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2,626,318

RADIO-FREQUENCY TRANSFORMER AND INDUCTANCE ELEMENT THEREFOR

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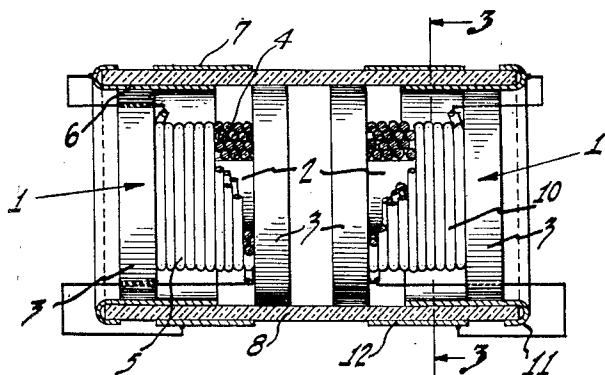


Fig. 1.

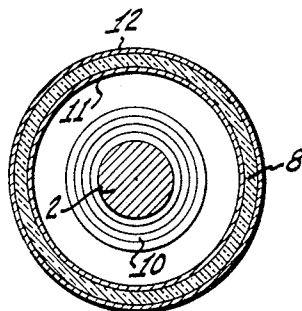


Fig. 3.

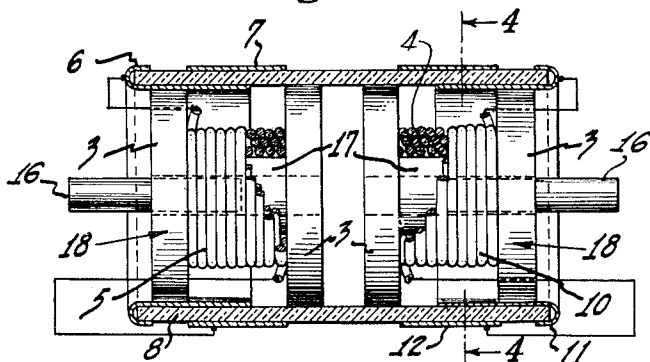


Fig. 2.

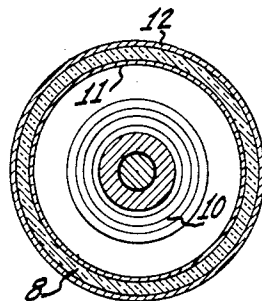


Fig. 4.

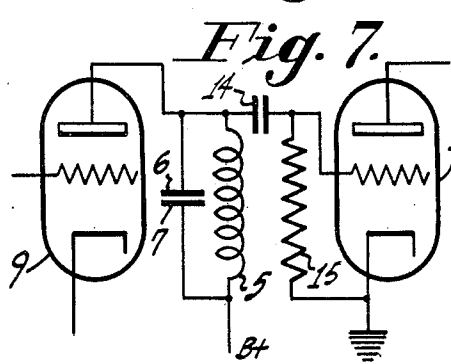


Fig. 5.

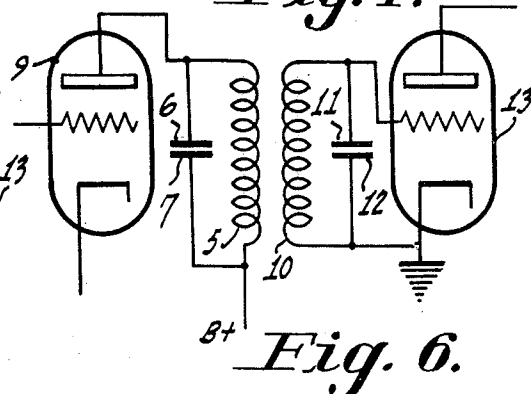
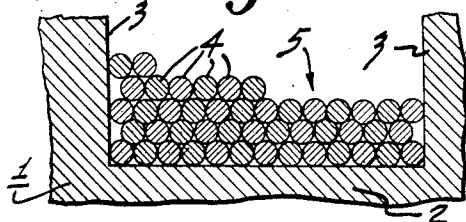


Fig. 6.



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RADIO-FREQUENCY TRANSFORMER AND
INDUCTANCE ELEMENT THEREFORAlton J. Torre, Westmont, N. J., assignor to Radio
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This invention relates to radio-frequency transformers and inductance elements therefor, and particularly to tuned radio-frequency transformers and inductance elements employing molded magnetic cores.

