June 11, 1946. W. J. POLYDOROFF 2,401,882

ULTRA HIGH FREQUENCY INDUCTOR

Filed Jan. 27, 1943

Fig. 1.

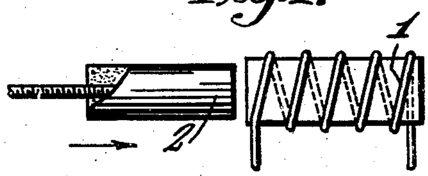


Fig. 2

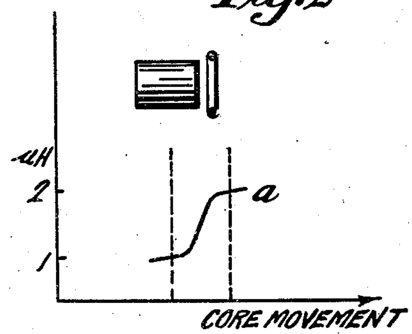


Fig. 3.

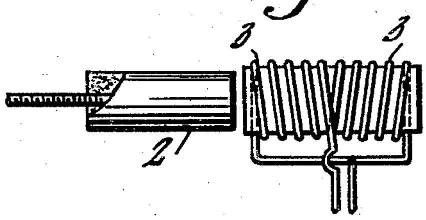


Fig. 4.

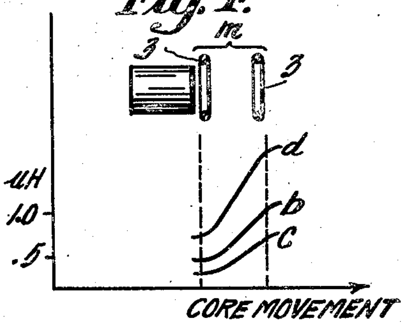


Fig. 5.

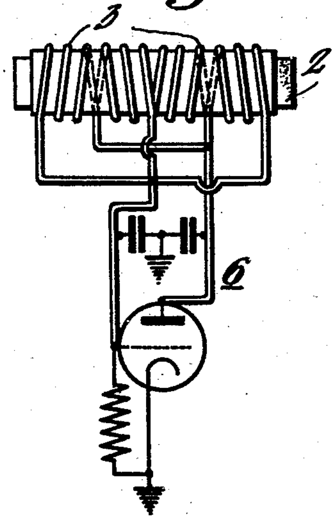
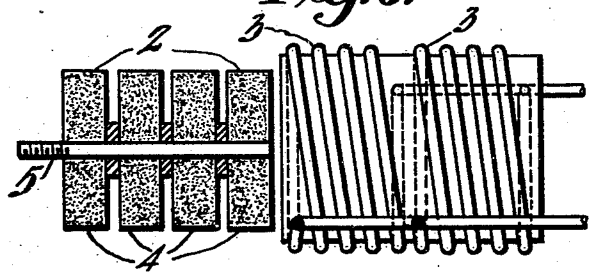


Fig. 6.



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UNITED STATES PATENT OFFICE

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ULTRA HIGH FREQUENCY INDUCTOR

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13 Claims. (Cl. 171—242)

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The present invention relates to high frequency circuits of tunable or adjustable type in which the inductance elements of the circuits are adjustable by means of ferro-magnetic cores.

Circuits including inductors of the above-mentioned type are, in general, applicable in cases where ultra high frequencies are to be dealt with, and particularly so in high frequency radio or the like transmitting equipment where the losses introduced through the use of iron cores must be kept as low as possible.

It has been a common practice in the inductance coils for such circuits to space the turns apart and to employ core materials of low loss nature. Both of these expedients greatly reduce the amount of inductance variation obtainable by the movement of the core in and out of the coil, so that the tuning range is greatly restricted.

The present invention has for one of its objects an improved construction of coil and core in which large inductance variations are obtainable while low core losses are maintained.

Another object of the invention is to improve tuning curve or variation of inductance, vs. linear displacement of the core.

Still another object of the invention is to provide such convenient designs which permit desired characteristics at high currents.

The invention is generally applicable to high frequency transmitting and receiving circuits when the usually employed coils are helically spacedly wound and the core material of low permeability is used and its utility extends to a frequency range from 2 to 100 mc.

