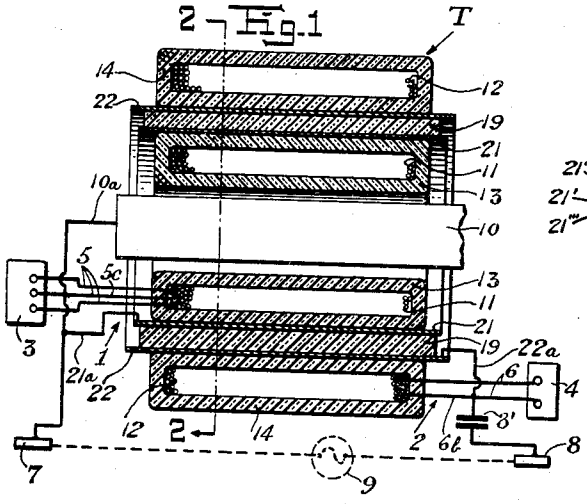
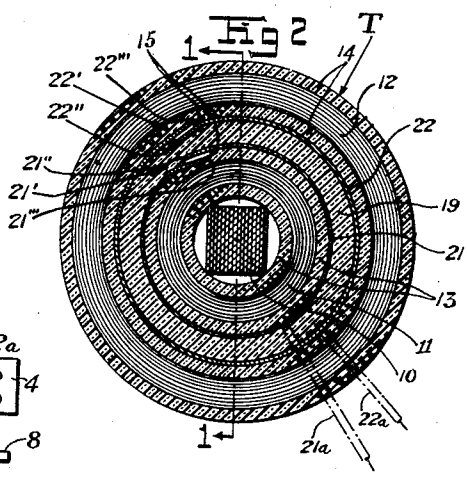
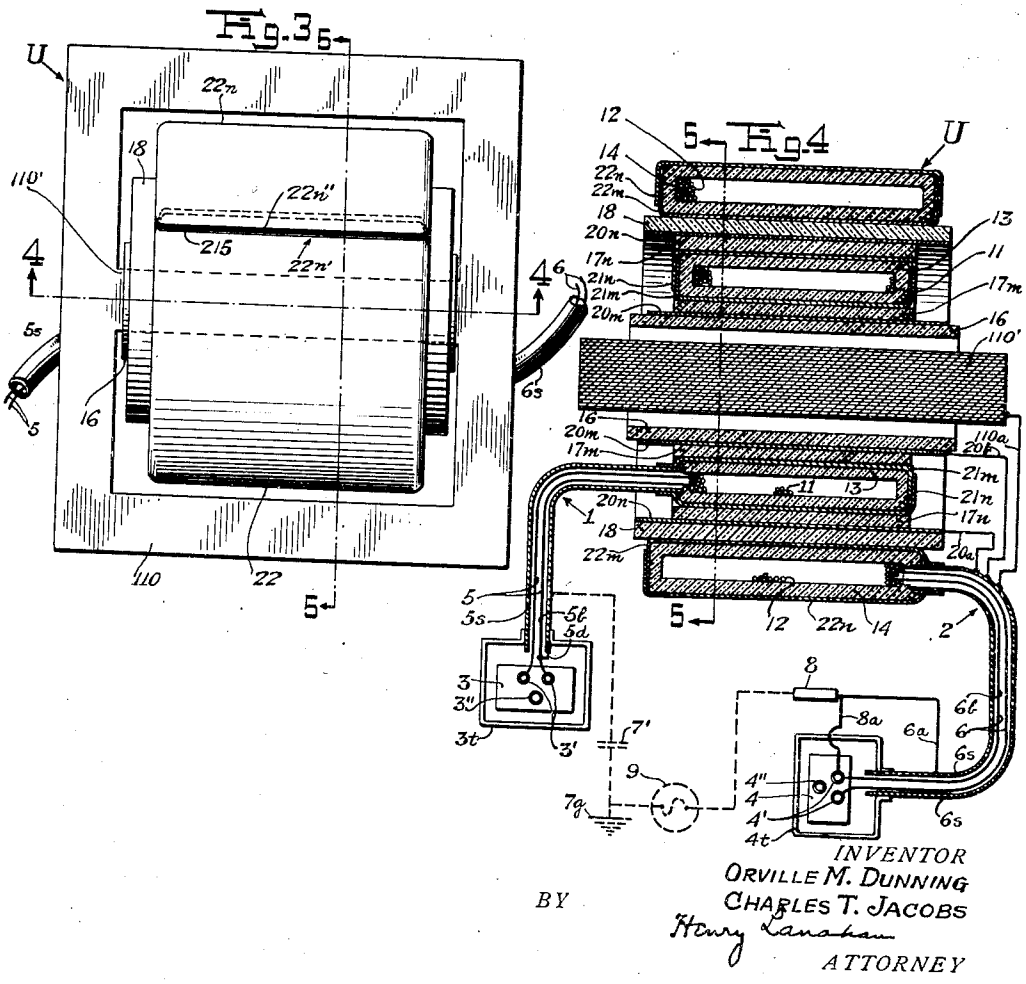
Aug. 22, 1939. O. M. DUNNING ET AL 2,170,048