Superior performance is achieved, in accordance with the invention, by utilizing more effectively the core and conductor material of the inductance elements to give more inductance and less resistance. The simple, compact arrangement results in better performance and is more economical both as to its own cost and in its space requirements, so that it is particularly useful as a component of radio receivers and other compact devices that are made in large quantities. The improved inductance element is peculiarly adapted for use in combination with a certain type of capacitor to form an improved radio-frequency transformer.

It is well known to those skilled in the art that the purpose of an electrical inductance is to store electromagnetic energy. It does this perfectly in the sense that no energy is wasted in storage, but it functions imperfectly in that energy necessarily is dissipated in the resistance of the conductor in passing to and from the inductance. It is like a water pail that does not leak, but that inherently spills a little water each time it is filled or emptied. Since in the alternating-current applications herein contemplated, the inductance element is charged with energy and uncharged many hundreds of thousands, or even millions, of times each second, it is apparent that the resistance of an inductance element relative to its inductance is a matter of importance. A widely recognized figure of merit of an electrical inductance at a given frequency is the ratio of the energy stored therein to that dissipated during its sinusoidal charge and discharge, and this ratio, when multiplied by a convenient proportionality factor, is known as the Q of the inductance element.

The principal object of the invention is to provide an inductance element having the highest possible Q consistent with the low cost and small size necessary for large quantity production. This object is achieved by arranging the core and conductor material to make the best use thereof as more fully described hereinafter.

The invention is directed to improvements in tuned radio-frequency circuits as distinguished from lower-frequency circuits that usually are untuned and that do not require a high Q . A radio-frequency transformer suitable for use as an intermediate-frequency transformer in a su-

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perheterodyne radio receiver will be described as an example of the invention. In addition to the dominant need for high Q , it is necessary in some applications that the intermediate-frequency transformer be shielded and that it be small. For large quantity production it should also be inexpensive.

A further object of the invention, therefore, is to provide a self-shielded, high- Q transformer that is a compact unit and that may be constructed cheaply. This object is achieved by combining with the aforementioned inductance elements a capacitor that dissipates very little energy and that is adapted to encompass and shield the inductance elements to form a compact and effectively shielded transformer. Another object of the invention is to provide a transformer that readily may be tuned to a predetermined frequency. This object is achieved, in one modification of the invention, by removing a suitable portion of one of the plates of the capacitor. This expedient is simple, inexpensive, and effective, but it has the disadvantage that the operator sometimes cannot be sure he has removed enough material until too much has been removed, requiring replacement of some of the plate material.

In another modification tuning is accomplished by sliding in or out an auxiliary core that is not critical in its adjustment because it constitutes only part of the magnetic path, and that advantageously may be of higher permeability than the core which constitutes the remainder of the path.

In the accompanying drawings:

Fig. 1 is a longitudinal sectional view of a transformer embodying the invention, certain portions thereof being shown schematically;

Fig. 2 is a longitudinal sectional view of a transformer embodying a modification of the invention, certain portions thereof being shown schematically;

Fig. 3 is a sectional view taken along the line 3-3 in Fig. 1;

Fig. 4 is a sectional view taken along the line 4-4 in Fig. 2;

Fig. 5 is a fragmentary sectional view of one of the inductance elements of Fig. 1;

Fig. 6 is a schematic diagram of a circuit employing a transformer in accordance with the invention; and

Fig. 7 is a schematic diagram of a circuit employing an inductance element in accordance with the invention.

Referring to Figure 1, a pair of spool-shaped

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cores 1, 1 are here shown, each core consisting of a body portion 2 and end flanges 3 integrally constructed as by molding of comminuted magnetic material in accordance with well-known practice. By magnetic material is meant material that is capable of being magnetized and that has a high magnetic permeability. Conductor 4 is random wound on body 2 between flanges 3 to form coil 5. In a typical intermediate-frequency transformer for a superheterodyne receiver employing a 455 kc. intermediate frequency, conductor 4 consisted of a solid copper conductor 0.0035 inch in diameter insulated with a type of enamel commonly known as Formex to an overall diameter of 0.0043 inch, coil 5 being about 0.12 inch wide and 0.06 inch deep. Flanges 3 extend beyond coil 5 sufficiently to form a path of large cross-sectional area, lines of force passing therebetween in the individual cores, interlinking all of the turns of coil 5.

