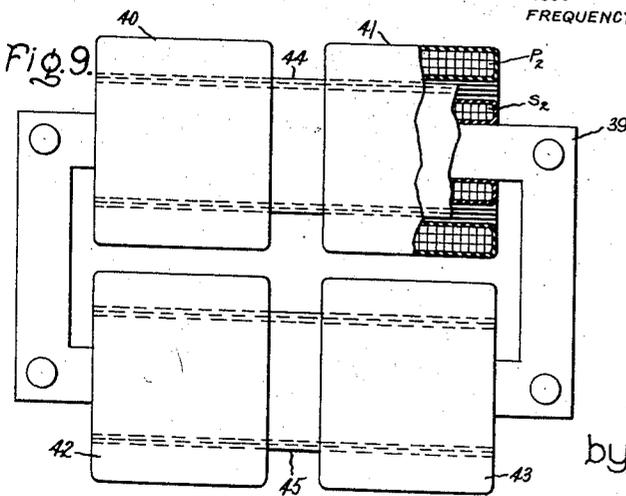
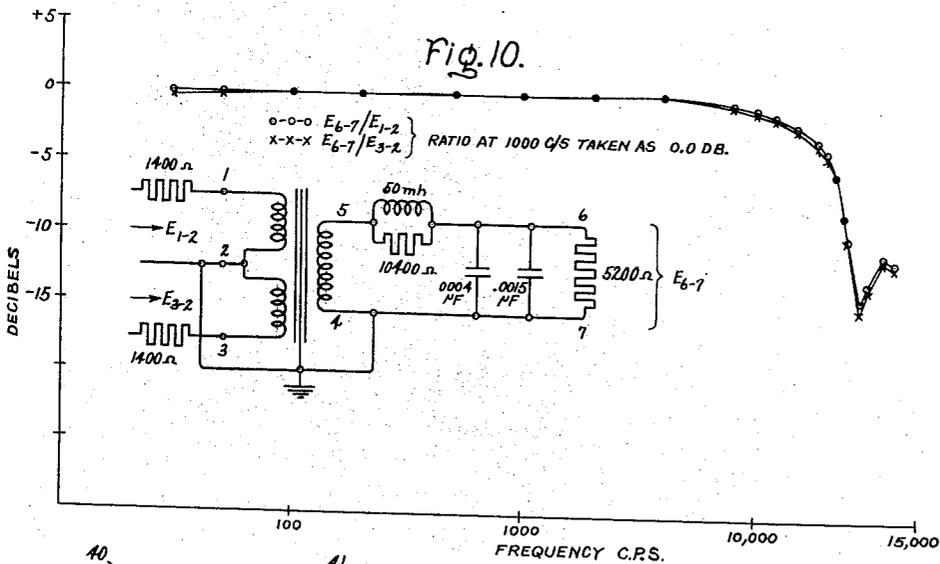
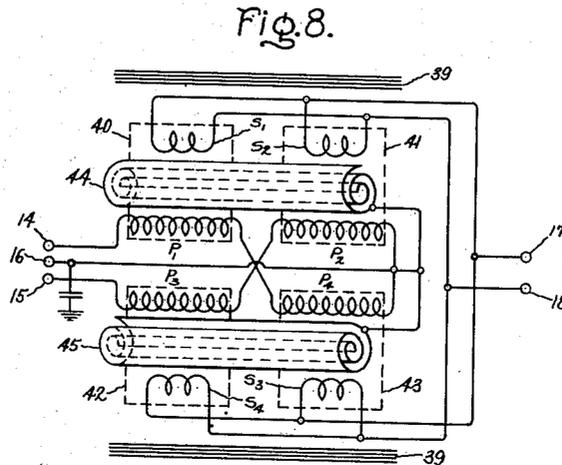
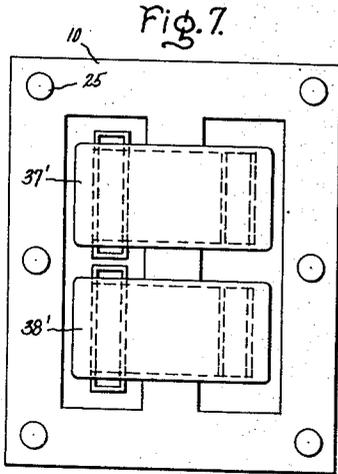
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2,553,324

