June 16, 1964 L. C. FOSTER 3,137,831

LAYER-WOUND AIR-CORE TRANSFORMER

Filed Feb. 13, 1958

Fig. 1

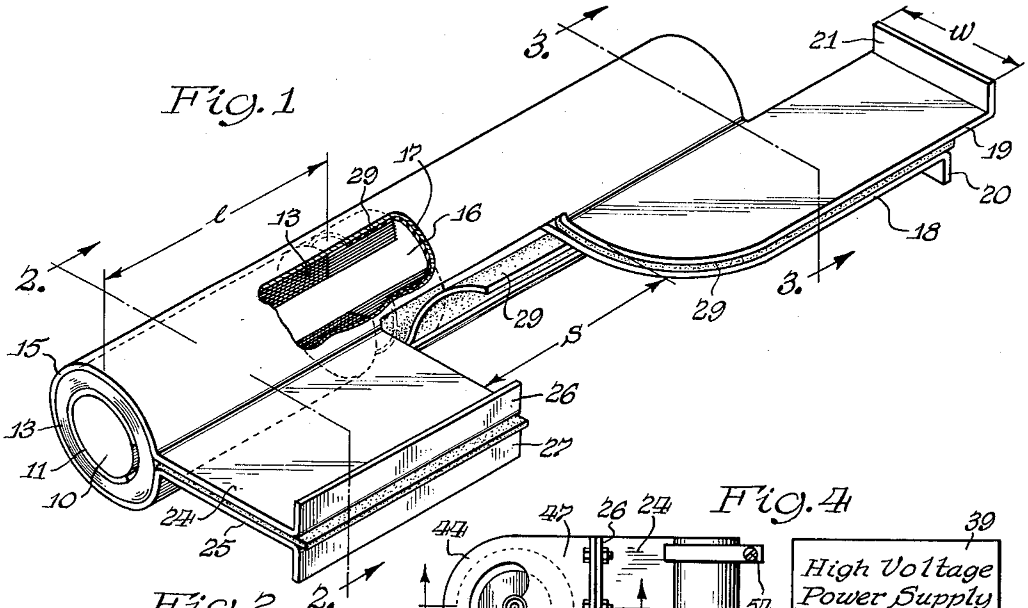


Fig. 2

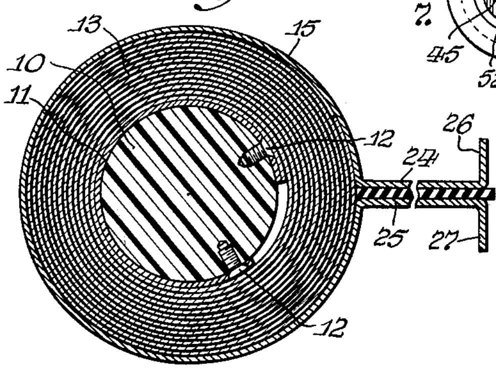


Fig. 4

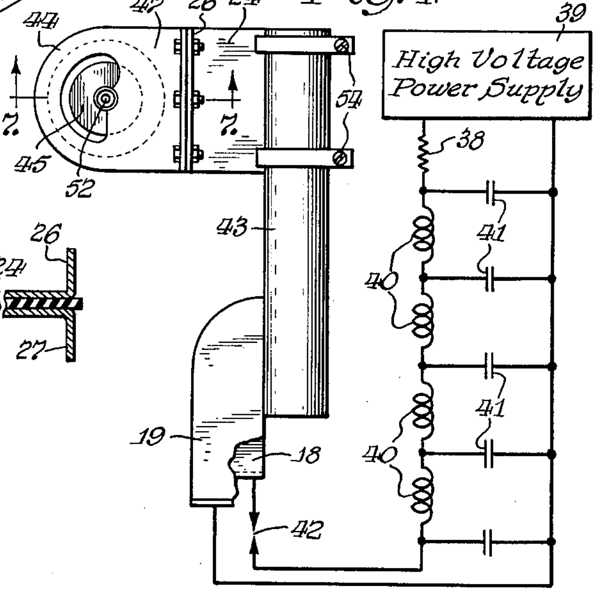


Fig. 3

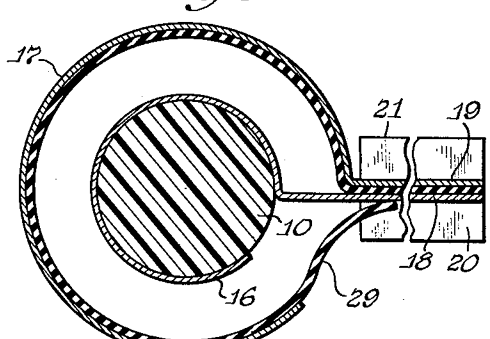
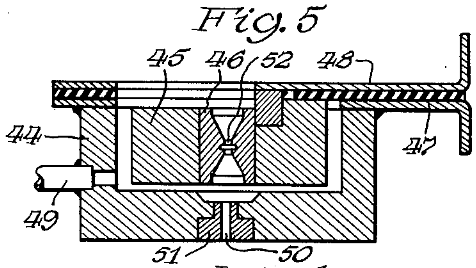


Fig. 5



Inventor
Leigh Curtis Foster
By Francis W. Crotty
Attorney

United States Patent Office

3,137,831
Patented June 16, 1964

3,137,831
LAYER-WOUND AIR-CORE TRANSFORMER

Leigh Curtis Foster, Los Altos, Calif., assignor to Zenith Radio Corporation, a corporation of Delaware

Filed Feb. 13, 1958, Ser. No. 715,062
9 Claims. (Cl. 336—223)

This invention relates in general to transformers and is particularly directed to transformers of the air-core type. The expression "air-core transformer" as used herein and in the appended claims means a transformer which has a core of non-magnetic and non-conductive material whether the core, in fact, be air or an insulating material employed to strengthen the structure mechanically.

Transformers, of course, have a myriad of applications and the desideratum in their design and construction has always been increased efficiency or greater and greater coupling coefficients of the windings with respect to one another. Two well known expedients have been resorted to in the past for the purpose of improving the transformer action: (1) the use of a magnetic core to concentrate the magnetic flux resulting from current flow in the windings and (2) the use of tuned windings. Neither is entirely satisfactory. Magnetic cores are objectionable because they introduce losses, specifically hysteresis losses, and they are subject to saturation which undesirably limits the energy handling capacity of the transformer. Moreover, they impose frequency limitations especially for high-frequency installations. Tuned windings similarly impose severe frequency limitations and may be likened to a brute force method of increasing transformer action. The improvement results from resonance effects rather than from any increase in efficiency due to an improved coefficient of coupling.

Transformers of the air-core type do avoid certain of the objectionable features of those employing magnetic cores but, as previously constructed, they have exhibited poor coupling coefficients and have not represented any real solution to the quest for a high-efficiency transformer. High efficiency, which is another expression for a high degree of coupling, is obviously desirable for any installation, but is essential in systems where the performance depends upon the attainment of "fast circuitry"; for example, in the field of controlled thermonuclear reaction.