COUPLED CIRCUIT SYSTEM

Filed March 20, 1935 2 Sheets-Sheet 1







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COUPLED CIRCUIT SYSTEM

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Fig. 5

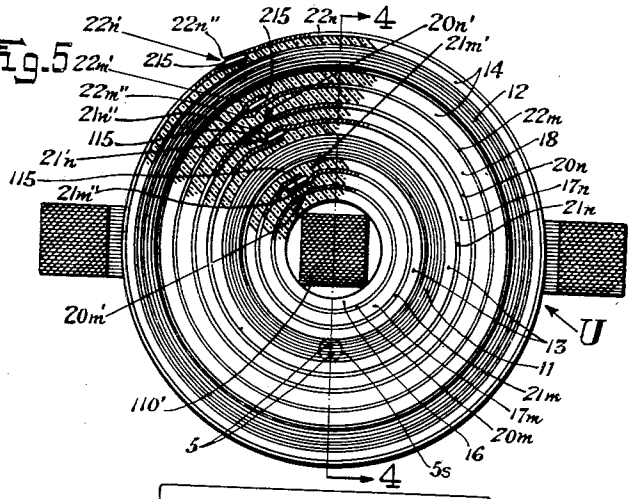
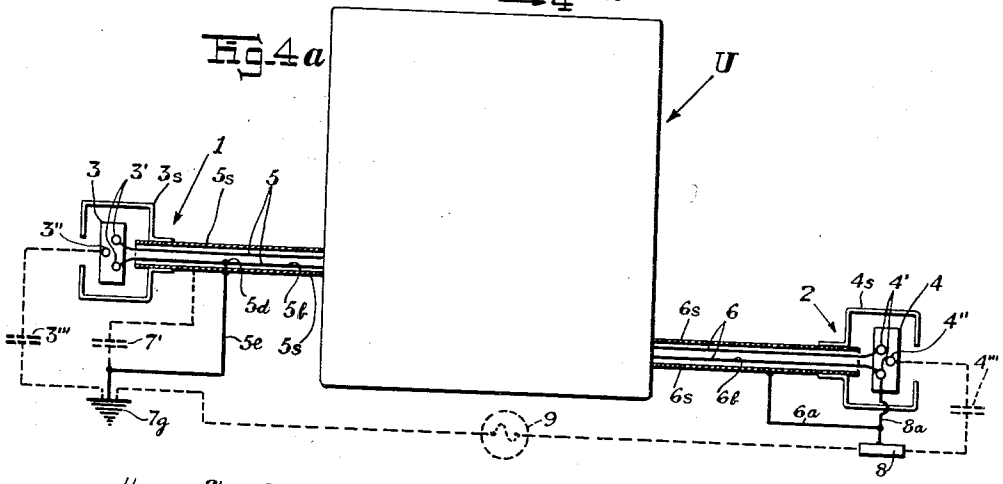


Fig. 4a



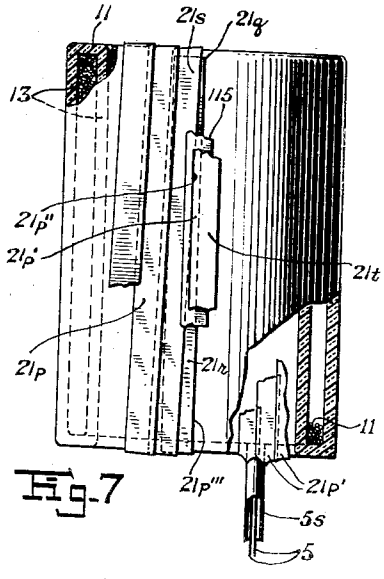


Fig. 7

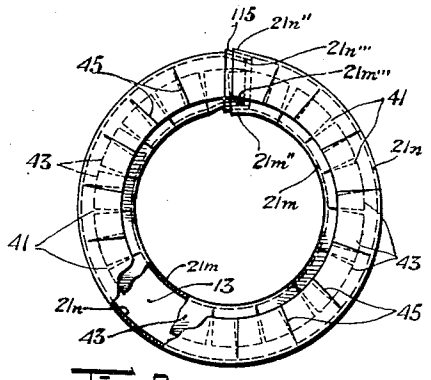


Fig. 6

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2,170,048

COUPLED CIRCUIT SYSTEM

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Application March 20, 1935, Serial No. 11,956

3 Claims. (Cl. 250—16)

This invention relates to systems of coupled circuits, and more particularly to the suppression or elimination of undesired effects on the circuits from various potentials impinging or tending to impinge thereon from outside sources. The invention is particularly concerned with "dynamic" potentials the dynamic potential of an object comprising the fluctuations (for example, periodic) in its absolute potential. It will be appreciated that two objects between which exists only a steady direct voltage, whether of zero or finite value, and no matter how the absolute potentials of the objects may jointly vary, will have the same dynamic potential; while different dynamic potentials are necessarily possessed by any two objects between which a fluctuating or alternating voltage could be measured.

It is a broad object of our invention to suppress or eliminate the effect, on the circuits and each circuit of a system of the class described, of a plurality of different dynamic potentials impinging or tending to impinge thereon.

It is an allied object of our invention to suppress or eliminate the effect on the circuits of a plurality of different dynamic potentials respectively impinging or tending to impinge thereon.

It is another object of our invention to provide a system free or substantially free of undesired effects from a plurality of different dynamic potentials impinging or tending to impinge thereon.

It is still another object to provide an improved transformer for coupling together circuits having different extrinsic dynamic potentials.

Another object is the provision of improved shielding means in such a transformer.

Still another object is the prevention of flux generation in the core of the transformer by currents produced in the shielding means as a result of different dynamic potentials acquired by those means.

Yet another object is the provision of improved means for shielding the circuits and system generally.

Other and allied objects will more fully appear from the following description and the appended claims.

In the description reference is had to the accompanying drawings, of which:

Figure 1 is a view, cross-sectional as to the coupling medium and schematic as to the rest of the circuits, of a coupled circuit system to which our invention has been applied in simple form;

Figure 2 is a cross-sectional view taken vertically through the coupling medium of Figure 1, along the line 2—2 of that figure;

Figure 3 is a plan view of a circuit coupling medium in the form of a closed core transformer;

Figure 4 is a cross-sectional view taken along the line 4—4 of Figure 3, illustrating not only the transformer but also the balance (the latter schematically) of a system to which our invention has been applied in preferred form;

Figure 4a is a view generally similar to Figure 4, but for convenience showing the transformer of Figure 4 only diagrammatically, and illustrating a modification of Figure 4 in respect of the circuit shielding means;

Figure 5 is a cross-sectional view taken along the lines 5—5 of Figures 3 and 4;

Figure 6 is an enlarged end view of one of the shielded windings of the transformer of Figures 3, 4 and 5; and

Figure 7 is an enlarged plan view of a winding shielded in an alternative manner and appropriate for use in place of one or both of the shielded windings shown in the transformer of Figures 3, 4 and 5.

