

Oct. 4, 1966

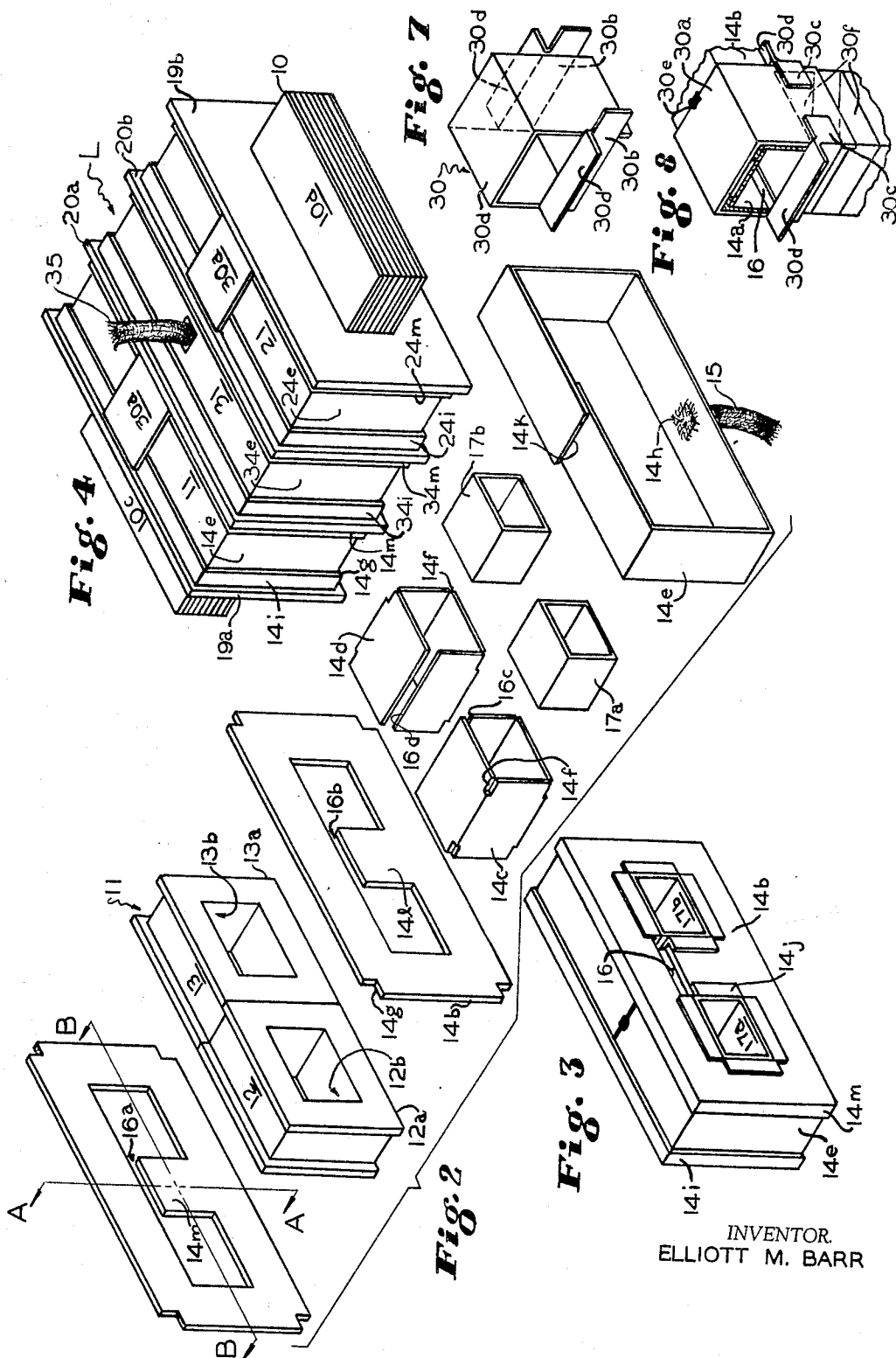
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3,277,416

SHIELDING ARRANGEMENT FOR TRANSFORMER

Filed Dec. 4, 1962

3 Sheets-Sheet 2



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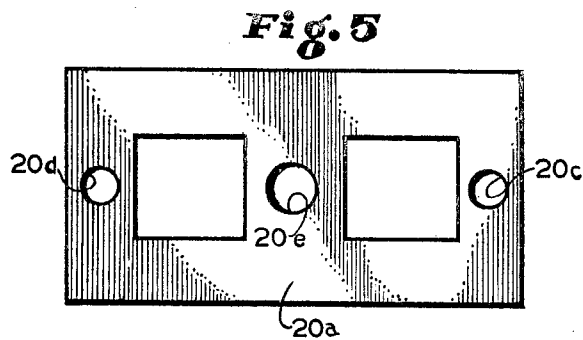
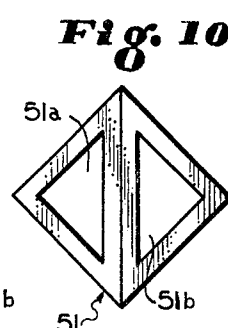
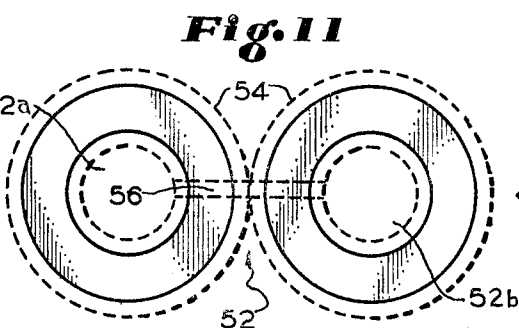
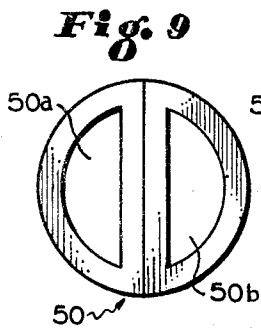
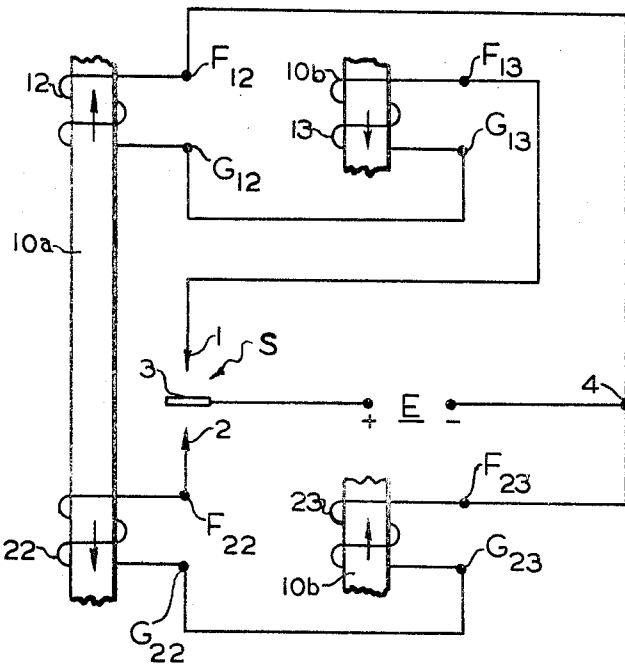
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SHIELDING ARRANGEMENT FOR TRANSFORMER