The invention will be better understood by reference to the accompanying drawing in which:

Fig. 1 shows a conventional type of variable ferro-inductor to which the invention is applicable;

Fig. 2 shows diagrammatically the inductance variation obtainable in the device shown in Fig. 1;

Fig. 3 shows an improved variable ferro-inductor according to the invention;

Fig. 4 shows diagrammatically the inductance variation obtainable in the device shown in Fig. 3;

Fig. 5 shows one application of an improved inductor according to the invention to an ultra high frequency circuit, and

Fig. 6 shows the invention in its application to transmitting equipment.

In the production of cores of common practice, composite core resistivity of a very high order is usually maintained to restrict the circulation of currents from one particle to another, practice showing, however, that an increase of such re-

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sistivity above 10,000 ohm-cms. does not produce appreciable improvement. The insulating films between the particles are so minute that there always is danger of breaking down the insulation under strong currents and by the heat developed in the core material during operation at high frequencies. To prevent such breakdowns in cores operating in high tension coils, additional insulating means are provided.

In the present invention, in order to further improve the operation of cores at higher frequencies or under strong currents, the cores may be made of powdered magnetic materials of low conductivity, a particularly suitable magnetic material of this kind being synthetically prepared pure magnetite (Fe_3O_4) but it possesses low permeability. Alloying of iron with silicon or antimony in high proportion of the non-magnetic agent also materially decreases the conductivity of the particles and thus reduces the losses.

The use of a low permeability core material necessitates different constructions of the inductors to compensate for the reduction of the effective permeability obtainable by such a core in a high frequency coil. Further, it has been definitely established that in high freqeuency coils usually employing spaced turns the effective permeability is still more reduced because of incomplete linkage from turn to turn due to the leakage field, this leakage becoming more pronounced as the frequency is increased.

The present invention provides for an improved construction of ultra high frequency or transmitter coils of the type in which adjustment is made by means of a ferro-magnetic core, whereby the above-described undesired effects are reduced or eliminated.

Referring now to Fig. 1 in which a known variable ferro-inductor is shown, a coil 1, designed for high frequency operation, has associated with it a core 2 which may be inserted or withdrawn from the coil to provide the required adjustment. Depending upon the nature of its employment, the coil may be from 2'' to ½'' in diameter and consist of several spaced turns of solid or hollow wire.

The core structure may be in the form of a cylinder or a cone. As already stated, the spacing between the turns reduces the effective permeability of the coil, yet this spacing is necessary to provide an elongated coil in which the effective permeability is usually increased, also to facilitate smooth adjustment of the inductance with linear movement of the core. Were it possible to place the turns closer together while maintaining the same length-to-diameter ratio, a higher effective permeability would be obtained.

For this reason alone we should use inductance as high as possible. However, the circuit considerations limit the value of the inductance to a value consistent with the amount of capacitance, residual or external, necessary to resonate the circuit at a given frequency. Thus we arrive at inductance values which become exceedingly small at frequencies approaching 100 megacycles. In practice such inductance can be realized with a single turn of ½" I. D. which in turn will require an adjusting cylindrical core of approximately ⅜" O. D. While this is applicable to a receiving circuit, the conditions met with in a transmitting circuit are of a more serious nature because, from the consideration of heat dissipation in the coil and the core, the diameters should be considerably increased and even one turn of wire will be too much to form a circuit of satisfactory L/C ratio for the above frequencies.

The inductance variations due to the core may be considered as consisting of two parts: one, the inductance variation in the turn or turns per se, and the other, the variation of mutual inductance or linkage between the turns, both variations adding together, the latter variation decreasing as the turns are spaced apart.

Let us consider now the inductance variation due to the change of inductance of the turn. Fig. 2 shows schematically one turn of inductance 1 and its variation due to the core 2. Curve *a* of S-type shows a rather abrupt change of inductance when one face of the core passes through a turn and as the core progresses through the turn the inductance change becomes negligible.

Fig. 3 shows an adjustable ferro-inductor in accordance with the invention in which the winding is arranged in a novel manner, by taking advantage of well-known inductances in parallel. Two coils 3, 3, of the same diameter and inductance, are shown side by side and connected together so as to form a parallel combination in aiding relation. Neglecting for the moment the mutual inductance between the two coils, the inductance of each parallel section, i. e. each coil, should be doubled in order to obtain the same inductance as in the case of Fig. 1.