A circuit point (or plurality of electrically identical circuit points) exposed either conductively (by an actually connected path) or electrostatically (by an inherent capacitative path) to an external object or device will tend to acquire the potential of that object; if the point is exposed to a plurality of external objects of differing dynamic potentials, it will tend to acquire a super-position of their dynamic potentials. The dynamic potential acquired by the point as a result of either such exposure may be termed "extrinsic"—i. e., resulting from an external influence. A whole circuit (comprising a plurality of electrically non-identical points) will acquire a single extrinsic dynamic potential if the exposure of all its points to external objects is only to one object or to a plurality of objects with mutually similar dynamic potentials. And while a whole circuit may acquire a plurality of different extrinsic dynamic potentials at several of its electrically non-identical points from respective external objects of differing dynamic potentials, such a condition is objectionable—in that spurious potential differences are created within the circuit to co-mingle their effect with those of the intended, or intrinsic, potential differences within the circuit.

When a circuit has acquired an extrinsic dynamic potential at one point therein from an external object, and an electrically distinct point of the circuit is electrostatically exposed to a sec-

ond external object of different dynamic potential, it is common to interpose a conductive shield in the exposing path; to render the shield effective, it is ordinarily connected by a path of negligible impedance to the first circuit point or the first external object. Electrostatic exposures to external objects of still other points of the same circuit are of course coped with by further shields similarly connected and/or by an appropriate extension of the first shield.

While such electrostatic shielding of a single circuit is well understood, we have found that special problems arise in connection with coupled circuits when the conditions under which the circuits operate entail the acquisition thereby of respectively different extrinsic dynamic potentials. These problems are occasioned largely by the capacities, within the medium coupling the circuits, between the members of the medium which are respectively connected in and form portions of the circuits and hence have different extrinsic potentials. Considering any one coupling medium member, it will be appreciated that it is electrostatically exposed through these capacities to the other members—each of which is as to it, and as to each and every one of its exposed points, an external object of dynamic potential differing from its own extrinsic dynamic potential. A shield interposed between any two such coupling medium members, no matter where that shield be connected, is still ineffective to eliminate the exposure of at least one of the members to an object of dynamic potential different from its own extrinsic dynamic potential. Thus, if the shielding be left "floating"—i. e., not conductively connected anywhere—it will take on a dynamic potential intermediate the extrinsic dynamic potentials of the two members, to each of which the shield will therefore be an external object of the mentioned undesirable nature. On the other hand, if the shielding be established at the extrinsic dynamic potential of either of the members, it is still as to the other member an external source of the same undesirable nature.

According to our invention there are interposed between adjacent coupling medium members two conductive shields; these shields are successively arranged, so that each electrostatically isolates the adjacent member from the other shield and the other member. Each shield is established at the extrinsic dynamic potential of the adjacent member, or in other words of the circuit containing that member. Thus the only dynamic potentials tending to impinge on either member within the coupling medium may be restricted to the extrinsic dynamic potential of that member itself.

Without intending thereby any unnecessary limitation of our invention, we have illustrated the same in connection with transformer coupling media, whose members adapted for connection in the respective circuits are coils or windings. A very simple form of open core transformer has been selected for use in Figure 1 as a vehicle for illustration of our invention in simple form. In this figure this transformer is shown in cross-section longitudinally through the core, while the balance of the system of circuits is shown in purely schematic manner.

The two circuits are shown as 1 and 2 respectively, mutually coupled by the transformer T. Circuit 1 comprises for example the source 3 of signal or other oscillations to be transmitted by the system, the primary winding 11 of the transformer T, and the leads 5 connecting source 3 to the primary winding 11. Circuit 2 comprises for example any load 4 to which the oscillations are to be transmitted, the secondary winding 12 of the transformer T, and the leads 6 connecting the secondary 12 to the lead 4. Purely by way of illustration of the independence of our invention from such details, the leads 5 have been shown as three in number, two of them joining the extremities of the winding 11 with the extremities of the source 3 and the third, 5c, joining the center of winding 11 with the center of the source; while the leads 6 have been shown as two in number, joining only the extremities of the load 4 with the extremities of the winding 12.

The circuits 1 and 2 have different extrinsic dynamic potentials. Purely by way of non-limitative illustration of manners in which such potentials may be acquired by the respective circuits, we have shown in Figure 1 two external objects 7 and 8 of different dynamic potentials (a potential relationship schematically indicated by the generator 9 of alternating voltage between these two objects); the object 7 being connected through negligible impedance to primary lead 5c and the object 8 being connected through a condenser 8' to one of the secondary leads 6, which lead we have designated as 6b. Thus the primary circuit 1 acquires an extrinsic dynamic potential at its lead 5c from the object 7, and the secondary circuit 2 acquires an extrinsic dynamic potential at its lead 6b from the object 8.

The transformer T comprises the central core 10; thereabout the primary winding 11, surrounded or encased by conventional insulation 13; thereabout the conductive shield 21, preferably somewhat overhanging the primary 11 on each end longitudinally of the core 10; about the shield 21 the layer of insulation 19; thereabout the conductive shield 22, for example of similar or a trifle greater longitudinal dimension to or than the shield 21; and about the shield 22 the secondary winding 12, surrounded or encased by conventional insulation 14 and preferably overhung on each end by the shield 22. The shield 21, which may be termed the "primary shield" because of its adjacency to the primary winding 11, is established at the extrinsic dynamic potential of the primary circuit, as by connection thereof to the center-tap primary lead 5c, already mentioned as a point of acquisition of extrinsic dynamic potential by the primary circuit. Correspondingly the shield 22, which may be termed the "secondary shield" because of its adjacency to the secondary winding 12, is established at the extrinsic dynamic potential of the secondary circuit, as by connection thereof to the secondary lead 6b, already mentioned as a point of acquisition of extrinsic dynamic potential by the secondary circuit.

It will be noted that a capacity exists between the primary winding 11 and the core 10, so that the primary winding is exposed electrostatically not only to the shield 21 but also to the core. In order to insure that the core will not upset the condition of circuit 1 acquiring only a single extrinsic potential, the core may be connected as by lead 10a to the primary lead 5c—i. e., positively established at the extrinsic dynamic potential of circuit 1. This is not necessary, however, if the core has no electrostatic exposure to objects other than the primary winding 11.