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United States Patent Office

3,277,416

Patented Oct. 4, 1966

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3,277,416

SHIELDING ARRANGEMENT FOR TRANSFORMER
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Filed Dec. 4, 1962, Ser. No. 242,304
10 Claims. (Cl. 336—84)

This invention relates to transformers and the general object of the invention is to provide a transformer of improved interference-rejection properties.

Another general object of the invention is to provide a transformer having shielded windings, that is readily produced in quantity, with a minimum of hand-crafting and individual attention, yet with such quality and precision of construction as to fulfill rather exacting performance specifications, particularly as regards interference rejection.

Other, more specific objects of the invention will emerge from the detailed description and claims appended hereto.

FIGURE 1 illustrates a measuring system, or the like, in combination with my novel transformer;

FIGURES 2 and 3 respectively illustrate an exploded shielded winding unit or module according to the invention, and the same unit in assembled condition;

FIGURE 4 illustrates a transformer, according to the invention, made up of winding units of the type shown in FIGURE 3;

FIGURE 5 illustrates a winding unit spacer for use in the transformer of FIGURE 4;

FIGURE 6 is a fragmentary diagram, along the lines of FIGURE 1, illustrating electrical interconnection of the winding modules used in the transformer of FIGURE 4;

FIGURES 7 and 8 respectively illustrate a cover that may be used to provide supplementary shielding for the winding unit of FIGURE 3, and a fragmentary view of such winding unit with said cover in place thereon; and

FIGURES 9, 10 and 11 elaborate a concept relied upon in expressing a structural feature of the invention.

FIGURE 1 illustrates, quite generally, my novel transformer in combination with such entities as may be provided in order that the whole defines what amounts to a measuring system.

Thus, a transducer T having a D.C. output (a thermocouple, say, sensing the temperature in a process of some sort), is provided, the E.M.F. of which is applied to a reference unit R which in turn provides a D.C. bias for the E.M.F. of the transducer T, and produces a net D.C. output combining the D.C. bias and transducer output.

At this point, it is convenient to chop the D.C. signal and modulate an A.C. carrier with the D.C. signal, or otherwise operate on the D.C. signal to the end of providing an A.C. signal, some characteristic of which is representative of the amplitude of the D.C. signal at any given instant more or less. For this purpose I provide the switch S, which is essentially a single pole, double throw switch having fixed contacts 1 and 2, and movable contact 3. Suitable means (not shown) are provided for vibrating contact 3 between contacts 1 and 2, to make and break the latter cyclically. Typically, the movable contact 3 is driven at the A.C. mains frequency (e.g., 60 cycles per second).

To convert the action of switch S to a modulation a transformer L, of construction peculiar to my invention, is provided. Transformer L is comprised of the continuous closed core 10 and a set of windings, including windings 11, 21, 31, of which windings 11 and 21 form a compound primary winding and winding 31 is a secondary winding. Core 10, in practice, would be built up from a number of laminations having the form of core 10, as illus-

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trated in FIGURE 1, which laminations would normally be made of some ferrous or like material having the usual magnetic properties associated with iron, steel, etc.

Winding 11 consists of two distinct induction coils 12 and 13, the turns of which are so oriented that a D.C. current therein in a given sense induces a magnetic flux in core 10 that is proportional to the total ampere turns represented by the coils 12 and 13.

Winding 21 consists of two distinct induction coils 22 and 23, the turns of which are so oriented that a D.C. current therein in a given sense induces a magnetic flux in core 10 that is proportional to the total ampere turns represented by the coils 12 and 13.

Windings 11 and 21 are made identical in total ampere turns, etc., so that the same given current in either winding will produce the same given magnetic flux in core 10. In order to apply this characteristic to the use of modulation, coils 23 and 13 are provided with a common terminal 4 and this common terminal 4 is connected to one side of the output of reference device R, those ends of windings 11 and 21 being chosen for connection to terminal 4 such that with respect to current flow into or out of terminal 4, the ampere turns of the one winding will have a sense opposite to the sense of the ampere turns of the other winding.

Accordingly, modulation is made possible by connecting the remaining end of winding 11 to fixed contact 1 of switch S, the remaining end of winding 21 to fixed contact 2 of switch S, and the remaining side of the output of reference device R to movable contact 3 of switch S.

Supposing a D.C. voltage to exist between terminal 4 and contact 3, it will be observed that also supposing windings 11 and 21 to have the same ampere turns and supposing the contacts 1, 2 and 3 of switch S to be shorted together, the winding sense depicted in FIGURE 1 indicates that the net core flux created, as a result of current flow simultaneously through windings 11 and 21, would be zero, since the induction action of the said windings are in mutual opposition; (note arrows on legs 10a and 10b, indicating this). Therefore, considering switch S as FIGURE 1 actually depicts it, moving contact 3 first to one of contacts 1 and 2, and then to the other thereof, would result in first energizing but one of windings 11 and 21, and then in energizing solely the other thereof, with the further result that a finite value of core flux having a given sense would first arise only to be followed by a core flux in a sense opposite said given sense.