In a transformer of the so-called double-tuned type, two similar inductance coils are placed end to end, as shown in Fig. 1, spaced apart sufficiently to give adequate electromagnetic coupling therebetween. Inductance coil 5 is tuned by a capacitor comprising inner plate 6 connected to one end of the inductance coil and outer plate 7 connected to the other end thereof, separated by dielectric 8 which preferably is cylindrical in form and made of some suitable ceramic material. Inner plate 6 is connected to the anode of preceding vacuum tube 9 and outer plate 7 is connected to a suitable B+ voltage supply as indicated in Figure 6.

Coil 10 may be like coil 5 or may differ therefrom as to the number of its turns but is random wound of enamel-covered wire directly on the other core 1 between flanges 3 which extend substantially beyond the coil. Coil 10 is tuned by the capacitor comprising inner plate 11 connected to one end of the coil and outer plate 12 connected to the other end thereof. Inner plate 11 is connected to the grid of tube 13 which may be followed by any suitable utilization circuit, not shown. Outer plate 12 is connected to ground, either directly as shown in Fig. 6 or through a low radio-frequency impedance, not shown.

Thus, outer plates 7 and 12 being at low potential or substantially at ground potential insofar as radio frequencies are concerned, serve as an effective shield to coils 5 and 10 whose fields are already confined more or less closely by the good magnetic path provided by the projecting edges of flanges 3. Outer plates 7 and 12 also serve to shield inner plates 6 and 11 which are at high radio-frequency potential with respect to ground. It is apparent that coils 5 and 10 and their tuning capacitors are thus connected by the shortest possible leads, thereby minimizing the resistance of the transformer circuit and also avoiding the undesirable extraneous electromagnetic fields that would result from longer leads extending outside of shielding plates 7 and 12.

If impedance coupling is to be used instead of transformer coupling, the primary portion of the transformer shown in either Fig. 1 or Fig. 2, with or without the secondary portion, may be employed as an impedance and utilized as shown by way of example in Fig. 7. Capacitor 14 connects plate 6 to the grid of tube 13 and resistor 15 connects the grid of tube 13 to a point in the circuit that is at a suitable D.-C. potential and shown as grounded. The impedance of capacitor 14 is so low and the resistance of resistor 15 is so high that these elements have a negligible effect on alternating currents flowing in the circuit.

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Each of the intermediate-frequency transformers in a radio receiver, for example, may, if desired, be pretuned to the same predetermined frequency before installation in the receiver, or each of the transformers may be tuned to the same frequency after installation. This tuning may be accomplished in a simple manner by removing a portion of the outer plates 7 or 12, which may be formed of a thin layer of sprayed silver or other metal, sufficient in area to give the necessary capacitance to tune the coil to the desired frequency.

Figure 2 shows an alternative embodiment of the invention in which a transformer is tuned to the desired frequency by adjusting auxiliary cores 16 to vary the inductance of coils 5 and 10. Except for openings in which auxiliary cores 16 are slidable, cores 18 are the same as cores 1 of Fig. 1. Since auxiliary cores 16 form only a relatively small part of the cross-sectional area of body portion 17 of core 18, their movement with respect to coils 5 or 10 results in a comparatively small variation in inductance so that the adjustment of cores 16 is not unduly critical, particularly at the high frequencies involved herein. The lines of force constituting the electromagnetic field of coil 5 are more dense in the outer portion of body 2 of the core near coil 5 and less dense at the center of the core. It is, therefore, feasible to employ material of higher permeability in auxiliary cores 16, thereby increasing the effectiveness of the magnetic path of core 18 notwithstanding that most presently known magnetic materials having higher permeability also have greater losses in a radio-frequency field than do lower-permeability materials.

Conductor 4 should have sufficient insulation so that it may be wound in direct contact with the body and flanges of core 1 without breaking down between turns or between the conductor and the core. This insulation should not be unnecessarily thick, however, in order that the turns of a coil may be close together and close to the core on which they are wound. Insulation heretofore used on so-called "litz" wire is satisfactory and a good grade of enamel insulation, such as Formex, is also satisfactory. In winding coil 5 the wire preferably should be guided by a fixed guide positioned a substantial distance from core 1 in order that the turns of coil 5 may assume the compact form shown in Fig. 5, where each turn rests in a groove between two previously wound turns, or directly against the core.