A cross-sectional view of the transformer T, taken transversely of the core 10, appears as

Figure 2. This illustrates the elements 11, 21, 19, 22 and 12 each as of generally cylindrical formation. An important qualification, however, is to be noted as to the shields 21 and 22. While each of these is preferably of the full 360 degrees circumferential extension about the core, each must be provided in this extension with a discontinuity, so that it does not form a closed electrical turn about the core. Accordingly each shield may be formed of an originally flat, thin, conductive sheet, curved about the next inner element of the transformer and provided with a discontinuity in the form of a lap 21' or 22' (corresponding to the designating numeral of the shield); the lap is formed by insulatedly overlapping the outer circumferential extremity 21'' or 22''' for a short distance over the inner circumferential extremity 21''' or 22'''. The insulation for each lap may be provided in any convenient manner, having been illustrated in each case as a narrow, thin strip 15 of insulation interposed between the shield extremities. In connection with the shields and with all of the insulation in Figures 1 and 2, it may be noted that their thicknesses have been materially exaggerated over those normally necessary, in the interest of illustration.

The structure of Figures 1 and 2 has been sufficiently described to set forth the feature of the two successive shields, each established at the extrinsic dynamic potential of the respectively adjacent winding or circuit. While this feature without further limitations may be sufficiently efficacious satisfactorily to meet the conditions under which the circuits may be required to operate, we have found that under some conditions—particularly with larger amplitudes of effective generator 9 voltage—further structural limitations must be adhered to. These are described following a consideration of the manner in which the requirement therefor arises.

It is obvious that a substantial capacity exists between the two shields 21 and 22. Because of the different dynamic potentials of these shields, or alternating voltage therebetween, an alternating current will flow through this capacity. (Specifically as to Figure 1, this current may be alternatively identified as that produced serially through the inter-shield capacity and the condenser 8' by the generator 9.) The capacity between the shields is distributed not merely longitudinally of the core, but also and more significantly circumferentially thereof; therefore various portions of the current entering or leaving either shield through the respective lead 21*a* or 22*a* flow in the shield circumferentially to various extents—i. e., to extents of various fractional parts of a turn about the core (up to a possible maximum of substantially a full turn in the case of lead connection at either extremity circumferential of the shield). Such current flow in each of the two shields will divide in opposite directions about the core (excepting of course in the extreme case of lead connection at a circumferential shield extremity); but we have found that with random relative arrangement of the laps 21' and 22' and/or of the points of connection to the shields of the leads 21*a* and 22*a* and/or of the lap-to-lead relationships, the current flow in the pair of shields at one peak instant will almost invariably considerably preponderate in a first direction about the core, in the opposite direction at the next peak instant, and so on—in other words, the pair of shields will constitute effectively some fractional part of a turn about the core for the alternating currents flowing from the generator 9. The traversal of this effective fractional part of a turn by these currents sets up a corresponding flux in the core 10 of the transformer, and thus induces a corresponding disturbing voltage in each of the windings of the transformer.

According to our invention we so mutually arrange the discontinuities or laps in, and points of connection to, the two shields as to balance out these shield currents in their flow about the core—in other words, as to render the pair of shields effectively an altogether negligible fraction of a turn about the core for currents from the generator 9. While it is possible to effect this net balancing wholly by balancing the current in one direction in one portion of each shield against the current in the opposite direction in another portion of the same shield, we have found the net balancing far more dependable if we alternatively or additionally balance the current flow in each portion of one shield against the current flow in a respectively corresponding portion of the other shield. For illustration of an appropriate arrangement, reference is again invited to Figure 2.

Herein it will be seen that the points of connection of the leads 21*a* and 22*a* to the respective shields are in substantial radial alignment with each other. Further the outer circumferential extremity 21'' of the primary shield—the extremity of that shield electrostatically exposed to the secondary shield—is in radial alignment with the inner circumferential extremity 22'' of the secondary shield—the extremity of that shield electrostatically exposed to the primary shield. Accordingly the shield currents enter and leave the transformer along the same radial line; and the infinitesimal current portion which respectively flows through each infinitesimal portion of the inter-shield capacity must traverse equal fractional turns in opposite directions in the respective shields. This effects balancing of the current in each portion of one shield against the current in a respectively corresponding portion of the other shield, and of course results in a thorough net balancing of the shield currents. This operational description must be mildly qualified by pointing out that it assumes the absence of any significant "cross capacities" in the neighborhood of the laps—i. e., capacity between shield portions respectively adjacent 21''' and 22'', or respectively adjacent 21'' and 22'''—or at least the substantial equality between these two cross capacities. Such assumptions are suite permissible in all normal cases, becoming almost rigorous when the mutually exposed extremities 21'' and 22'' are accurately aligned and when the thickness of the insulation 19 in the neighborhood of the laps is small and when, as illustrated and preferred but not indispensable, the extremities 21'' and 22'' are pointed in the same circumferential direction.

Additionally it may be noted that in Figure 2 the points of connection of leads 21*a* and 22*a* to the respective shields are each diametrically opposite the respective discontinuity or, in more precise terms, opposite that extremity of the respective shield which is exposed to the other shield (extremities 21'' and 22'')—an optional limitation which, when carried out either additionally to or in place of the balancing arrangement described in the preceding paragraph, results in a balancing of the current in that half of each shield which extends in one direction from

the lead connection against the current in the other half of the same shield, these currents obviously flowing in opposite directions. The reason why we prefer not to place entire or principal reliance on this second balancing arrangement is that its effectiveness is a function of the uniformity of the inter-shield capacity per small unit shield area—a characteristic which is not of influence on the first described balancing arrangement.

While the open core transformer represents a usable type for many purposes, and while because of its simplicity it forms an especially convenient vehicle for initial description of some of the fundamental features of our invention, the closed core transformer remains a far more widely employed type. While our invention might to material advantage be incorporated in and with a closed core transformer in precisely the form illustrated for the open core transformer, there are certain refinements and other features which are desirably included when the closed core transformer is employed, as well as in any case wherein the operational requirements for the circuits are unusually severe. Accordingly we proceed to a description of our invention in a refined form, applied to and with a transformer having a closed core, for example of the shell type. This has been illustrated in Figures 3, 4 and 5, Figure 3 being a plan view of a transformer U, the details of which appear in the cross-sectional Figures 4 and 5.