Efforts have been made to obtain a thermonuclear reaction by confining a plasma of a suitable reactant within an exceedingly concentrated magnetic field fashioned to enclose a reaction space and by pouring energy into that space. It is necessary in an apparatus pursuing this approach to nuclear reaction to supply enormous quantities of energy in short pulse intervals which may be in the order of 50 microseconds or less and that can be accomplished only through fast circuits. Such circuits are characterized by the fact that their inductance has been reduced as nearly as possible to an essential minimum.

In practice, the energy is delivered from condenser banks and condensers have been developed which have a very low internal inductance. Such a condenser is described and claimed in a copending application, Serial No. 711,376, filed January 27, 1958, now Patent No. 3,024,394, under the name of Winfield W. Salisbury, and assigned to the same assignee as the present invention. Techniques have also been perfected for minimizing the inductance of the leads or conductors employed in constructing the system and a switch for controlling current flow in the system, while of itself contributing a minimum of inductance, is the subject of another copending application, Serial No. 715,000, filed February 13, 1958, now

Patent No. 2,996,633, in the name of Leigh Curtis Foster, and, likewise, assigned to the same assignee as the present invention. The remaining component of the system, which can be a major source of unwanted inductance, is the transformer employed to achieve currents of extreme intensity in the magnetic structure. Transformers heretofore employed for this purpose have been of more or less conventional construction, exhibiting unnecessary leakage inductance and impairing optimum performance of the system.

It is an object of the invention, therefore, to provide a transformer of the air-core type, particularly useful at high frequencies and avoiding one or more of the aforementioned limitations of prior devices.

It is a further object of the invention to provide an air-core transformer exhibiting an extraordinarily-high coefficient of coupling.