It has heretofore been supposed that higher Q of magnetic-core radio-frequency inductance elements would be attained with a plurality of universal-wound sections in order to reduce the distributed capacitance of the coil by separating appreciably the individual turns thereof. Frequently litz wire, formed of a plurality of small strands each insulated from the others, has been used reduce losses due to skin effect by providing a greater proportion of surface conductor material (an inherent geometrical property of small conductors compared to large ones) because of a strong tendency of radio-frequency currents to concentrate at and near the surface of a conductor. These expedients have been objectionable because special machines are required to wind universal coils and, more important, the coils thus wound have been too bulky for maximum inductance. Litz wire is expensive and laborious to apply because of the difficulty of cleaning the individual strands before soldering. These objections have been overcome and, in addition, substantially higher Q has been obtained, in accord-

ance with the invention, merely by random winding ordinary enamel-covered wire directly in a slot in a magnetic core. By random winding is meant the winding of wire in a slot with whatever distribution naturally occurs when the wire is guided by a stationary guide a substantial distance from the slot. The circular wire thus fills to the greatest possible extent the interstices between turns, as shown in Fig. 5, and the lines of force surrounding each current-carrying conductor thus interlink the greatest possible number of turns. As is well known to those skilled in the art, this interlinkage of lines of force with conductors is called inductance and lines of force that merely occupy the interstices between turns, without interlinking turns other than the ones that produce them, are largely wasted insofar as inductance is concerned.

It is thus apparent that the inductance of a given quantity of wire is greater if the turns are random wound than if they are universal wound, since in universal winding the wire guide moves back and forth rapidly to cause successive turns to cross over those underneath, thereby causing larger interstices between turns and, therefore, greater waste of lines of force. Furthermore, the average turn length is less with random winding because the turns do not encompass unnecessary waste space and consequently the resistance of the coil is lowered by the same improvement that increases the inductance. But the increase in inductance is greater than that due merely to bringing the turns into closer proximity with each other by reducing the size of the interstices between them. Random winding also brings the turns closer to the magnetic core so that the greatest possible number of lines of force are multiplied by passing through the magnetic material, thereby similarly multiplying the inductance.

What has been said of universal winding applies also to other forms of coils heretofore used for high-Q radio-frequency inductances, such as progressive universal, basket-weave coils, layer-wound coils with insulation between layers, or multiple-pie coils in which a plurality of separate coil sections are connected in series to reduce the distributed capacitance. In all of these arrangements, the electromagnetic lines of force do not interlink the greatest possible percentage of the conductors and the maximum number of lines of force do not pass through the magnetic core, thereby failing to conform to the spirit of the present invention.

If litz wire were used instead of solid (single-stranded) enamel-covered wire, there would be more interstices that would decrease the inductance so that a greater length of litz wire would be required to produce a given inductance and it consequently would have greater total resistance notwithstanding that the resistivity per unit length of litz wire may be less than that of solid wire of the same cross-sectional area. It should be noted, however, that this statement and that of the preceding two paragraphs apply only to magnetic-core radio-frequency inductance elements of the type herein disclosed wherein reducing the interstices between turns increases the inductance not only by bringing the turns into closer proximity with each other, but also by bringing the average turn into closer proximity to a high-permeability magnetic core.

It is recognized that random winding of inductance coils, such as loudspeaker fields, has long been practiced merely as a matter of winding expediency. In accordance with the invention, the

simplicity of random winding is of value, but of far more importance is the increased inductance for a given resistance (higher Q) due not alone to random winding, but to the combination of random winding directly on a particular kind of magnetic core that acts on the greatest possible number of lines of force produced by current flowing through the random winding.

The resistance of the coil is minimized effectively in accordance with the invention by making the conductor shorter as a result of reducing the sizes of the interstices between turns, and by making the conductor more effective by placing it in closer proximity to a magnetic core having flanges extending beyond the coil. From another viewpoint, a certain conductor gives more inductance when random wound directly in contact with the bottom and sides of a slot in the magnetic core of the invention, thereby forming a higher Q inductance element than would result from other forms of winding or from winding over the usual paper or cloth insulation.