WIDE BAND AUDIO AND VIDEO TRANSFORMER

Filed July 27, 1949

2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,553,324

WIDE BAND AUDIO AND VIDEO TRANSFORMER

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Application July 27, 1949, Serial No. 107,131

9 Claims. (Cl. 171-119)

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My invention relates to improvements in wide band audio and video frequency transformers and, more particularly, to improvements in such transformers wherein electrostatic shielding is employed.

In circuits employing wide-band transformers, for example audio-frequency or video-frequency amplitude modulation circuits, previous transformer designs have not provided sufficient high frequency response at frequencies above 10 kilo- cycles to permit the use of feedback without the addition of correction networks. One source of trouble lies in the lack of symmetry between the two halves of the push-pull, primary winding of the transformer. This unbalance may be traced to leakage inductance and to capacitance un- balances.

In attempting to design a transformer having a desired band-pass characteristic, a number of conflicting factors are encountered. With a given size of core, the total number of turns is fixed by the voltage and impedance requirements at the low frequency end of the required pass- band. The leakage inductances and distributed capacitances of these coils may be so high as to cause cut-off or distortion at a high frequency which is less than the desired value (e. g., from 150 kc. up to 2 mc.). Some improvement may be made by increasing the size of the core to reduce the turns and by inter-leaving the coils, but such gains as are thereby made in reduced leakage inductances are often more than offset by in- creased distributed capacitances due to longer mean turns and a greater number of coil surfaces.

Electrostatic shields have been used to reduce the effects of distributed coupling capacities be- tween windings (which account for much of the capacitance unbalance). By making the wind- ings symmetrical, the leakage inductances and distributed capacitances will then be more nearly balanced. However, the addition of electrostatic shields tends to increase the distributed capaci- tances in shunt with the windings. Hence, a balanced design is not easily obtained without either increasing the distributed capacitance or the leakage inductance between the halves of the primary winding. The increase of the leakage inductance between the halves of the primary is especially undesirable for class B push-pull operation, due to the half-wave operation of these windings.

In accordance with my invention, many of these design difficulties are overcome, and su- perior band-pass characteristics are obtained, by employing a plurality of electrostatic shields

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which are constructed and coupled together in a particular manner, as will be more fully described in the following specification. Briefly, I employ at least two spiral or helical electrostatic shields between sections of the primary and secondary windings. Each of these shields has one or more turns, and the several shields are so coupled electrically that voltages induced therein, due to leakage flux, assist each other in producing cir- culating shield current which in turn produces a magnetomotive force opposing that due to cur- rents in the primary and secondary windings. Voltages induced therein due to normal core fluxes are equal and subtractive; hence, they pro- duce no circulating shield current.

It is therefore an object of my invention to provide an improved high-frequency transformer that has low leakage inductance as well as low distributed capacitance.

It is a further object of my invention to pro- vide an improved high-frequency, wide-band transformer having improved electrostatic shield- ing means.

A further object of my invention is to provide an improved wide-band, push-pull Class B modu- lation transformer having improved response at high frequencies without sacrificing low fre- quency performance.

For additional objects and advantages, and for a better understanding of the invention, atten- tion is now directed to the following description and accompanying drawings. The features of the invention believed to be novel are particu- larly pointed out in the appended claims.