As FIGURE 1 indicates, secondary winding 31 consists of coils 32 and 33, the ampere turns of which are so directed that the inductive characteristic of the one coil aids that of the other. The repetition of the make-break cycle of switch S, as described above results in voltages being induced in coils 32 and 33 by transformer action, and these coil voltages would add to produce a voltage across the coils in series that would be the sum of the absolute magnitude of the individual coil voltages at any given instant. The output voltage across winding 31 is an A.C. voltage of substantially square wave form.

I therefore provide suitable A.C. amplifying means, depicted as amplifier A, in FIGURE 1, for amplifying the output of winding 31, in order to provide a suitable input for a load M connected to the output of amplifier A. In view of what has already been said herein, by way of illustration, as to transformer T and reference device R, load M may be considered essentially a motor having for its purpose the operation of a valve or other control element, or of a recorder, indicator, or other exhibiting device. In the former case, a conventional arrangement would be that valve or control element operation by motor M would change a temperature sensed by transducer T in such fashion that the D.C. output

of the transducer would neutralize the D.C. bias of reference device R, thereby reducing the net output of device R to zero. In the latter case, the motor would operate not on the temperature sensed by transducer T, but on the reference device R, adjusting the bias of the latter to neutralize the E.M.F. of the transducer, thereby reducing the output of device R to zero, as in the said former case, and, at the same time, adjusting the position of a pointer, recorder-stylus, or the like, to correspond to said temperature.

Functionally speaking, the foregoing is well known in the prior art, is a matter of routine practice, and, as to the modulation and transformer aspects thereof is considered to be desirable practice for a number of reasons, including the fact that use of transformer coupling creates the possibility of rejecting certain types of electrical interference at the transformer. For example, at some point in the output circuitry connected to secondary winding 31 there will be a circuit common, a ground to one side of the A.C. mains, or the like, which could couple through the signal circuit to a point of a potential differing from that of the line voltage. Suppose, for example there is an output circuit ground to one side of the A.C. mains, and the transducer T is a thermocouple and happens to contact the other side of the mains. Obviously, the transformer L is a barrier to completing a circuit across the A.C. mains via the signal circuit.

In practice, however, the matter is not so simple for the transformer is obviously not an infinite D.C. resistance, and necessarily has some capacity coupling its primary and secondary windings together. It is, moreover, subject to the effect of stray fields, both electrostatic and electromagnetic. These effects are normally dealt with by proper insulation, electrostatic shielding, magnetic shielding, and careful attention to impedance relations, mode of arranging circuit connections, and so forth.

While some of these effects may be eliminated, or almost wholly suppressed, after a point, relatively little can be done with the capacitance of the transformer, other than to arrange the elements of this capacitance in such a way as to reduce the net effect thereof in the matter of coupling interference into the secondary circuit of the system, or to complicate the circuitry with active devices, such as amplifiers, arranged to neutralize transformer capacitance, and having that sole purpose, essentially.

One expedient for controlling the capacity of a transformer and for rejecting electrostatic influences is shielding. Such shielding is shown in FIGURE 1, wherein the broken lines denoted by numerals 14, 24 and 34 represent electrostatic shields. For the present, each shield may be considered an envelope, made of D.C. conductive material, such as metal foil, metallized paint, metal mesh, or the like, defining an integral, equipotential surface completely surrounding one of the windings 11, 21 and 31, except where it is necessary to take the winding leads out of the shield to some point exterior to the transformer as a whole, indicated at 15, 25 and 35, which numerals denote lengths of tubular metal braid, or the like, D.C.-connected to the corresponding shield. It should be added that the shielding is conveniently extended around the various primary leads, the modulator, and, in general, around any impedance in the primary circuit of the transformer, the whole shielding system (except shield 34 and its extension 35 on the secondary side of the transformer) thus constituted being connected to some potential in the primary circuit. The remainder of the shielding, namely shield 34 and its extension 35, are connected to ground or equivalent, on the secondary side. Conveniently, the primary shielding is left floating on one of the transducer terminals. Therefore, should a signal between ground or equivalent, and the primary shielding arise (say that transducer T is a thermocouple and it or one of its leads contacts a point at a potential

different from that of the shielding on the secondary side of the transformer), a current will flow between shield 34, on the one hand, and shields 14 and 24 on the other via the capacitance between the former and each of the latter. With the arrangement of coils and shields shown in the drawing, this capacitive current will be unable to induce any net flux in the core. For example, consider current flow between shields 14 and 34, in the sense of the arrows placed just over those portions of core legs 10a and 10b between shields 14 and 34. Here it is evident that any flux created in leg 10a by the said current will be opposed by the flux created in leg 10b by the current. Supposing the intershield current to be uniformly distributed in the space between the shields, and legs 10a and 10b to be parallel and alike, the net flux thus created will be zero.

The same follows if we consider the intershield current between shields 24 and 34, having reference to the arrows placed just over the portions of legs 10a and 10b showing between shields 24 and 34, which arrows indicate the sense of the current flow between shields 24 and 34, when the current between shields 14 and 34 is as indicated supra. It will be noted that if either lead to contacts 1 and 2 of the modulator were broken (which would change the modulating action half-way instead of full-wave, and which is feasible) the operative remainder of the transformer coupling would still remain unaffected by the interfering current.

Likewise, it will be apparent that the leads of either one of windings 11 and 21 could be interchanged (at contact 1 and terminal 4), and an A.C. signal to be measured placed directly across terminals 1 and 2. (We may suppose that we have modulated some external A.C. carrier in accordance with the output of reference device R in preference to chopping said output in the manner shown, and still desire to couple the modulated A.C. carrier to the amplifier A via transformer L.)

As indicated, each individual coil of windings 13, 23 and 33 circumscribes one or the other of legs 10a and 10b of core 10. Each of shields 14, 24 and 34, therefore, necessarily circumscribe both of legs 10a and 10b as a whole, thereby creating a D.C.-conductive closed path about legs 10a and 10b as a whole. This path is the equivalent of a shorted turn circumscribing the two legs, but since any net flux in core 10 appears to the shorted turn as a flux in leg 10a in one sense, and as the same flux in leg 10b, but in a sense opposite said one sense, that flux which is created by primary windings 13 and 23 does not create any net voltage in one sense or the other in said turn.