The primary and secondary circuits are again designated as 1 and 2, circuit 1 comprising the source 3 (for example a microphone), primary winding 11, and leads 5 between the output terminals 3' of source 3 and the electrical extremities of winding 11; and circuit 2 comprising secondary winding 12, load 4 (for example the first stage of an audio frequency amplifier), and leads 6 between the electrical secondary winding extremities and the load input terminals 4'. The core of the transformer U is designated as 110, having the central leg 119' about which the primary and secondary windings are concentrically disposed.

In these figures we have shown the primary and secondary winding shields not merely in successive interposition between the windings (as in Figures 1 and 2), but each completely encasing its respective winding (together of course with the insulation 13 or 14 provided thereabout). One reason for this is that although the simple shield interposition eliminates the electrostatic exposure of either winding to the opposite winding and the shield therefor so far as this exposure occurs (as it does principally) along straight lines, this exposure can also to a very restricted degree occur along curved lines, and to that degree is obviously poorly guarded against by the structure of the first figures; under sufficiently severe operational conditions this becomes important. Another reason, peculiar to the closed core transformer and important as to at least all but one of the windings, is that the core, which of course must be exposed electrostatically to no more than one of the windings, now so extends as to have inherent capacity to the ends of all the windings and to the periphery of the outside winding.

Each of the primary and secondary winding shields has been illustrated in Figures 3, 4 and 5 as comprising an inner shield element (21*m* for the primary and 22*m* for the secondary) extending circumferentially immediately inside of the insulation 13 or 14 for the respective winding, and having its ends portions (considered in a direction axial of the winding) folded outwardly or away from the winding axis to lie against the ends of the winding insulation 13 or 14; and an outer shield element (21*n* for the primary and 22*n* for the secondary) extending circumferentially immediately outside of the respective insulation 13 or 14, and having its end portions folded inwardly or toward the winding axis to lie against and make electrical contact with the folded-over end portions of the respective inner shield element. Both inner and outer members of each shield are provided with a discontinuity in the form of a lap (21*m'*, 21*n'*, 22*m'* and 22*n'* for shield elements 21*m*, 21*n*, 22*m* and 22*n* respectively), the laps in the inner and outer elements of each one shield being in radial alignment with each other and forming a continuous lap insulated by insulation which may be in the form of a strip or overlapping series of strips encircling the winding parallel to its axis; these strips are designated as 115 for the primary winding shield and 215 for the secondary winding shield.

The illustration of Figures 3, 4 and 5 as to this shield structure encasing each winding is supplemented by Figure 6—and enlarged end view of one of the windings (arbitrarily the primary) and its inner and outer shield elements. The shield elements are conveniently of thin, soft copper foil or other like conductive material. In order to facilitate the outward folding of the end portions of the inner shield element 21*m*, longitudinal cuts 41 may be made in each end portion, dividing the same into a succession of tabs 43 which may be folded outwardly without difficulty and cemented against the ends of the insulation 13. While the inward folding of the end portions of the outer shield element 21*n* may be similarly facilitated, the material of the shield element, if thin and soft, will readily fold inwardly without cuts and form within itself ridges or folds which we have illustrated as 45. We have found that the cementing, by thin, so-called "household" cement, of the folded-over portions of the outer shield element to those of the inner shield element does not, if well pressed out, interfere with the requisite electrical contact between the two shield elements. Figure 6 plainly illustrates the continuity of the laps 21*m'* and 21*n'* in the inner and outer shield elements respectively, achieved by cementing the insulating strip or series of strips 115 in place before the folding over of the end portions of the outer shield element is completed. It is of course possible to form one of the shield elements (preferably the inner) without overhanging end portions, and simply to fold the end portions of the other shield element completely about the ends of the insulation 13 into overlapping contact with the first shield element. It will be understood that the primary shielding structure so specifically described with reference to Figure 6 may be identically followed in connection with the shielding of the secondary winding 12, the designating numerals being considered in each instance as greater by one than those appearing in Figure 6.

The transformer U, as illustrated in Figures 3 through 5, comprises the shell type core with its central leg element 110'; thereabout a layer of insulation 16; thereover a generally cylindrical shield element 20*m* hereinafter referred to; thereover a layer of insulating 17*m*; thereover the primary winding 11, successively encased or surrounded by the insulation 13 and the shielding 21*m*—21*n* as above described; thereover a

layer of insulation 17*n*; thereover a generally cylindrical shield element 20*n* hereinafter referred to; thereover a layer of insulation 18; and thereover the secondary winding 12, successively encased or surrounded by the insulation 14 and the shielding 22*m*—22*n* as above described. As will hereinafter appear, the employment of the shield elements 20*m* and 20*n* is not indispensable, and the omission of both or either of these elements may be attended by the merging of the immediately adjacent insulating layer 17*m* and/or 17*n*, as the case may be, into the respective insulating layer 16 and/or 18.

In order that the primary and secondary leads (5 and 6 respectively) shall not, by inherent capacities to elements of the transformer, counteract or undo the effect of the complete shielding of each of the primary and secondary windings, at least their portions near the transformer should be shielded by shielding connected to the respective winding shielding. Accordingly we have shown about the respective leads conductive braid shielding 5*s* and 6*s*. This shielding may in each case enter the respective winding shielding, the inner and outer winding shield elements (21*m* and 21*n* or 22*m* and 22*n*) being formed for a short distance along the braid shielding adjacent its point of entry and making electrical contact thereto. By this arrangement the lead shieldings may become the connecting leads (analogous to 21*a* and 22*a* of Figure 1) for the primary and secondary winding shields. The application of fluctuating different potentials between the respective lead shieldings 5*s* and 6*s* is contemplated; but the typical means illustrated in Figure 4 by which this occurs is described at a later point in this specification.