It is a specific object of the invention to provide a layer-wound air-core autotransformer which has a coefficient of coupling in excess of 95 percent and which, with its terminal conductors, exhibits a minimum of leakage inductance.

A high-frequency air-core transformer, constructed in accordance with the invention, comprises a first winding which includes a plurality of layer-wound turns of a conductor having a width much greater than its thickness which thickness is of the order of a skin depth at the operating frequency. There is a second winding in concentric relation to the turns of, and having an axial length approximately equal to that of the indiivdual turns of, the first winding to constitute therewith an air-core transformer in which the overall thickness of the windings is small relative to the diameter of the core and to the axial length of the windings. Insulating material is interposed between turns of the windings and a first pair of conductors is connected to the first and last turns of the first winding and they extend in a direction normal to current flow in that winding and are disposed in a closely-apposed mutually-parallel relation. Another pair of conductors comprising flat strips having a width very much greater than their thickness is connected to the opposed electrical ends of the second winding and extend therefrom in a mutually-parallel relation.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The organization and manner of operation of the invention, together with further objects and advantages thereof, may best be understood by referance to the following description taken in connection with the accompanying drawings, in the several figures of which like reference numerals identify like elements, and in which:

FIGURE 1 is a perspective view of a high-frequency air-core autotransformer embodying the teachings of the subject invention;

FIGURES 2 and 3 are sectional views taken at the points designated by section lines **2—2** and **3—3** in FIGURE 1;

FIGURE 4 is a schematic representation of an electrical system utilizing the transformer of FIGURE 1; while

FIGURE 5 is a cross-sectional detail of one of the components of the system of FIGURE 4.

Referring now more particularly to FIGURE 1, the transformer there represented is of the air-core type, as defined hereinabove, and is especially useful in high-frequency high-current applications because of its extraordinarily-low leakage inductance. For example, the transformer is uniquely applicable to controlled thermonuclear reaction apparatus in which a condenser bank is coupled by means of the transformer to a magnetic structure to which currents of an exceedingly-high intensity are to be delivered for short pulse intervals represented by the discharge of the condenser bank. The transformer, in that application, may be employed for a current step-up and the operating frequency is the frequency of the oscillatory discharge of energy in the magnetic structure. The transformer, as will be explained in detail in the ensuing description, preserves the desired steep risetime of the pulse phenomenon in the system by virtue of the fact that the transformer represents an essential minimum inductance in the coupling between the condenser bank as a voltage source and the magnetic structure as a load.

For the purpose of specific embodiment, it will be assumed that the arrangement in FIGURE 1 is an autotransformer having a core **10** for the purpose of increasing the structure mechanically. The core is non-magnetic and non-conductive, being made of canvas based Bakelite, Lucite or other similar material.

The transformer includes a first or primary winding featuring a plurality of layer-wound turns of a conductor having a width that is much greater, several orders of magnitude greater, than its thickness. The forming of the conductor into layer-wound turns results in the width dimension of the stock becoming the axial length "l" of the winding. Before considering this winding in greater detail, it is appropriate to comment on the matter of conductor thickness. The thickness is selected as a compromise between the electrical and mechanical properties of the winding. The thinner the conductor, the better is the winding from the standpoint of its coupling properties, but the resistance of the winding, which varies with thickness, is acceptable for a thickness equal to one skin depth at the operating frequency. The expression for "skin depth" is as follows:

$$\alpha = K\sqrt{\frac{\rho}{f\mu}}$$

in which:

α is the skin depth;
K is a constant depending on the units used,
ρ is the resistivity of the conductive stock from which the winding is constructed;
μ is the permeability of the conductive stock; and
f is the operating frequency.

In addition to the coupling properties and resistance represented by the winding, consideration must be given to its mechanical strength which is enhanced by constructing the winding of heavy stock. A very suitable and appropriate compromise is one in which the conductor thickness is of the order of one skin depth which represents a condition of relatively low power loss within the transformer and hence high efficiency. However, if the transformer is in a system wherein its resistance is not of paramount importance and may be subordinated to enhance the coupling properties, it is highly desirable to construct the winding of two different winding conductors of different thicknesses, the conductor of heavier stock being relied upon for mechanical strength and the conductor of lesser thickness contributing to enhanced coupling properties. Indeed, such a construction is represented in the embodiment under consideration.