Inasmuch as the magnetic field is highly concentrated inside the coil and immediately outside its ends, it is important that there be no air gap in the magnetic core in these regions. Even the very short joint formed by two closely abutting core sections in the central region of the coil seriously will reduce the effectiveness of the core. Since it is not feasible to eliminate all joints and air gaps, it is best to place the air gap in the outer portion of the magnetic path where its area and that of the adjacent core face may be large and hence the effect on the magnetic circuit will be relatively small. To this end, flanges 3 extend substantially beyond coil 5, as previously described, in order that the resultant large area between the flanges outside the coil will form an air gap that is large in cross-sectional area in comparison with its length. All of the lines of force passing between these outer portions of the flanges interlink all of the conductors of coil 5, thereby forming a maximum inductance.

Thus, in a cheap and simple construction, high-permeability magnetic material is provided in the place where it will do the most good, that is, in the region where the lines of force are most dense, and a large-area transition member (flange 3) is interposed between the high-density region and the low-density, large-area air gap thereby forming an effective and efficient magnetic path. A random-wound coil less closely associated with this magnetic core, or one associated with a less effective core not having flanges extending beyond the coil, would not possess fully the aforesaid advantages and might be less efficient than coils hereto known.

It will be understood that the invention is not limited to the precise form depicted herein as an example, but that it includes modifications thereof within the scope of the following claims:

What I claim is:

1. In a high-Q radio-frequency electrical inductance structure a high permeability magnetic core having a hollow narrow body portion and two spaced flanges integral therewith extending outwardly from the body portion, and an elongated-insulated conductor random wound directly on said body portion against and between said flanges to form a coil, said flanges extending beyond said coil a substantial distance to form a part of a magnetic circuit enclosing all of the turns of said coil, and an auxiliary high permeability magnetic core slidably mounted

in said hollow body portion to vary the inductance of said inductance element, said auxiliary core having higher permeability than said body portion, and an electrostatic shielding structure for said inductance structure comprising a pair of concentric spaced capacitor electrodes, the inner one of said concentric capacitor electrodes surrounding and engaging at least one of the flanges of said inductance structure.

2. In a radio-frequency transformer apparatus: a pair of high-Q electrical inductance structures each comprising a magnetic core having a narrow body portion and two spaced flanges integral therewith; an elongated-insulated conductor random wound directly on said body portion against and between said flanges to form a coil, said flanges extending beyond said coil a substantial distance to form part of a magnetic circuit enclosing all of the turns of said coil; two pairs of concentrically spaced capacitor electrodes, the inner ones of said concentric capacitor electrodes respectively surrounding and engaging the flanges of each of said pair of inductance structures.

3. In a high-Q radio-frequency electrical inductance structure: a magnetic core having a high permeability at radio frequencies, said core including a narrow body portion and two spaced flanges integral with and extending outwardly from the body portion, an elongated single-stranded insulated conductor wound directly on said body portion and between said flanges to form closely packed turns of a coil, a first capacitor element surrounding and engaging at least one of said flanges, a dielectric sleeve surrounding and engaging said first capacitor element, and a second capacitor element surrounding and engaging said dielectric sleeve.

4. The combination as defined by claim 2 in which the capacitor structure includes a dielectric tube having inner and outer surfaces, and capacitor electrodes on the respective surfaces for cooperating with the intervening portions of the dielectric to provide a capacitor for each inductance structure.

5. The combination as defined by claim 4 in which the outer capacitor electrodes are in the form of sprayed metal coatings, portions of which are readily removable for capacitance adjusting purposes.

6. The combination as defined by claim 5 in which the body portion of at least one core is hollow, and an auxiliary core is slidably held in said hollow body for adjusting the corresponding inductance, said auxiliary core having a

higher permeability and a greater loss than the hollow body portion.

7. In a high frequency transformer structure: two coaxially spaced magnetic cores, each of said cores including a relatively short cylindrical body portion provided at its opposite ends with relatively large diameter flanges, a pair of single-stranded elongated insulated conductors respectively wound directly on said body portions between the flanges thereon, a first pair of capacitor elements respectively concentrically surrounding and engaging the remotely disposed flanges of said cores, a dielectric tube extending the length of said coaxially spaced cores surrounding and engaging said first pair of capacitor elements, a second pair of capacitor elements surrounding and engaging said dielectric tube being respectively in concentric relation with said body portions, and connections for each of said coils connecting the opposite ends thereof respectively to the capacitor elements concentric therewith.

8. The combination as defined by claim 7 in which the body portion of at least one of said cores is hollow, and an auxiliary core is slidably positioned within said body portion for adjusting the corresponding body inductance.

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