On the other hand, the shorted turns defined by shields 14, 24, and 34 have several beneficial effects. One of these is that the shields "strap" the transformer, namely, a common transformer practice is to circumscribe the transformer with a single band of copper, or the like, so as to define a shorted turn about the core of the transformer as a whole, for the purpose of cutting down flux leakage from the transformer core. It will be appreciated that flux leakage can create unbalanced conditions in the transformer resulting in undersired voltages due to uneven flux distribution, and/or unintended linkages between coils due to stray flux.

The foregoing aspect of the shields 14, 24 and 34 is electromagnetic in nature as opposed to their electrostatic properties, which would be relatively little affected if the closed turns were cut through so as to prevent circulation of a current around the core 10 via the shield.

Another aspect of the shields has to do with the core to winding and/or shield capacitance. If this capacitance couples an interfering current through the transformer via the two legs 10a and 10b of core 10, the shorted turns of the shields will induce a counter-current in said legs that will reduce the net effect of the interfering current. This, again, is an electromagnetic effect of the shields.

It is to be noted that it is often as necessary to so con-

fine the magnetic field of the transformer, as it is to keep external fields out of the transformer, which is frequently housed in Mumetal, or like external magnetic shielding, for this dual purpose. Since the strapping effect of shields 14, 24 and 34 aids in this insofar as the transformer field is concerned, the degree of shielding effect required of the external magnetic shielding, is substantially reduced.

As FIGURE 1 suggests, the shielding configuration necessary to fulfill the functions set out above is obtained most conveniently by means of bobbin-type coils, that is, coils which are each wound on its own form, spool or bobbin, which are then mounted side by side on the core legs. This is to be contrasted to layer-style winding wherein the individual coils are wound in layers, one on top of the other with interleaving shielding between winding layers, as may be appropriate, and often on but one leg of an E-I core, in an attempt to secure some degree of freedom from interference in the form of intershield current. While it is evident that the windings and shields of FIGURE 1 could be laid one on top of the other without altering the electrostatic shielding effect of the shields, the path or paths of the capacitive current between the shields would be at right angles, more or less, to that taken by said current in the transformer according to FIGURE 1. As a result, a net flux would be created in the core, for the capacitive current now would be directed in and out of the plane of FIGURE 1 with the result that whether the current path were between the legs 10a and 10b, and/or to one side or another of either or both legs 10a and 10b, additive fluxes would be induced in the core 10.

Various proposals have heretofore been made, in the way of layer-type winding and shield arrangements, in which the intershield current is supposed to be neutralized or compensated for.

However, I have found it is most difficult to obtain effective shielding and balance of the transformer structure by following these prior art proposals, and practically impossible to do so on a mass production basis. In contrast, the principles of my invention, as shown in FIGURE 3, can be implemented by the coil unit shown in FIGURES 2 et al., which is easy to produce on a large lot basis, yet may be used to produce well-balanced and efficiently-shielded transformers, with a minimum of skill and effort devoted to adjusting individual transformers for optimum interference rejection properties.

The basis of the unit shown in FIGURES 2 et al. is a dual coil winding wherein the coils are mounted side by side in a sort of "figure-8" shield having a slot, insulated imbrication, or like interruption, completely through the node or septum where the upper and lower bight of the "figure-8," cross or merge, respectively. The structural realization of this form is best apprehended from consideration of the exploded view of FIGURE 2, wherein reference numerals 11, 12 and 13, respectively, denote the half-primary 11, and its coils 12 and 13, of FIGURE 1. Coils 12 and 13 are wound on suitable forms such as square bobbins 12a and 13a, of molded nylon, or other suitable material. Shield 14 of FIGURE 1 is represented by side-plates 14a and 14b, a pair of square ferrules 14c and 14d, and a side-plate spacing band 14e. Side-plates, side-plate spacing band and ferrules must be made of D.C.-conducting material, preferably very thin sheet copper, or like material, the D.C.-resistance of which is low enough to neglect. Thickness of the metal parts has been considerably exaggerated for ease in rendering it in the figures.

Side-plates 14a and 14b are octiform, that is to say, each is shaped like a "figure-8," and each is slotted through the septum of the "figure-8," as shown at 16a and 16b, respectively. Moreover, ferrules 14c and 14d are slotted along their lengths as shown at 16c and 16d, respectively. Finally, the four corners of each of side-plates 14a and 14b are notched, as exemplified at 14g on side-plate 14b, and the ferrules each have their six corners (being open at both ends, each would have eight corners, four at each

end, save that the slot therein takes in two of the eight) slit or notched out, as exemplified in heavy black line, both at 14f of ferrule 14d, and at the other of the said six corners of each ferrule.

The exploded parts so dimensioned that if they are compressed, to the state indicated in FIGURE 3, side-plates 14a and 14b, ferrules 14c and 14d, and spacing band 14e, form a complete envelope for the winding 11, including coils 12 and 13, and their bobbins 12a and 13a, except for slots 16a through 16d, and a hole 14h in spacing band 14e.

As indicated, the coils 12 and 13 are square-wound, hence windows or cut-outs 12b and 13b in the bobbins 12a and 13a, are square, too, as are the corresponding windows or cut-outs in side-plates 14a and 14b, and the corresponding passages through ferrules 14c and 14d.

As is evident from FIGURE 3, the notches 14f, 14g et al., of FIGURE 2, create tabs along the peripheries of side-plates 14a and 14b, and along the ends of ferrules 14c and 14d, that may be bent over, as exemplified at 14i, 14n, and 14j, whereby the ferrules 14c and 14d clasp spacer band 14e and side-plates 14a and 14b, and side-plates, ferrules, and spacer band form one continuous whole insofar as D.C. conduction is concerned, by reason of the numerous metal to metal contacts made at the peripheries and windows of the side-plates 14a and 14b, the edges of the band 14e and the ends of ferrules 14c and 14d.