In the drawings:

Fig. 1 is a circuit diagram of a push-pull modu- lation transformer embodying my invention;

Fig. 2 is a side elevation view of a shell-type transformer structure having the circuit arrange- ment of Fig. 1, with certain portions cut away to show details of internal constructions;

Fig. 3 is a sectional end view of the transformer structure of Fig. 2 looking upward from the plane 3-3;

Fig. 4 is a partially cut-away, side elevation view of a modified transformer structure which may also have the circuit arrangement of Fig. 1;

Fig. 5 is a circuit diagram of a push-pull trans- former of the multiple coil type embodying the invention;

Figs. 6 and 7 are side elevation views of a core type and a shell type transformer, respectively, which may utilize the circuit arrangement of Fig. 5;

Fig. 8 is a schematic diagram of another type

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of multiple coil, push-pull modulation transformer embodying the invention and having four pairs of windings;

Fig. 9 is a side elevation view of the transformer of Fig. 8, with one of the coil assemblies partially cut away to show internal construction; and

Fig. 10 shows a particular test circuit and resultant frequency response characteristics for an audio modulation transformer embodying the invention.

In the several figures of the drawing, corresponding elements have been given corresponding reference numerals. In the structural views of Figs. 2, 3, 4, 6, 7 and 9, external terminal connections, and connections between transformer windings have been omitted, since they are clearly shown in the corresponding circuit diagrams and their inclusion in the structural views would only tend to cause confusion.

The transformer shown in Fig. 1 comprises a laminated magnetic core 10, a pair of primary windings 11 and 12 and an intermediate secondary winding 13. The primary windings 11 and 12 are connected in series between a pair of input terminals 14 and 15, with a center-tap connection to an input terminal 16 to permit push-pull input. The secondary winding 13 is connected to a pair of output terminals 17, 18. In accordance with my invention, the respective primary windings are shielded from the interposed secondary winding 13 by means of grounded electrostatic shields 19 and 20. The shields 19, 20 are also represented in the form of windings, the structure of which will be more fully explained shortly, and they are connected in a closed circuit in such polarity that voltages induced therein due to leakage flux will assist each other in producing circulating current therein. Voltages induced therein due to the no-load component of core flux are substantially equal and opposite; hence practically no circulating shield current flows under no-load conditions and normal excitation.

One practical form of construction of the transformer of Fig. 1 is represented in Figs. 2 and 3. The magnetic core 10 is represented as being of the shell type and consists of a rectangular stack of laminations secured together in any suitable manner, as by rivets 25. The coils and shields are all concentrically wound on a central leg of the core, with the secondary winding interposed between the inner primary winding 11 and the outer primary winding 12. The secondary winding 13 is also shielded from the primary windings 11 and 12 by the shields 19 and 20, respectively. In this embodiment, the shields 19 and 20 are each composed of several turns of a conducting metal strip, preferably copper, formed into a tubular spiral, having a width substantially equal to the axial length of the transformer windings. The several turns of each shield are insulated from each other by any suitable material, and also insulated from the adjacent coil windings. As is best seen in Fig. 3, tubular spiral shields 19 and 20 are connected in a closed circuit by means of end straps 26 and 27 to form a closed circuit. The shields are wound in opposite directions and the inner end of shield 19 is connected to the outer end of shield 20 by means of connecting strap 26, while the outer end of shield 19 is connected to the inner end of shield 20 by means of connecting strap 27. The opposite edges of the shields are also preferably connected together in similar manner,

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as represented by the connecting straps 28 and 29 in Fig. 2, in order to provide sufficient current-carrying capacity. Thus the two shields are connected together in a closed circuit, and the polarities of the windings are such that leakage flux cutting the shields, due to load current in the secondary or either primary, induces additive voltages therein. This in turn causes a circulating current to flow in the two shields which develops a magnetomotive force opposing that producing the leakage flux and effectively reducing the net leakage inductance of the transformer.