Assuming that inductance is proportional to the square of the number of turns it will be seen that each section requires an increased number of turns by the factor of 1.41 so that the whole coil combination has approximately three times as many turns as before. This also means that for the same geometrical dimensions the turns of each section must be spaced from one another by one-third of the spacing required in the previous example, which, as already explained, considerably improves the linkage between the turns at high frequency and consequent effective permeability. The choice of proper diameter of the wire (hollow tubing) for a satisfactory coil for high frequency calls for the use of relatively thick wire which means that the effective coil diameter with respect to the core is increased. This also causes decrease of effective permeability. When two coils in parallel are provided, as described it is permissible to decrease size of wire, which becomes another contributing factor to the increased inductance variation. It is of course understood that the above reasoning equally well applies to paralleling of several sections together so that a still greater number of turns may be used. In selecting the method of laying parallel sections together one must bear in mind (*a*) that all sections must be laid in aiding relation, (*b*) that the sections with their connecting wires have substantially equal inductance, and (*c*) that the sections are laid symmetrically. Fig. 3 shows such a symmetrical arrangement for two sections and Fig. 5 shows the same method applied to a 4-section coil.

Referring now to Fig. 4 and neglecting again inductance variation due to change of mutual or linkage inductance between the turns, we may consider the inductance variation produced by the same core in an inductor having two turns in parallel. The curve *b* shows the variation of inductance from minimum to maximum for the same length of travel of the core as in Fig. 2. The curve now becomes more gradual, thus enabling improved selection of frequencies if the core is used as a tuning element. While the total inductance variation of the inductor due to change of inductance in the turns per se remains substantially the same as in Fig. 2, the additive mutual inductance variation separately shown by curve *c* accounts for an improved total inductance variation *d*. The same line of reasoning applies to a coil having a plurality of turns wound in several parallel sections, as shown in Fig. 5. This figure also shows the application of a multi-section coil to an U. H. F. oscillator 6 of the Colpitts type.

In the design of transmitter coils, enough surface must be provided to secure dissipation of heat generated in the coil at high frequencies. The above described expedient usually adds to the metal surface of the coil from which heat is more readily radiated and results in cooler operation of the system.

A core composed either of metallic particles insulated from each other, or of a non-metallic magnetic substance, is usually a poor conductor of heat and in spite of all precautions may develop considerable heat inside of its mass when used in a transmitting circuit. These design considerations are shown in Fig. 6. In this figure a transmitter coil 3 having a ribbon type of winding is shown. This provides a coil having a large surface, the winding consisting of two parallel-connected sections and the core 2 being formed of a plurality of sections 4 with air spacing between them and mounted upon an insulating rod, 5. The comminuted particles may be bound together by an inorganic binder, for instance, of ceramic nature, to avoid deterioration of core at elevated temperatures.

It has been observed that the coil alone has a certain drift of inductance at high temperatures, which drift is somewhat increased when the core is also heated. In ferro-inductors having low permeability material, such as above described, the temperature coefficient may be estimated as being approximately ½ percent for 100° F. rise. As transmitter coils may easily reach this temperature increase during operation, it is recommended, in circuits of the kind described, that fixed capacitors having an equal and opposite temperature coefficient be employed in order that the circuits may remain stable at different temperatures of operation.

The invention may be employed to an advantage in the receiving circuits calling for considerable range of frequencies, such as for instance 6–18 mc. band. In such circuit the minimum inductance required should be of the order of 1 microhenry and may be realized by closely winding on the same tubing of two sections in parallel to a total length of 1'', such as schematically shown on Fig. 3 and for the inductance variation to employ a cylindrical core closely fitting in the inside of the tube and of a length slightly in excess of 1''. In that frequency range the core material must be of relatively low permeability in order to reduce the core losses, hence the employment of special windings is recommended. In a construction as described the total inductance variation of 3:1 may be realized so that the whole range is covered in two steps: 6 to 10 mc. and 10 to 18 mc., the second range being obtainable by disconnecting part of a capacitor or by switching the sections of the windings or parts of same from a series to a parallel combination.