However, the slots 16a through 16d, join end to end, so that the D.C. path from the vicinity of holes 14h to 14k, which latter marks the place where the strip of metal defining the space band has its ends soldered together to close the spacer band, does not include the septum of the octiform shape, that septum being, in the assembled shield or shielded winding module, the composite of the next adjacent sides of ferrules 14c and 14d, and the septa separating the windows of side-plates 14a and 14b. The composite septum, thus defined, is thus slotted completely through by the composite slot 16, composed of slots 16a through 16d.

The hole 14h in spacer band 14e provides for the coil-leads shielding 15 which, as shown, is tubular flexible braid, preferably copper, or the like, the end filaments of which are splayed over around the circumference of hole 14h, and are soldered to the spacer band 14e.

A pair of open-ended square ferrules 17a and 17b made of insulating material are provided so that the core legs 10a and 10b of core 10 can support the half-primary 11, without being in electrical contact therewith.

The slot 16, it will be noted, is located at one extremity of the septum of the shield 14, and the leads 18 of the primary-half are located directly opposite, but like the slot, symmetrically disposed with respect to the windows in the shield and core assembly, which windows are formed by the square passages through ferrules 17a and 17b. Coils, ferrules, side-plates and spacer band are bilaterally symmetric in shape, number of turns, etc., with respect to a plane A-A extending in the line of the explosion of parts in FIGURE 2, which plane would also be a vertical bisector of core 10, normal to the view adopted in the case of FIGURE 1.

FIGURE 4 shows the entire transformer that would result in adopting the construction shown in FIGURES 2 and 3 for all three windings, 11, 21 and 31. The complete assembly also includes spacer plates 19a, 19b, 20a and 20b, there being provided like endmost plates 19a and 19b having substantially the form of side-plates 14a and 14b, and inner spacing plates 20a and 20b of like form except that, as shown in FIGURE 5, holes such as indicated at 20c, 20d and 20e, may be provided for purposes to be indicated hereinafter. Core 10 may be of the usual shell-type wherein the core is formed by stacking windowed, rectangular laminations having one side missing, and butting these with a stack of solid laminations correspond-

ing to the missing sides to substantially confine the magnetic circuit in a ferrous loop.

The four plates 19a, 19b, 20a and 20b are made of insulating material so that, as will be evident from FIGURES 3 and 4, the shielding 14, 24, and 34 is insulated from each other by plates 20a and 20b, and from core 10 by plates 19a and 19b and ferrules 17a and 17b.

Also visible in FIGURE 4 are the bent-over edges 24i, 24n, 34i and 34n corresponding to like bent-over edges 14i and 14n of side plates 14a and 14b, the side plates to which said edges 24i et al. belong not being visible otherwise in FIGURE 4.

Insofar as the shielding 14, 24 and 34 is concerned, each is identical to the other, hence, as FIGURE 4 indicates, the shielding 34 is reversely oriented on the core 10 with respect to shielding 14 and 24. Each of the shielding 14, 24 and 34 is bilaterally symmetric with respect to a plane B—B extending in the line of the exposed parts in FIGURE 2, which plane would be the horizontal bisector of core 10 normal to the view adopted in FIGURE 1, except for hole 14h and its counterparts (not shown) in shielding 24 and 34, joint 14k and its counterparts (not shown) in shielding 24 and 34, and slot 16 and its counterparts (not shown) in shielding 24 and 34, and winding lead shielding 15, 25 and 35. Hence, the non-symmetric elements of shielding 34 (and of the coil leads of the winding therein), therefore are located on the one side of plane B—B, and the corresponding non-symmetric elements of shielding 14 and 24 are located on the other side of the plane B—B and, except for this, bilateral symmetry obtains with respect to plane B—B.

The foregoing construction has quite substantial consequences insofar as is concerned ease of manufacture and assembly, and of predetermination and adjustment of electrical symmetry.

The creation of the shield and winding assembly of FIGURES 2 and 3 would begin with a pair of identical bobbins 12a and 13a, which we may suppose supported in the position shown, but somewhat spaced to permit the coils to be wound therein. Next, envisage winding each bobbin in a sense counter to each other and terminating the winding starts and finish next adjacent each other, so that if we connect the start leads of each coil together and connect the series-connected coils by their finish leads across a D.C. source, the magnetic field of one coil would be exactly opposite the other, and both fields would be parallel to plane A—A.

The coils, wound in this way, then, are supported together as shown in FIGURE 2 with the next adjacent flat edges of their bobbins flush up against each other. The start leads are then soldered together and pigtail leads soldered to the finish leads. The exposed layers of wire are than overlaid with insulating tape (following the path indicated by band 14e, but between the bobbin flanges) passing on both sides of the pigtail leads so that these are centered with respect to the two coils, and depart straight-away therefrom. The pigtail leads are twisted for noise reduction and are coded to permit identifying the individual finish leads. If desired, a perforated strip of mica (not shown) may be laid between the flanges on one side of the taped coil-pair, the pigtails passing through the perforation in the strip, in order to help center the pigtails and protect the coil insulation and insulating tape in the vicinity of the soldered joints in this area from the heat of soldering operations on the shield structure to be applied.

Spacing band 14e, in the form of a flat strip of tinned .005 copper, say, and having hole 14h and braided shielding 15 affixed thereto, as illustrated in FIGURE 2, is bent around the taped coils and soldered at the overlap denoted by reference numeral 14k, the pigtails being received in said hole and braided shield 15. Preferably the strip is wide enough to rest on the edges of the bobbin flanges. Then, the ferrules 17a and 17b may be fitted into the windows 12b and 13b of the taped and banded

coil assembly. The ferrules will be cut long enough that their ends project from both sides of the said windows, about the depth of the notches 14f, whereby the projecting parts of the ferrules define the tabs noted before.