Specifically, the primary winding is formed of a first conductor **11** having a thickness equal to several skin depths and having a length very large compared with insulation thickness, such that it may represent the greater portion of the first coil turn. This first conductor is mechanically secured to the core as by mounting screws **12, 12**; preferably, it is anchored to the core at a number of spaced points. The remaining turns of the primary, except for the ultimate turn which also becomes the secondary for an autotransformer, comprise convolutions of a second conductor **13** layer-wound over first conductor **11**. The second conductor may have a thickness approximately equal to one skin depth, but, as indicated above, where the resistance of the winding is not of critical importance, a thickness of ½ of a skin depth or even less, is appropriate for the purpose of enhancing the coupling properties of the transformer. The second conductor has a surface contact with the aforementioned portion of turn **11** by being merely placed thereover and being mechanically secured thereto only by the ultimate binding of the winding. Both conductors **11** and **13** have the same width so that the axial dimension of the multi-turn primary is the same from layer to layer and insulating material is interposed between succeeding layers except, of course, that no insulation is introduced between the leading portions of conductors **11** and **13** which are to be in overlapping engagement, as described. Preferably, the insulation has a minimum thickness in relation to the voltage rating of the transformer.

There is a second winding **15** in concentric relation to the first winding and having an axial length which is approximately equal to that of the primary. Specifically, this is a single-turn winding and, since the arrangement is an autotransformer, it is in effect, a continuation of the primary winding, but is formed from a third conductor. That conductor has a surface contact with the penultimate primary turn, that is to say, winding conductor **15** merely overlays the final turn formed by conductor **13**. Conductor **15** preferably has the same thickness as conductor **11** in order to impart mechanical strength to the transformer. The secondary, in conjunction with the primary winding, constitutes an air-core transformer in which the overall thickness of the windings is very small relative to the diameter of the core and relative to the axial length of the transformer windings. The ratio of the core area to the winding area should, preferably, be at least 4 or 5 to 1 and ratio of winding length to winding thickness should be at least 10 to 1.

In order to couple the transformer electrically and mechanically into an electrical system, conductor pairs are associated with both windings. Since an autotransformer is shown, the lead-in conductors of the primary and secondary windings may have some portions in common. The conductor pair for the primary connect to the first and last turns thereof and actually take the form of extensions of winding conductors **11** and **15**. The extension of winding turn **11** is designated **16** and the extension of the final turn **15** is designated **17**; they extend in a direction normal to current flow in the windings. Actually, each such extension is in the nature of a portion of a coil turn but not so as to be completely closed upon itself, as indicated in the sectional view of FIGURE 3. The conductors are disposed in closely-apposed mutually-parallel relation and have a separation corresponding to the overall winding thickness of the transformer. This is a most convenient feature from the standpoint of fabrication, although it is recognized that section **17** can be reduced in diameter through a drawing process so that the two conductors, while remaining parallel to one another, have a separation less than the overall winding thickness. The conductors **16** and **17** form a type of co-axial line serving as the lead in for the primary and are terminated in wide low-inductance terminal strips **18, 19**. Strip **18**, which is an extension of conductor **16**, projects out through the wide slot defined by the adjacent edges of conductor **17** and strip **19**, as clearly appears in FIGURE 1, projects from conductor **17**. It is convenient to form them from the same stock as primary turn **11** and final turn **15**. Strips **18, 19** are very wide in relation to their separation and are as close together as the voltage gradient permits. It is preferable that a layer **29** of insulation be interposed between them which is continuous into the separation region between conductors **16** and **17** forming the section of coaxial lead. This insulation should overlap the interturn insulation of the primary winding as shown in FIGURE 1. The terminal portions of strips **18, 19** are flanged sections **20, 21** which facilitate making mechanical connections between the primary lead ins and another electrical element; for example, the terminal strips of a condenser bank, or other energy source.

The conductor pair, connected to the secondary winding, is designated **24, 25** and again is in the form of flat conductor strips made of the same stock as, and preferably integral with, winding conductor **15**. They are likewise arranged in closely-apposed mutually-parallel relation with a minimum separation consistent with the electrical requirements and are insulated with respect to one another by any suitable insulating material. They also terminate in flanged sections **26, 27** to facilitate connecting the winding to a load. The separation "S" between primary lead ins **18, 19** and secondary terminal strips **24, 25** is generally determined by the requirements of the particular installation. The shorter this dimension can be, consistent with the necessary insulated relation of these terminal strips from one another, the better because a shorter section contributes the least amount of inductance.