Because of these fluctuating different potentials there will tend to occur, as in the case of transformer T of earlier figures, a current flow between shielding elements of the transformer U. The latter transformer is conveniently considered at this point with the omission, which is permissible, of both the shield elements 20*m* and 20*n*. It will be seen that the exposed lap extremities of the winding shield elements, and in particular those two (21*n*'' and 22*m*'') which are mutually exposed, are in radial alignment with each other; that the points of connection to the two winding shields—i. e., of entry of the leads 5*s* and 6*s* thereinto—are in radial alignment with each other; and (as preferred but not essential) that the laps or discontinuities are arranged at least nearly diametrically opposite the respective points of lead connection. Thus those specifications which were shown desirable for the balancing of shield currents in connection with transformer T are observed in connection with transformer U. But in transformer U there exist additional opportunities for shield current flow. The outer portions of the core (i. e., other than the central leg element 10') form conductive elements which are respectively adjacent circumferentially different portions of the winding shields (e. g., portions at the ends of those shields and on the periphery of the secondary shield) and which have capacities to those portions; through any of these capacities across which a dynamic potential difference exists there may flow alternating currents which must pass through portions of the respective shields. We cope with the shield currents so arising by maintaining at least a moderate spacing of all winding shields from the outer core portions; by arranging the points of connection to the winding shields in a 90 degree displacement from the plane of the core (i. e., midway circumferentially of the shields between corresponding shield-core capacities); and by maintaining as nearly similar as possible such respectively corresponding capacities (e. g., capacities symmetrically disposed about the line 4—4 in Figure 5). Thereby the shield currents through these capacities are maintained small and divide in opposite directions in each one shield member, and the mutually opposed flows are quite well equalized and satisfactorily balance each other. Of course the core may be established at the potential of the shield of one of the windings, as by connection thereof by lead 10*a* to the secondary lead shielding 6*s*, rendering the shield current flow just discussed significant as to the other winding only.

The other described structure of a pair of shields interposed between two windings of the transformer, with particular arrangements of shield discontinuities and leads within the pair, is generically applicable for interposition between any two transformer elements having different dynamic potentials. Utility of this structure in other positions than simply between two windings may be found. For example, if the primary and secondary windings are separately formed and shielded, as hereinafter suggested as one method of construction, it may be difficult accurately to align the discontinuities of the two winding shields. In this case it is convenient to rely on only the first of the winding shields as a member of the specially arranged pair; and to complete the pair by a further shield interposed between the winding shields, having its discontinuity and point of lead connection in proper relationship to those of the first winding shield, and established at the dynamic potential of the second winding shield. In this case the specially arranged pair becomes interposed between the first winding and the second winding shield, and this shield may have its point of lead connection and its discontinuity randomly arranged with respect to those of the pair. We have illustrated such a further shield as the shield element 20*n* abovementioned; and while as illustrated it is appropriately arranged within the transformer to form the specially arranged pair with either winding shield, it may be considered to have been accurately installed over the primary winding shield and to form the pair therewith.

While the discontinuity in the shield 20*n*, which we may term the "intermediate shield", may of course be a lap as above described for other shields, we have found it permissible to employ for this shield a simplified "gap" discontinuity, wherein the circumferential extension of the shield is a trifle less than 360 degrees and the extremities of the shield are accordingly separated by a slight gap 20*n*'. Proper alignment of this discontinuity with the adjacent lap discontinuity in the primary winding shield is provided by radially aligning the center line of the gap 20*n*' with the thereto exposed primary lap extremity 21*n*''. The lead 20*a* for the intermediate shield, connected thereto in radial alignment with the point of connection of the primary shield lead 5*s*, is connected to the secondary lead shielding 6*s*. Because of the secondary winding shield potential thus acquired, and the interposition between the winding shields, the intermediate shield takes the place of the secondary winding shield as a conductor of inter-shield currents. In order to insure that the intermediate shield is quite ef-

fectively so interposed, we have made it materially to overhang the shielded primary winding on each end, so that curved as well as straight lines between primary and secondary winding shields are intercepted by the intermediate shield; this is faciltated by the illustrated restriction of length of the primary winding, which also helps to minimize capacities of the primary winding shielding to outer portions of the core as above discussed. Alternatively, of course, we may extend the insulation 17*n* inwardly against the ends of the shielded primary winding, and fold the end portions of the intermediate shield 20*n* inwardly against this extended insulation.

The inner shield element (21*m*) for the primary winding has a relatively large capacity to the core leg element 10' which, while theoretically symmetrically distributed circumferentially, may not be so in practise—particularly if the core leg fits loosely or non-centrally within the windings. When this primary shield is, as illustrated, at a different potential dynamically from the core, it is possible that the resulting shield currents therein to and from this capacity will, no matter where the point of lead connection to the primary winding shield be made, flow unbalancedly through the shield element 21*m* and set up an undesired flux in the core. As a preventive against this we may employ the shield 20*m* illustrated and abovementioned, interposed between the shield element 21*m* and the core leg element 10', and forming with the shield element 21*m* a specially arranged pair of shields such as abovementioned but interposed between the primary winding and the core leg element. The shield 20*m* is generally similar to the shield 20*n*, having a corresponding gap or other discontinuity 20*m'* in radial alignment with the thereto exposed lap extremity 21*m''* of the primary winding shield, having a lead 20*b* connected thereto at a point in radial alignment with the point of lead connection to the primary winding shielding, and being thereby connected with the secondary lead shielding and hence with the core. The shield 20*m* of course takes the place of the core leg element 10' as a conductor of shield currents otherwise flowing to that element from the shield element 21*m*, restricting these currents to the specially arranged shield pair 21*m*—20*m* wherein they will be properly balanced.

As illustrated, all of the elements of the transformer other than a first of the shielded windings (e. g., the primary winding 11 and its shielding 21*m*—21*n*) are established at the extrinsic dynamic potential of the other winding (e. g., the secondary winding 12); and shielding at that dynamic potential (e. g., shields 20*m* inside and 20*n* outside the shielded primary winding) substantially isolates the first shielded winding electrostatically from all such other elements. It may be mentioned that under these circumstances, and depending on the stringency of the operational requirements for the circuits, it may be permissible to omit the shielding of the second winding (e. g., of secondary winding 12); we have, however, generally preferred to retain the latter shielding in any event. Of course the electrostatic isolation of the shielded primary from all other elements of the transformer may be rendered not merely substantially but practically perfectly complete by folding over the end portions of the shields 20*m* and 20*n* into overlapping contact with each other against the ends of the shielded primary, the insulation 17*m* and/or 17*n* having first been folded over against the shielded primary ends and the discontinuities in shields 20*m* and 20n being, as illustrated, in radial alignment with each other.