While my invention is not limited in its broad application to the specific arrangements or dimensions of the various elements, as a practical matter I have found that the sum of the conductor cross-sections of the two shields should be reasonably large as compared to the conductor cross-section of the secondary winding for most satisfactory operation. It is desirable that this ratio should approach one to one. That is, the active cross-sectional area of the metal shield 19, as viewed in Fig. 3, plus the active cross-sectional area of the metal shield 20 should roughly equal the active cross-sectional area of the secondary winding 13. However, this is not too critical, and actual tests have shown that this ratio can be varied over a considerable range without losing effectiveness insofar as reduction of harmonic distortion at high frequencies is concerned. If copper strip of sufficient thickness is used for the shields, only a single turn may be necessary for one or both of the shields; otherwise several turns may be necessary to obtain the necessary cross-sectional area of metal, as represented in the embodiment of Figs. 1-3.

Fig. 4 shows a similar transformer construction embodying my invention, but which differs from the construction previously described in that the shields 19' and 20' are each composed of a heavy, narrow copper strip formed into a single-layer helix. The two windings are connected together at their ends by means of suitable straps 35 and 36, so as to permit flow of circulating current due to the leakage flux in the same sense as in the previously-described construction of Figs. 1-3.

Fig. 5 is a schematic diagram of a transformer having two sets of magnetically-coupled coils 37 and 38, of the type commonly employed in Class B push-pull amplifier circuits. Each of the two sets of coils and shields may be constructed in exactly the same manner as previously described in connection with the embodiment of Figs. 1-3 or in connection with the embodiment of Fig. 4. Therefore, the corresponding windings in the two sets have been given the same reference numerals with the suffix letters *a* and *b* added. In this type of transformer, the four shielding windings 19*a*, 20*a*, 19*b*, 20*b* all have their lower ends effectively grounded at signal frequencies through bypass capacitor 22. Figs. 6 and 7 further illustrate that the two sets of coils in the transformer of Fig. 5 may be magnetically coupled either by means of a core type of construction, having the coils 37 and 38 on opposite legs as represented in Fig. 6, or by means of shell type of construction, having similar coils 37' and 38' on the same leg as represented in Fig. 7.

Figs. 8 and 9 respectively illustrate the circuit arrangement and mechanical construction of another type of multiple winding modulation transformer embodying my invention. This construc-

tion employs two sets of magnetically-coupled coils 40 and 41 on one leg of a rectangular laminated core 39, and two other sets of magnetically-coupled coils 42 and 43 on the other leg of the core. This transformer is represented as being of the step-down type, commonly employed in audio modulation circuits, having four primary windings P₁, P₂, P₃ and P₄ cross-connected in series-parallel relation, and also having four corresponding secondary windings S₁, S₂, S₃ and S₄ all connected in parallel.

The shield construction in the transformer of Figs. 8 and 9 differs from that of previously-described constructions. The upper sets of coils 40 and 41 are provided with a common shield 44 in the form of a tubular spiral having an axial length sufficiently great to extend completely through the two sets of coils. The lower sets of coils 42 and 43 are similarly provided with a common spiral shield 45. In this construction the right-hand and left-hand sections of each of the shields 44 and 45 each respectively perform the function of one of the two shields in the constructions of Figs. 1-3. Since each shield is in the form of a single continuous sheet extending between two sets of coils, there is no necessity for additional connecting straps across the ends to complete a closed current path through the shield sections. For example, assume an instantaneous direction of current flow in the primary winding P₁ in Fig. 8 such that leakage flux due to loading of the secondary section S₁ induces a flow of current from the inner surface of the left-hand section of shield 44 toward the outer surface thereof. At the same time, since the instantaneous polarity of primary winding P₂ is reversed, leakage flux due to loading of secondary section S₂ will induce a flow of current in the right-hand section of shield 44 from the outer surface toward the inner surface. Since the two surfaces are electrically connected together through the intermediate portions of the shield between the two sets of coils, it can readily be seen that a closed circuit is provided for the circulating shield currents which functions in the same manner as in the previously-described transformer constructions.