In general, a transformer consists of two windings or coils capable of producing an alternating magnetic field within the core when excited with a proper current in one of the windings, which field occupies essentially the same volume of space with the same vector orientation, regardless of which coil is excited. The energy stored in common by a given current, so as to be available to either coil, represents the energy which can be transferred from one to another in each cycle. While the energy is stored in such a way as to be available to only one coil and not to the other represents a leakage inductance, the described transformer is characterized by the fact that its geometric or physical characteristics accomplish a maximum of energy transfer with a minimum of leakage inductance. Expressed in other words, good coupling and high efficiency result when all the volumes, enclosed by coils within the transformer, are kept to a minimum consistent with adequate insulation. This is achieved with the described structure and, additionally, the auto-type construction, as distinguished from a secondary which is mechanically and electrically separate from the primary, eliminates primary to secondary insulation and further enhances the coupling factor.

The coaxial-type lead ins **16, 17** and the connecting terminal strips **24, 25** of the secondary also permit great reduction in leakage inductance. They employ the concept that if exciting conductors are close to the surface on which they induce currents, that is to say, close in terms of their width, and their width is large compared to the skin depth, image currents appear in close physical proximity in the conductors which is a necessary condition for low inductance. It will be noted that the cross-sectional area of the turns of the transformer, including their interturn insulation, is small compared with the area enclosed by the smallest turn. The more that is true of the construction, the larger is the coefficient of coupling and the greater is its efficiency. The length of the windings in the axial direction is large compared with the other linear dimensions, particularly with respect to the radial thickness of the winding space. In sum, the transformer exhibits a very high coefficient of coupling and has very much improved efficiency. It is observed that the improvement in coefficient is attained without the need of a core of magnetic material and without the requirement of tuned windings.

Terminal strips **18, 19** are the high voltage low current, input to the transformer and terminal strips **24, 25** are the low voltage high-current output connections. Electrically, elements **19** and **24** may be considered as one and may be thought of as the primary ground lead. Then, terminal strip **18** may be considered the primary + and strip **25** may be thought of as the secondary + conductor.

One embodiment of the transformer of FIGURES 1–3 which has been employed for handling secondary currents of the order of 3,000,000 amperes, using a primary source of 25 kilovolts at 300,000 amperes, was found to exhibit a coupling coefficient in excess of 96 to 98%. It had the following dimensions and characteristics:

Core diameter	2".
Number of primary turns	10.
Conductors **11** and **15** (sheets of copper)	0.40" to 0.60" thick.
Conductor **13** (sheet of copper)	.0108" thick.
Interturn insulation, two layers of	.003" thick Mylar.
Winding length "*l*"	12".
Dimension "S"	6".
Width "W" of primary lead in	7".

It is frequently desirable to permit the insulation material of the primary winding to protrude beyond the winding itself, perhaps to an extent of 3". This avoids any tendency to breakdown by virtue of potential gradients along the surface of the insulation.

The transformer construction may be used to great advantage in an electrical system of the type represented in FIGURE 4 which delivers energy during pulse intervals to establish intense magnetic fields within a reaction chamber of a thermonuclear apparatus. Consideration need be given here only to the electrical system for developing the magnetic field. The system is in the form of a transmission line comprising series inductors **40, 40** and parallel condensers **41, 41**. Preferably, they are condensers which have low internal inductance and, to that end, may be constructed as described in the above-identified application of Winfield W. Salisbury. The condensers are charged from a high voltage D.C. source **39** through a current-limiting resistor **38**. The transmission line is electrically connected through a switch **42** of the arc discharge type and an air-core transformer **43** constructed in accordance with the present invention to a load. Preferably, switch **42** is a low inductance device constructed in the manner described in the above-identified Foster application.

The load which is shown in cross section in FIGURE 5 comprises a hollow conductive cylinder **44** within which is housed a single-turn coil **45**. The coil has a central bore which accommodates a magnetic flux concentrator **46**. A ground lead **47** extends from the chamber casing **44** for connection with the ground lead **24** of the transformer secondary. There is another lead in **48** for connection with the other secondary terminal strip **25**, which is insulated from conductor **47**, although arranged in parallel relation therewith and having a minimum separation compatible with the requirements of the electrical system. Lead-in **48** is mechanically and electrically coupled with coil **45**.