Side-plates 14a and 14b are then fitted to the taped, banded and ferruled coil assembly with the aforesaid tabs projecting from the side-plate windows and more or less flush against the edges thereof. The tabs are then bent over against the side-plates, pressing the latter firmly against the flanges of the coils, and a few, or all thereof, are soldered to the side-plates to assure D.C. continuity between ferrules and side-plates. The side-plates are so dimensioned as to overlap the outer contour of spacer band 14e by about the distance of notches 14g et al., whereby to define tabs, that are then bent over against the outer surface of the spacer band, and soldered to the spacer band at several places or substantially all along the seams therebetween. If place-wise soldering is used, in either or both of the ferrules and side-plates, and the side-plates and ferrules, the symmetry of construction followed thus far should be observed, though it is not strictly essential if the materials used are copper or like highly-conductive material and highly-conductive solder joints can be made. Of course, if good D.C. contact can be made without soldering, say by mere pressure of the assembled transformer parts on each other, by means of conducting paint, adhesive, or the like, soldering may be entirely dispensed with. However, wherever contact is poor or absent, there is a possibility of high resistance or electrostatic leakage, which may electrically unbalance the assembly.

If the transformer to be constructed were to be 1:1 in turns ratio (secondary turns versus half-primary turns), the several windings 11, 21 and 31 may each be exactly identical to the others. Moreover, for ratios other than unity, each half-primary may still be exactly like its fellows, though not like the secondaries. This is because the mode of winding allows the electromagnetic orientation of the half-primaries on the core to be taken care of by interconnecting the half-primaries and chopper, in the manner shown in FIGURE 6, wherein certain of the elements of FIGURE 1 are reproduced in some cases fragmentarily, and the reference device R and transducer T have been replaced by a D.C. source E. In this figure, the reference characters F indicate the finish leads of the several coils 12, 13, 22 and 23, these latter being variously subscribed to the characters F in order to distinguish among the different finish leads. Likewise, the characters G are similarly subscribed to permit distinguishing the several start leads.

It will be recalled that the pigtails of the coils were coded to permit identification of coil leads. We see then that finish lead F₁₂ of coil 12 is in effect a pigtail connected to terminal 4, the center tap of the transformer primary and the negative terminal of source E. Continuing in this vein, start G₁₂ of coil 12 and G₁₃ of coil 13, is the soldered connection made to begin with in producing the coil assembly. Finish lead F₁₃, then, is in effect, a pigtail connected to contact 1 of modulator S.

Again, the start leads G₂₂ and G₂₃ of coils 22 and 23 would be the soldered coil connection made in producing this coil assembly, and finish leads F₂₂ and F₂₃ would be the respective pigtails applied to the finish leads of coils 22 and 23. In this case, however, the pigtail of finish lead F₂₂ of coil 22, is connected to contact 2 of switch S and the pigtail of the finish lead F₂₃ of coil 23 is connected to the center tap 4, that is, electromagnetically speaking, the finish leads F₁₂ and F₁₃ correspond, in that order, to finish leads F₂₂ and F₂₃, in that order.

As a result, if source E is imagined to drive a current from its position terminal, through chopper S and the coils, to its negative terminal and center tap 4, upon following the arrow heads showing the alternate current paths via contacts 1 and 2, it is seen that the flux in legs

10a and 10b is in one sense or the other depending on which of contacts 1 and 2 is made by contact 3. Thus, making contact 2 creates a flux having the sense of the arrow at the lower end leg 10a which continues as indicated in broken line, on to leg 10b, where its sense is in that of the arrow on the fragment of 10b shown inside coil 23. When contact 1 is made, however, the arrow on the top portion of leg 10a, the broken line continuation thereof to the arrow on the portion of leg 10b inside coil 13, and the last said arrow, indicate that the flux in core 10 is reversed in its clock sense from the clock sense it had when contact 2 is made. This is the desired action of course.

The slot 16, and its counterparts (not shown) on the shielded winding modules 24 and 34, is a "window" through which the several coils see each other, and the core, etc., so to speak, via distributed capacitance directly between coils, coils and core, etc. The end to be attained by the shielding, however, insofar as possible, is to assure that no part of the transformer but the shielding directly involves the coils in a distributed capacitance. It is therefore desirable to reduce the residual capacitance directly involving the several coils by capping window 16, and its said counterparts with a slot cover 30, such as is shown in FIGURES 7 and 8 prior to assembling the winding modules on the transformer core (a portion 30a of said cover is visible on modules 14 and 24, as indicated in FIGURE 4).

As FIGURE 7 indicates, cover 30 is simply a more or less U-shaped strip 30a having arms 30b at one end thereof, the said arms and both ends of the strip covering and extending beyond the several parts of slot 16, tabs 30c being provided that are bent over the end of strip 30a, flanges 30d being provided to assure overlap of the slots 16d of ferrules 14c and 14d, and the cover 30, which would normally be of the same D.C. conductive material as spacer band 14e, being solder-tacked to the latter at 30e. It is necessary that the cover 30 be insulated from the portion of the shield-septum extending upward toward slot 16, hence, a few wraps of insulating tape 30f are wound around the last said portion to prevent D.C. contact between cover 30 and said portion of said septum. The tap wraps are shown partly in dotted line. The coil 12 and bobbin 12a and part of the corresponding shielding have been omitted for clarity in FIGURE 8.

Other shielding material that would be suitable are foil, metallized or foil-coated paper. For instance, paper-backed foil is quite convenient, since it can be fitted snugly to the contours of the bobbin-pair 12a and 13a, using suitable adhesive to adhere together pieces, quite similar to those from which the illustrated shielding elements are formed into a homogenous envelope, wherein D.C. conductivity between seams is assured by overlapping the said seams with a layer of D.C. conductive paint. In this type of construction, the foil side of the shielding material would be on the outside. The sheet metal shielding envisaged, supra, is stiff enough to require forming tools to shape, and is not readily maintained in its final shape on the bobbins without soldering. The more flexible material requires no forming tools, holds the shape given it under mere smoothing with the fingers, and eliminates soldering and its possibilities for thermal damage to winding insulation, etc.

The bobbin pair could also be shielding by dipping in D.C. conductive paint, after a preliminary dipping in some insulating resin, paint, or the like, the slot 16 being formed afterward by stripping the paint in the corresponding area, covering the slot with insulating tape, as in the case of the species of FIGURE 8, and painting over the tape from a point spaced from one edge of the tape wrapping to and over onto the original conducting layer bounding the other edge of said tape wrap.