The transformer U being of novel nature, we may supplement the detailed description of its structure above set forth by a description of a manner in which we have satisfactorily assembled it. We have separately formed the primary and secondary windings, with their conventional encasing insulation 13 and 14, and shielded them with elements 21*m*—21*n* and 22*m*—22*n* in manner more particularly described above. The insulating layer 17*n* has been formed about the shielded primary winding by winding circumferentially thereabout flat insulating paper, such as "fish-paper", and securing at least the external extremity of the wind with cement. The insulating layer 17*m* has been formed by coiling similar paper into a small, loose tubular form and passing it axially within the shielded primary winding, thereupon expanding it into contact with the inside of the shielded winding and securing at least the inner or exposed extremity of the paper with cement. The proper circumferential length of the intermediate shield 20*n* to afford the slight gap 21*n'* has been determined by test, and the soft, thin, conductive shield material cut to size and cemented over the insulating layer 17*n*—of course with its gap in proper alignment. The proper circumferential length of the shield 20*m* has been similarly determined, and the shield material cut to size, coiled into small, loose tubular form, inserted inside the insulating layer 17*m*, and expanded into contact therewith and cemented thereto. The insulating layer 16 has been formed over the shield 20*n* similarly as was layer 17*n* over the shielded winding; and the insulating layer 16 has been formed within the shield 20*m* similarly as was layer 17*m* within the shielded winding. This has completed the primary assembly. The shielded secondary winding, formed with appropriate dimensions, has been slipped snugly over the primary assembly, and the transformer assembly completed by stacking of the core. It will be understood that this procedure, with the separate formation and shielding of the two windings as distinguished for example from a progressive outward winding and building up process from layer 16 to outer secondary winding shield element 22*n*, is disclosed merely as one which we have actually employed and have thought to facilitate the proper formation of the primary and secondary winding shielding 21*m*—21*n* and 22*m*—22*n*; it is not disclosed with any limiting intention whatsoever.

While we have shown in Figures 3 through 6 and described above a construction of inner and outer shield elements (21*m* and 21*n* or 22*m* and 22*n*) for fully encasing each of the two windings 11 and 12, we do not intend any limitation of the encasing shielding means for the windings to this particular construction. By way of illustration of an alternative means which we have employed, we have shown in Figure 7 a primary winding 11 encased in shielding which is in the form of a strip 21*p* of thin, soft conductive material (for example copper) toroidally wound about the winding 11 (this of course being first insulated by its conventional insulation 13), after the fashion of the cloth tape frequently wound about a coil for mechanically binding it into a rigid unit. In the interest of illustration this strip 21*p* is shown only fractionally wound about the primary winding 11. The initial extremity 21*q* of the strip 21*p* may be cemented to the in-

sulation 13 practically at one end of the winding 11, and a first turn 21r of the strip 21p made about the winding 11 so that inner and outer portions of the turn are quite parallel with the axis of winding 11. Beginning with the second turn 21s, the turns are made slightly angularly with respect to the axis of winding 11, so that the winding of the strip 21p progresses toroidally about the primary winding 11, but with each successive turn of the strip overlapping and contacting with the immediately preceding one. Before the winding of the strip 21p is completed, the insulating strip or series of strips 115 (fractionally shown in Figure 7) is secured over the beginning circumferential extremity 21p''' of the toroidal strip 21p winding, inside and outside of the primary winding 11 in quite similar fashion to the installation of the member 115 in earlier figures. The toroidal winding of the strip 21p is continued entirely about the winding 11, the final turn 21t (fractionally shown) overlapping the strip 115 and therethrough the extremity 21p''', and being arranged with inner and outer portions quite parallel with the winding 11 axis. This construction provides the insulated lap 21p', having the exposed extremity 21p''; and it will be understood that in the assembly in the transformer of the winding shielded as just set forth, this lap and its exposed extremity will be arranged as set forth for the laps and their extremities hereinabove. In Figure 7 a small part of the forward portion of winding 11 and insulation 13 has been broken away to show the rearward portion, with the shielding strip 21p thereabout and the entry of leads 5 to the winding 11. These leads of course enter the winding shielding within the lead shielding 5s, the strip 21p in those of its turns appropriate thereto being formed around and making electrical contact with the lead shielding 5s.

It will be understood that while we have illustrated the windings herein as cylindrical, we intend thereby no unnecessary limitation whatsoever; the application of our invention to windings of such other or distorted cross-sections as squares or the like will be entirely obvious. It is also to be understood that by the term "radial alignment" herein we do not intend to imply any restriction of the aligned points or regions to a single line extending radially and normally away from the axis, but rather a restriction or substantial restriction to a single plane containing and extending radially from the axis.

The description of Figures 3 et seq. may be completed by referring to the portions of the system other than the transformer U, which other portions in one arrangement have been shown in Figure 4, and in a modified arrangement in Figure 4a; the latter figure may first be referred to. A requirement for extrinsic dynamic potential difference between primary and secondary circuits has been assumed; and as a typical but non-limitative reason for this requirement, it may be considered that the load 4 must be conductively connected to an external object 8 of dynamic potential differing widely from that of ground, while the primary shielding (and hence the primary circuit, whose extrinsic dynamic potential must follow that of its shielding) cannot be permitted to acquire a potential so dynamically different from ground potential (for example because of shock hazard). In accordance with these conditions the lower-shown input terminal 4' of the load 4 has been shown connected as by the connection 8a to object 8. In order that the secondary circuit acquire but one extrinsic potential, its lead and winding shielding may also be connected to the object 8, as by lead 6a. Under severe operational conditions it is very probable that the outer portions of the leads 6 will, if they remain unshielded, be sufficiently electrostatically exposed to some external source or sources of still other dynamic potentials to cause difficulty; accordingly we show a conductive shield 4s extending partially about the load 4, and the lead shielding 6s entering and electrically contacting with the shield 4s. The extent of the secondary circuit shielding means thus provided is intended to be sufficient to isolate the secondary circuit electrostatically from all objects of dynamic potential other than that of object 8 (this potential being the extrinsic dynamic potential of the secondary circuit, in view of the negligible impedance shield connection 6a and of the circuit connection 8a, whether of negligible or finite impedance); the secondary shielding is permitted, however, to expose electrostatically to the object 8 only, some point or points in the secondary circuit—such as the intermediate point 4'' in the load 4, through the inherent capacity 4'''.