A first port **49** leads from chamber **44** to a vacuum system and another port **50**, provided in an insulating member **51**, permits a suitable reactant gas such as deuterium to be admitted into the interior of the flux concentrator **46**.

The electrical system of FIGURE 4 is one in which the energy represented by condensers **41, 41** is applied to the primary of transformer **43** to develop in the secondary winding a very high current which circulates through the single-turn coil **45**, and, the transformer action develops extremely intense magnetic fields within the constricted section **52** of flux concentrator **46**. Using the transformer of the type for which specifications have been given above, and exciting the system from a condenser bank capable of delivering 300,000 amperes when charged to 25 kilovolts, results in an exciting current for chamber **43** in the order of 3,000,000 amperes.

Any electrical system conducting currents of this magnitude develops tremendous mechanical forces, especially when its conductive surfaces are in closely-apposed relation as required to minimize leakage inductance. For that reason, mechanical clamps **54** are placed over the transformer assembly, to resist the forces tending to destroy the transformer windings and its terminal strips. In addition to external clamps, or as an alternative to such clamps, heavy machine bolts may project through the lead-in conductors 18, 19 and 24, 25 further to strengthen the structure against the circuit forces. Of course, it is necessary that such bolts be insulated from those conductors.

The low-inducance lead-in conductors 16, 17 and 24, 25 are especially desirable in the described application of the transformer but need not necessarily be employed in other installations. For example, where the transformer is used for attaining a large voltage step up, the inductance of the secondary, which would have a large number of turns compared with the primary, would be so high that low-inductance lead ins would not be essential. Low-inductance lead-ins would still be desirable for the primary winding however.

While a particular embodiment of the invention has been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. A high-frequency air-core transformer comprising: a first winding including a plurality of layer-wound turns of a conductor having a width much greater than its thickness and having a thickness of the order of a skin depth at the operating frequency; a second winding in concentric relation to the turns of, and having an axial length approximately equal to that of the individual turns of, said first winding to constitute therewith an air-core transformer in which the overall thickness of the windings is small relative to the diameter of the core and to the axial length of the windings; insulating material between turns of said first winding; a first pair of conductors connected to the first and last turns of said first winding, extending in a direction normal to current flow in said winding, and disposed in closely-apposed mutually-parallel relation; and another pair of conductors connected to said second winding comprising flat strips having a width very much greater than their thickness and extending therefrom in closely-apposed mutually-parallel relation.

2. A high-frequency transformer comprising: a first winding including a plurality of layer-wound turns of a conductor having a width much greater than its thickness; a second winding in concentric relation to the turns of, and having an axial length approximately equal to that of the individual turns of, said first winding to constitute therewith a transformer in which the overall thickness of the windings is small relative to the diameter of the core and to the axial length of said windings; insulating material between turns of said first winding having a minimal thickness in relation to the voltage rating of the transformer, having a width substantially greater than the width of said first winding and projecting beyond said first winding on at least one side thereof; a first pair of conductors connected to the first and last turns of said first winding, extending in a direction normal to current flow in said winding, and disposed in closely-apposed mutually-parallel relation; and another pair of conductors connected to said second winding comprising flat strips having a width much greater than their thickness and extending therefrom in closely-apposed mutually-parallel relation.

3. A high-frequency air-core transformer comprising: a core of non-magnetic and non-conductive material; a primary winding including a first conductor turn mechanically secured to said core and including several turns of a second conductor layer-wound over said first turn and having a surface contact therewith; a secondary winding in concentric relation to, and having an axial length approximately equal to that of the individual turns of, said first winding to constitute therewith an air-core transformer in which the overall thickness of the windings is small relative to the diameter of the core and to the axial length of said windings; insulating material between turns of said primary winding; a first pair of conductors connected to the first and last turns of said primary winding; and another pair of conductors connected to electrically opposed ends of said secondary winding.

4. A high-frequency auto-transformer comprising: a core of non-magnetic and non-conductive material; a primary winding including a first conductor turn mechanically secured to said core and including several turns of a second conductor layer-wound over said first turn, said first conductor having a substantially greater thickness than said second conductor and both conductors having a width much greater than their thickness; a secondary winding having less turns than and having an axial length approximately equal to that of said primary and comprising a third conductor having a surface contact with said second conductor to constitute, in effect, a continuation of said primary at the operating frequency of the transformer and defining with said primary an air-core auto-transformer in which the overall thickness of the windings is small relative to the diameter of the core and to the axial length of said windings; insulating material between turns of said primary winding; a first pair of conductors connected to the first and last turns of said primary winding; and another pair of conductors connected to electrically opposed ends of said secondary winding.