The construction illustrated in FIGURES 2 to 5, inclusive, is inherently symmetric, and this symmetry,

which is a crucial factor in obtaining the highest degree of interference rejection, is readily obtained to almost any desired degree of perfection in a routine manner. Furthermore, though the tolerances involved in stamping out parts, in assembling the winding units and transformers, and so on, may be such that some undesirable degree of asymmetry is displayed by a finished transformer, which symmetry adversely affects the interference-rejecting ability of the finished transformer, such asymmetry is easily compensated for on a lot basis. This is done by adjusting the size of the holes in the spacers 20a and 20b, as for example, holes 20c, 20d and 20e in spacer 20a. These spacers form part of the dielectric of the distributed capacitance between shields 14 and 24, 24 and 34. Adjusting hole sizes relative to each other is, in effect, treating the intershield capacitance as if it consists of three paralleled branches of capacitors, one such branch being centrally through the transformer between and parallel to core legs 10a and 10b, another branch being virtually along leg 10a and the third being virtually along leg 10b. While such adjustment actually only affects the distributed capacity in the immediate vicinity of the holes in the spacer, it provides, to a sufficient approximation, the effect of redistributing the intershield capacitance to the extent desired, and, for any given production lot of transformers, the adjustment of shield-hole size or sizes in one transformer thereof, one thereof in general suits the needs of the others of the lot, i.e., the adjusted spacers are the same in every transformer of the lot. Where the spacers 20a and 20b are initially provided with three holes as illustrated, obviously, one, several or all of the holes of one or of both spacers may require adjustment in a given case.

The spacers 20a and 20b also may be initially provided without such holes, which then are only supplied, in such manner and in such size as is indicated by testing a sample transformer of a given lot to see what the lot needs in the way of adjustment of intershield capacitance. For the purposes of such test, of course, all four spacers 19a, 19b, 20a and 20b of the sample transformer initially would be imperforate (save for the core-leg receiving windows therein, of course).

In any event, the test involved in both cases is basically to determine to what extent an A.C. voltage, across the capacitance between shields 14 and 24 in parallel with the capacitance between shields 14 and 34, is reflected in the voltage across winding 31. For example, one terminal of an A.C. source may be connected to both shielding 15 and 25, and the other terminal thereof to shielding 35. Any difference between the voltage across winding 31 when the A.C. source is thus connected, and the voltage across winding 31 with the A.C. source disconnected, will be largely due to asymmetry of the distributed capacitance between shields 14, 24 and 34.

In the claims appended hereto, I have freely used the terms "octiform" and "figure-8," without intending any distinction between the two terms, other than that the former is a convenient way to express the latter concept as an adjective and less strongly suggests the typographical aspect of the term "figure-8."

It is to be understood that the term "figure-8" is used to suggest the essence of the configuration thus expressed rather than the minutiae of typography and script. For my purpose, a "figure-8" shaped, or "octiform" entity is any discrete body or discrete portion of a body, wherein said body or portion of a body has any arbitrary contour, surface, envelope, etc., and said contour, surface, envelope, etc., is pierced by a pair of holes each of which is distinct from the other and do not communicate with one another save through the region external to said contour, surface, envelope, etc., unless a slot or the like is provided between the holes after the fashion indicated in the case of slot 16b of sideplate 14b, slot 16d of ferrule 14d, and the composite slot 16 (as defined in connection with the description, supra, of FIGURE 3).

The portions of the material surrounding or defining such holes in each case form a bight, and the ends of each bight merge with each other at a common node, i.e., in a septum, so that the figure-8 or octiform configuration is composed of a pair of bights and a septum joining the ends of the bights. While the aforesaid slot interrupts the septum and prevents it from literally merging the ends of the bights, the interruption of the equi-potential surface, as such, is small, and if the treatment of FIGURES 7 and 8 be followed, practically nil, except as regards prevention of shorted turns about legs 10a and 10b individually. Hence, despite the slotting, the bights may be said to be merged by the septum. Thus, within the range of the terms "octiform" and "figure-8" are the configurations illustrated in FIGURES 9, 10 and 11 showing views of respective octiform configurations 50, 51 and 52 which may be taken to represent alternate configurations of the bobbin pair 12a and 13a, or of the coils thereon, the reference characters 50a, 50b, 51a, 51b and 52a and 52b, representing the several windows or holes through the bobbins. Note that in FIGURE 11 the corresponding shielding would have a septum of very small extent and that slotting such septum would more or less extirpate it, depending on how closely the shielding (indicated at 54 in dashed line; as is the slot thereof, denoted by reference numeral 56) follows the circular contours of the bobbins of the pair 52.

Having fully described my invention both in principle and in the best form thereof known to me thus far, and, as well the manner of making and using my invention, I claim:

1. A transformer having a closed core consisting essentially of ferromagnetic material providing a substantially continuous closed low reluctance path and including first and second ferrous legs, said legs extending parallel to and spaced from each other; a primary winding including first and second coils, a secondary winding including first and second coils; each of said first coils having its turns circumscribing one of said legs and said first coils being supported side by side on said one of said legs; each of said second coils having its turns circumscribing the other of said legs and said second coils being supported side by side on said other of said legs, first D.C. conductive shielding having an octiform surface separating said first and second coils of said primary winding from said secondary winding; second D.C. conductive shielding having an octiform surface separating said first and second coils of said secondary winding from the said octiform surface of said first D.C. conductive shielding; the said shieldings being insulated each from the other, and each thereof surrounding each of said legs individually and both said legs as a whole, so that each said shielding has a figure-8 configuration the bights of which circumscribe said legs and merge in a septum lying between said legs, said bights and said septum defining said octiform surface of each said shielding.

2. The transformer of claim 1, wherein the said septum has an interruption in the nature of a slot extending from and through the side of said septum next adjacent one of said legs to and through the side of said septum next adjacent the other of said legs; the location of said interruption being such as to preserve a D.C. conductive path about the said core as a whole, via said bights, while eliminating D.C. conductive paths about the individual legs of said core, via said septum.

3. The transformer of claim 1, wherein the one said shielding substantially completely envelops the corresponding one of the said windings; and the other said shielding substantially completely envelops the other of the said windings.