To meet the outlined conditions the primary circuit extrinsic dynamic potential may be made the dynamic potential of ground, shown as 7g and from which the dynamic potential difference of the object 8 has been dottedly indicated by the generator 9. Thus one of the primary leads 5 (designated as 5b) may be connected as by lead 5d with the lead shielding 5s, and the lead shielding as by lead 5e to ground. A shield 3s may be provided partially about the source 3, and entered and electrically contacted with by the primary lead shielding 5s, analogously to the arrangement described for the secondary circuit. Some unshielded point or points in the primary circuit may be assumed to be left electrostatically exposed by the composite primary shielding, but only to ground—such for example as the intermediate point 3'' in the source 3, through the inherent capacity 3'''.

While the system as thus described will operate satisfactorily, it is frequently troublesome to connect the lead 5e from the primary circuit and shielding to ground, particularly in the case of portable apparatus. If this connection be omitted, its place will be taken by the inherent capacity 7' naturally existing between the primary shielding and ground. Now the primary shielding will acquire a dynamic potential intermediate those of ground and of the object 8, to which two dynamic potential sources the primary shielding is exposed through the respective finite impedance paths of capacity 7' and the inter-shield capacity within the transformer U. The primary circuit is of course conductively exposed to the primary shielding through the lead 5d if this be retained, or electrostatically exposed through the large capacity between shielding and primary circuit if this connection 5d be omitted. But at the point 3'' the primary circuit is electrostatically exposed to ground through the capacity 3'''. Accordingly, excepting in a purely fortuitous case, the primary circuit will acquire different extrinsic dynamic potentials at respectively different points, which cannot be permitted for reasons early above discussed.

It is to be understood that the exposed point 3'' in the primary circuit is intended to be typical of any point or points so exposed in that circuit, and that its illustration as a point in the source 3 is by way of example only.

According to our invention in its preferred em-

bodiment, as illustrated in Figure 4, we extend the shielding of the primary circuit so that it includes complete winding shielding as above described, complete lead shielding and complete source shielding such as conductive enclosure 3*t* encasing the source 3—in other words, so as to provide complete encasement of the entire circuit in commonly conductive shielding means. This of course eliminates all electrostatic exposures of circuit points such as that of point 3'' through the capacity 3'''. It will be understood that we use the term "complete encasement" in the sense of essentially complete electrostatic isolation; and that any encasement which provides such isolation, though penetrable by other forces than electrostatic, will be a satisfactory one. (Indeed, it is necessary if source 3 be a microphone that the enclosure 3*t* thereabout be acoustically penetrable, while remaining electrostatically essentially impenetrable; it may accordingly be of single or laminated relatively fine wire cloth.) By this complete circuit encasement we are enabled to leave the entire primary shielding "floating"—i. e., conductively unconnected to any external object—or to connect it to any external object which temporary convenience or apparatus requirements external to the circuits may dictate; conductive connection of the primary circuit to the primary shielding, as by lead 5*d*, being retained or omitted at will. We may of course so completely encase the secondary circuit, as we have illustrated in Figure 4 by the substitution of the complete enclosure 4*t* for the partial shields 4*s* of Figure 4*a*; but so long as the operating requirements necessitate some conductive connection such as 8*a* from the secondary circuit to the external object 8, the secondary shielding must be conductively connected with the secondary circuit and that object, to one or the other by a connection of negligible impedance such as the lead 6*a*.

In the claims hereto appended we intend to claim the various novel combinations, sub-combinations and features which we have disclosed as broadly as the state of the art will permit.

We claim:

1. In combination, a plurality of closed circuits; a coupling medium having a plurality of members respectively included in said circuits; a plurality of conductive shields for isolating said members respectively within said coupling medium; and a plurality of shielding means at mutually different dynamic potentials and respectively associated with said circuits external to said coupling means, each of said conductive shields having the dynamic potential of the respective said shielding means, and each of said shielding means extending about its associated circuit sufficiently to limit the acquisition of extrinsic dynamic potentials by that circuit to the dynamic potential of that shielding means.

2. In combination, a closed circuit and a second circuit; a coupling medium having first and second members respectively included in said circuits; first and second conductive shields for isolating said members respectively within said coupling medium; and first and second shielding means respectively at mutually different first and second dynamic potentials and respectively associated with said circuits external to said coupling means, said conductive shields respectively having said first and second dynamic potentials, and said first shielding means extending about said closed circuit sufficiently to limit acquisition of extrinsic dynamic potentials by that circuit to said first dynamic potential.

3. In a transformer system including a core element and two windings circumferential thereto, two conductive shields for said windings respectively, each said shield extending between its respective winding and the other shield, and a third conductive shield interposed between said two shields, each of the three shields being provided with a circumferential discontinuity and with connecting means, the discontinuities in and connecting means to said third shield and a first of said two shields being so arranged as to balance out fluctuating circumferential shield currents produced by a difference of dynamic potential of those shields, and said third shield and the second of said two shields being at the same dynamic potential.

ORVILLE M. DUNNING.
CHARLES T. JACOBS.

CERTIFICATE OF CORRECTION.

Patent No. 2,170,048. August 22, 1939.

ORVILLE M. DUNNING, ET AL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 2, first column, line 44, for the word "source" read object; page 3, first column, line 5, strike out "the"; line 18, for " 22''' " read 22''; and second column, line 56, for "suite" read quite; page 4, second column, line 1, for "ends" read end; page 5, first column, lines 33 and 38 respectively, for "fluctuating" read fluctuatingly; page 6, first column, line 6, for "facilitated" read facilitated; and second column, line 26, for "21n'" read 20n'; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 3rd day of October, A. D. 1939.

Henry Van Arsdale,
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