5. A high-frequency auto-transformer comprising: a core of non-magnetic and non-conductive material; a primary winding including a first conductor turn mechanically secured to said core and including several turns of a second conductor having a thickness of about one skin depth at the operating frequency, layer-wound over said first turn, said first conductor having a substantially greater thickness than said second conductor and both conductors having a width much greater than their thickness; a secondary winding having an axial length approximately equal to that of said primary and comprising a third conductor having a thickness equal to that of said first conductor and constituting, in effect, a continuation of said primary at the operating frequency of the transformer and defining with said primary an air-core auto-transformer in which the overall thickness of the windings is small relative to the diameter of the core and to the axial length of said windings; insulating material between turns of said primary winding; a first pair of conductors connected to the first and last turns of said primary winding; and another pair of conductors connected to electrically opposed ends of said secondary winding.

6. A high-frequency auto-transformer comprising: a core of non-magnetic and non-conductive material; a primary winding including a first conductor turn mechanically secured to said core and including several turns of a second conductor having a thickness less than a skin depth at the operating frequency, layer-wound over said first turn, said first conductor having a substantially greater thickness than said second conductor and both conductors having a width much greater than their thickness; a secondary winding having an axial length approximately equal to that of said primary and comprising a third conductor having a thickness equal to that of said first conductor and constituting, in effect, a continuation of said primary at the operating frequency of the transformer and defining with said primary an air-core auto-transformer in which the overall thickness of the windings is small relative to the diameter of the core and to the axial length of said windings; insulating material between turns of said primary winding; a first pair of conductors connected to the first and last turns of said primary winding; and another pair of conductors connected to electrically opposed ends of said secondary winding.

7. A high-frequency air-core transformer comprising: a first winding including a plurality of layer-wound turns of a conductor having a width much greater than its thickness; a second winding in concentric relation to the

turns of, and having an axial length approximately equal to that of, said first winding to constitute therewith an air-core transformer in which the overall thickness of the windings is small relative to the diameter of the core and to the axial length of said windings; insulating material between turns of said first winding; a first pair of conductors extending coaxially from said first and last turns of said first winding to constitute a coaxial type of lead-in for the transformer; and another pair of conductors connected to said second winding comprising flat strips having a width approximately equal to the axial length of said winding and extending therefrom in closely-apposed mutually-parallel relation.

8. A high-frequency air-core transformer comprising: a first winding including a plurality of layer-wound turns of a conductor having a width much greater than its thickness; a second winding in concentric relation to the turns of, and having an axial length approximately equal to that of, said first winding to constitute therewith an air-core transformer in which the overall thickness of the windings is small relative to the diameter of the core and to the axial lengths of said windings; insulating material between turns of said first winding; a first pair of conductors extending coaxially from said first and last turns of said first winding to constitute a coaxial type of lead-in for the transformer; low inductance terminal strips projecting from the conductors of said coaxial lead-in and insulated from one another; and another pair of conductors connected to said second winding comprising flat strips having a width much greater than their thickness

and extending therefrom in closely-apposed mutually-parallel relation.

9. A high-frequency air-core auto-transformer comprising: a primary winding including a plurality of layer-wound turns of a conductor having a width much greater than its thickness; a single-turn secondary winding constituting, in effect, a continuation of said primary and defining therewith an air-core auto-transformer in which the overall thickness of the windings is small relative to the diameter of the core and to the axial length of said windings; insulating material between turns of said primary winding; a first conductor constituting an axial extension of the first turn of said primary; a second conductor constituting an axial extension of said secondary and defining with said first conductor a coaxial type of lead-in; low-inductance terminal strips projecting from the conductors of said lead-in and insulated from one another; and another pair of terminal strips projecting from said secondary for connection to a load.

References Cited in the file of this patent

UNITED STATES PATENTS

217,466	Le Conte	July 15, 1879
2,577,707	Kerns et al.	Dec. 4, 1951
2,662,162	Blok	Dec. 8, 1953
2,710,947	Gaston	June 14, 1955
2,855,576	Rohatyn	Oct. 7, 1958
2,856,577	Schmidt	Oct. 14, 1958
2,863,130	Gray et al.	Dec. 2, 1958
2,963,669	Salisbury	Dec. 6, 1960