4. The transformer of claim 1, wherein each bight of one said shielding, and the septum thereof, is tubular, and such bights open into one another and into such septum; said first coil of one of said windings being enveloped in part by the septum of the one said shielding, and said sec-

ond coil of said one of said windings being enveloped in part by the last said septum, the remainder of the last said first coil being enveloped by one bight of the said one said shielding and the remainder of the last said second coil being enveloped by the other bight of the said one said shielding; the other said shielding being like the said one said shielding and enveloping the other of said windings like the said one said shielding envelops the said one of said windings.

5. Transformer structure for use with a chopper and having a primary winding wherein each half thereof is, cyclically, switched into and out of a low-impedance circuit, and out of and into a high-impedance circuit, the arrangement being approximately that neither one of such halves, nor the pair thereof is, in both said circuits simultaneously and/or out of both said circuits simultaneously, said transformer structure including, in combination, a closed core consisting essentially of ferromagnetic material providing a substantially continuous closed low reluctance path and said core having a pair of leg portions, a primary winding wound on said core, and a secondary winding on said core; said primary winding including a first pair of coils, one coil thereof being on one of said leg portions and the other coil thereof being on the other of said leg portions; said primary winding also including a second pair of coils, one coil thereof being on one of said leg portions and the other coil thereof being on said other of said leg portions; said secondary winding including a third pair of coils, one coil thereof being on one of said leg portions and the other coil thereof being on the other of said leg portions; each said leg having the coils thereon mounted thereon side by side; the coils of said first pair being connected to each other and wound in a sense such as to constitute a said half of a primary winding, and to be in series-aiding relation relative to voltages induced therein by a magnetic flux in a closed flux path including both said leg portions in series; the coils of said second pair being connected to each other and wound in a sense such as to constitute another said half of a primary winding, and to be in series-aiding relation relative to voltages induced therein by said magnetic flux; said one said half and said another said half being connected together in series-opposing relation relative to voltages induced therein by said magnetic flux; said secondary winding being between the said halves of said primary winding; first D.C. conductive shielding having an octiform surface separating said first pair of coils of said primary winding from said coils of said secondary winding; said first D.C. conductive shielding having another octiform surface separating said second pair of coils of said primary winding from said coils of said secondary winding; second D.C. conductive shielding having an octiform surface separating said one octiform surface from said coils of said secondary winding; said second D.C. conductive shielding having a further octiform surface separating said another octiform surface from said coils of said secondary winding; said shieldings being insulated each from the other, and each thereof surrounding each of said legs individually and both said legs as a whole, so that each said shielding has a figure 8 configuration, the bights of which circumscribe said legs and merge in a septum lying between said legs, and a pair of said bights and a said septum defining each said octiform surface.

6. A transformer having a closed core consisting essentially of ferromagnetic material providing a substantially continuous closed low reluctance path and including first and second ferrous legs, said legs extending parallel to and spaced from each other; a primary winding consisting of first and second primary winding halves each including first and second coils; a secondary winding including first and second coils; each of said first coils having its turns circumscribing one of said legs and said first coils being supported side by side on said one of said legs; each of said second coils having its turns circumscribing the other of said legs and said second coils

being supported side by side on said other of said legs; first D.C. conductive shielding having one octiform surface separating said first and second coils of said first primary winding half from the said coils of said secondary winding; said first D.C. conductive shielding having another octiform surface separating said first and second coils of said second primary winding half from the said coils of said secondary winding; second D.C. conductive shielding having one octiform surface separating said first and second coils of said secondary winding from said one octiform surface of said first D.C. conductive shielding; said second D.C. conductive shielding having another octiform surface separating said first and second coils of said secondary winding from said another octiform surface of said first D.C. conductive shielding; said first coil of said secondary winding being positioned between said first coils of said primary winding halves and said second coil of said secondary winding being positioned between said second coils of said primary winding halves; the said shieldings being insulated each from the other, and each thereof surrounding each of said legs individually and both said legs as a whole, so that each said shielding has a figure-8 configuration the bights of which circumscribe said legs and merge in a septum lying between said legs, and a pair of said bights and a said septum defining each said octiform surface.

7. The transformer of claim 6, wherein the said septum has an interruption in the nature of a slot extending from and through the side of said septum next adjacent one of said legs to and through the side of said septum next adjacent the other of said legs; the location of said interruption being such as to preserve a D.C. conductive path about the said core as a whole via said bights, while eliminating D.C. conductive paths about the individual legs of said core, via said septum.

8. The transformer of claim 6 wherein one said winding is substantially completely enveloped by the corresponding said shielding; and the other said winding is substantially completely enveloped by the other said shielding.

9. The transformer of claim 6, wherein each said octiform surface of one said shielding is defined by tubular means of figure-8 form having a pair of bights and a septum, wherein each of said bights is tubular, said septum is tubular and said bights merge with and open into said septum and each other; the said first and second coils of the corresponding said winding being substan-

tially enveloped by said tubular means, the arrangement being that a said first coil is enveloped in part by the last said septum, and a said second coil is enveloped in part by said last said septum; the remainder of the last said first coil being enveloped by one said bight opening into and merging with said last said septum and another said bight, and the remainder of the last said second coil being enveloped by said another said bight opening into and merging with said last said septum and the said one said bight; the other said shielding being defined by tubular means of a form like the tubular means of the said one said shielding; the said tubular means of said other said shielding enveloping the said first and second coils of the other said winding like the tubular means of the said one said shielding envelops the said first and second coils of the corresponding said winding.

10. The transformer of claim 6, including octiform spacers of insulating material, each said spacer surrounding each of said legs individually and both of said legs as a whole, so as to have a figure-8 configuration, the bights of which circumscribe said legs and merge in a septum lying between said legs, said spacers being positioned between said shielding, and separating the said surfaces of one said shielding from the said surfaces of the other said shielding; each said spacer having the amount of material in one said bight thereof opposite said septum, the amount of material in the other said bight thereof opposite said septum and the amount of material in said septum so proportioned with respect to each other as to compensate for lack of uniformity in distributed capacitance between said shieldings.

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