Fig. 10 shows a circuit which was used for testing a particular audio modulation transformer embodying my invention, together with plotted curves showing the frequency response characteristics thereof. The equivalent plate resistances of the push-pull amplifier tubes, which would normally be connected to the input terminals 1-2 and 2-3 of the transformer, were simulated by two 1400-ohm series resistors. The output circuit connected to the terminals 4-5 included a conventional filter network including a 50-millihenry choke shunted by a 10,400-ohm resistor. The .0004 microfarad capacitor simulated the distributed capacitance of the modulation reactor which would normally appear in the output circuit, while the .0015-microfarad capacitor simulated the load and by-pass capacitances of the transmitting system. The 5200-ohm resistance simulated the plate resistance of the modulated tube.

The plotted curves of Fig. 10 show that the output voltage for this particular circuit combination was flat within 3 db. from about 30 cps. to about 12,000 cps. If the transformer had been feeding a pure resistance load, even better high frequency response would have been secured.

It will be appreciated that in any of the transformer constructions embodying my invention,

leakage flux appears between the two shield sections whenever current flows in a secondary winding or any primary winding, causing voltage unbalances which induce circulating shield currents. These currents, in turn, develop magnetomotive forces opposing those due to the leakage flux and thereby effectively reduce the transformer leakage inductance. By increasing the spacings between the windings, the distributed capacity is also reduced. Tests on actual transformers have shown a substantial reduction in the leakage inductance of the transformer, as well as substantial improvements in high frequency response and wave shape of the primary voltage. Calculations on a particular configuration show that, by employing the shielding construction of my invention, it should be possible to reduce the leakage inductance to about two-thirds of the value which it would have without the shielding windings. Actual tests on transformers built according to this invention have shown some error between calculated and measured values of leakage inductance, the latter values being considerably lower. This can be attributed to the effect of the winding resistances upon the measurements. However, careful distortion measurements upon a series of test transformers, arranged so as to permit insertion of resistance in the shield current path, have shown that the degree of effectiveness in distortion reduction corresponds very well with that of the calculated value of inductance, rather than with the measured value. While not limited thereto, I have found that this type of construction is particularly suited to class B audio and video modulation transformers in which it is normally difficult to reduce distortion to a reasonable value, due to the non-uniform loading of the transformer over the operating cycle.

While several specific embodiments have been shown and described, it will, of course, be understood that various other modifications may be made without departing from the invention. The appended claims are therefore intended to cover any such modifications within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A transformer comprising a magnetic core and at least two primary windings each magnetically coupled through said core to a secondary winding, a conductive electrostatic shield interposed between each said primary winding and the associated secondary winding, each of said shields also comprising an insulated winding of at least one turn, and means electrically coupling said shields together in a closed circuit in such polarity that voltages induced in the respective shields due to transformer leakage flux are additive, whereby current flows in said circuit which is effective to reduce the leakage inductance of said transformer.

2. In an inductance device, a magnetic core structure, a plurality of coupled windings arranged around said core, a plurality of conductive electrostatic shields interposed between said windings, means for insulating said shields from said windings, said shields each having the shape of a winding of at least one turn, and means for connecting said shields in a closed circuit so that additive voltages are induced therein due to leakage flux between said coupled windings, whereby circulating currents flow in said shields which are effective to reduce the leakage inductance of said device.

3. A coupling transformer of the push-pull to single-ended type comprising a core structure, a secondary winding and a pair of series-connected primary windings, said windings being coaxially arranged around said core structure with said secondary winding interposed between said primary windings, an electrostatic shield interposed between one of said primary windings and said secondary winding, a second electrostatic shield interposed between the other of said primary windings and said secondary winding, means for insulating said windings from said shields, each of said shields comprising one or more insulated turns of electrically conducting material, means for connecting said shields in a closed electric circuit in which leakage flux between said primary and secondary windings induces a circulating current which produces a flux opposing said leakage flux.

4. A wide-band coupling transformer comprising a pair of interconnected primary windings each coaxially wound with a secondary winding around a leg of a common magnetic core structure, a shielding winding interposed between each said primary winding and the associated secondary winding, and means connecting said shielding windings in closed circuit so that leakage flux cutting each shielding winding due to current in said transformer induces additive voltages in said circuit.

5. A high-frequency, wide-band transformer comprising an even number of interconnected primary windings each coaxially arranged with respect to a secondary winding on a common magnetic core structure, a conductive electrostatic shield insulated from and interposed between each said primary winding and associated secondary winding, each shield consisting of a metal sheet having a width at least equal to the axial length of the adjacent secondary winding and formed into a multi-turn spiral coil, and means electrically connecting said shields in a closed circuit in such polarity that leakage flux cutting each shield induces an additive voltage in said circuit.

6. A wide-band coupling transformer comprising a magnetic core and a pair of primary windings each coaxially arranged with respect to a secondary winding, an electrostatic shield interposed between each said primary winding and the associated secondary winding, each of said shields being formed of a flat metal strip coiled into a spiral of one or more turns, means insulating said turns from each other and from said windings, the axial length of each of said shields being at least as great as that of the adjacent secondary winding and the sum of the effective conductor cross-sectional areas of said shields being comparable to the effective conductor cross-sectional area of said secondary winding, and means electrically coupling said shields in a closed electrical circuit in such polarity that leakage flux between the adjacent windings induces a circulating current in said coupled shields, thereby producing a flux opposing said leakage flux.

7. A high-frequency, wide-band coupling transformer having a set of input terminals and a set of output terminals, a common magnetic core having three coaxial coils thereon, the inner and outer ones of said coils being interconnected with one set of said terminals and the intermediate coil being interconnected with the other

set of said terminals, a pair of conductive, electrostatic shields interposed respectively between said inner and outer coils and said intermediate coil and insulated therefrom, each shield comprising one or more insulated turns of metal sheet formed into a spiral, said shields having axial lengths at least equal to the axial length of said coils, and means conductively interconnecting the edges of said two shields so that leakage flux cutting either of said shields induces a circulating current through both shields which produces a flux opposing said leakage flux, thereby effectively reducing the leakage inductance of said transformer.

8. A high-frequency, wide-band coupling transformer having a set of input terminals and a set of output terminals, a common magnetic core having three coaxial coils thereon, the inner and outer ones of said coils being interconnected with one set of said terminals and the intermediate coil being interconnected with the other set of said terminals, a pair of conductive, electrostatic shields interposed respectively between said inner and outer coils and said intermediate coil and insulated therefrom, each shield comprising a flat metal strip formed into a single-layer helix having an axial length at least equal to the axial length of said coils, and means conductively connecting said two helices in a closed circuit in such polarity that leakage flux cutting either of said shields induces a circulating current in said circuit which in turn produces a flux opposing said leakage flux, thereby effectively reducing the leakage inductance of said transformer.

9. A high-frequency, wide-band coupling transformer having a set of input terminals and a set of output terminals, a common magnetic core having three coaxial cylindrical coils thereon, the inner and outer ones of said coils being interconnected with one set of said terminals and the intermediate coil being interconnected with the other set of said terminals, a pair of conductive, electrostatic shields interposed respectively between said inner and outer coils and said intermediate coil and insulated therefrom, each shield comprising a flat metal strip formed into a single-layer cylindrical helix having an axial length at least equal to the axial length of said coils, the sum of the effective conductor cross-sectional areas of said shields being comparable to the effective conductor cross-sectional area of said secondary winding, and means conductively connecting said two helices in a closed circuit in such polarity that leakage flux cutting either of said shields induces a circulating current in said circuit which in turn produces a flux opposing said leakage flux, thereby effectively reducing the leakage inductance of said transformer.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,388,473	Dunton	Nov. 6, 1945

FOREIGN PATENTS

Number	Country	Date
390,348	Great Britain	May 31, 1932