If further increase in inductance range is desired within the same geometric limitations of the coil, more sections can be wound, each to still higher inductance and parallel together as per Fig. 5, so that still thinner wire and more turns in the coil will produce higher inductance variation.

As another extreme application of the present invention to ultra high frequency circuits may be the case. Normally, a single turn inductance will be employed. In order to further reduce the inductance value and therefore increase the operating frequency of the inductor it is proposed in accordance with this invention to use a wide metal ribbon formed as a single turn, the width of the ribbon being slightly less than the length of the adjusting core. Additionally, this single turn may be slotted transversely to its axis so that in effect several turns are spaced from each other by the width of the slots, and joined at the bottom of each turn by common metal thus forming a parallel connection as already explained in Fig. 4. The practice shows that the inductance and the losses in such coil are both greatly reduced and the effective permeability due to the core is noticeably increased. The slots cut in the solid metal may be so varied in their shape and length that all sectional turns are of substantially the same inductance.

Having thus described my invention, what I claim is:

1. A variable ferromagnetic inductor including a coil and a moveable ferromagnetic core of low permeability, said coil and core being co-axial and said coil comprising a plurality of identical solenoidal sections, each of said sections being wound in opposite direction to the next adjacent section, said sections being positioned end to end along the common axis and connected in parallel in aiding sense.

2. A ferromagnetic inductor as claimed in claim 1 wherein the core is composed of particles of high resistivity.

3. A variable ferromagnetic inductor including a coil and moveable ferromagnetic core, said coil and core being coaxial and said coil comprising a plurality of solenoidal sections, said sections being positioned end to end along the common axis and connected in parallel in aiding sense, said core being composed of disc sections separated from each other to improve the heat dissipation of said core.

4. A variable ferromagnetic inductor suitable for ultra high frequencies including a coil and a ferromagnetic core composed of particles of high resistivity, said coil and core being co-axial, said coil having a total desired inductance obtained through paralleling of several identical sections of much higher inductance, said sections being positioned end to end along the common axis of said coil and said core to thereby greatly increase the number of turns in said inductance traversed by said core during its movement, said identical sections being wound in opposite direction to the next adjacent section.

5. An inductance device comprising a plurality of coils disposed end to end and electrically connected in parallel, and a magnetic core arranged for axial movement with respect to said coils.

6. An inductance device comprising a plurality of coils disposed end to end and electrically connected in parallel with their magnetic flux mutually aiding, and a comminuted magnetic core arranged for axial movement with respect to said coils.

7. An inductance device comprising a plurality of coils wound on a form and disposed end to end, said coils being electrically connected in parallel with their magnetic flux mutually aiding, and a comminuted magnetic core adapted to be moved axially within the coil form.

8. An inductance device comprising a plurality of short coils disposed end to end and electrically connected in parallel, a coil form on which the several coils are wound, and a magnetic core adapted to be moved axially within the coil form.

9. An inductance device comprising a plurality of short coils disposed end to end and electrically connected in parallel with their magnetic flux mutually aiding, a coil form on which the several coils are wound, and a comminuted magnetic core adapted to be moved axially within the coil form.

10. An inductance device comprising a coil having a plurality of windings which are wound together on a form, the turns of said windings being spaced and only the terminals of the windings being electrically connected to effect a parallel connection of the windings with their magnetic flux mutually aiding, and a comminuted magnetic core arranged for movement within the coil form.

11. An adjustable magnetically tuned resonant circuit, comprising a plurality of coils electrically connected in parallel and with their magnetic flux mutually aiding, and an adjustable magnetic core cooperating with said coils, the arrangement being such that the operating range of said circuit is extended beyond that obtainable with a single coil having substantially the same inductance as the plurality of parallel coils.

12. An adjustable magnetically tuned resonant circuit, comprising a plurality of coils co-axially disposed end to end, electrically connected in parallel and with their magnetic flux mutually aiding, and an adjustable magnetic core cooperating with said coils, the arrangement being such that the operating range of said circuit is extended beyond that obtainable with a single coil having substantially the same inductance as the plurality of parallel coils.

13. An adjustable magnetically tuned resonant circuit, comprising a coil having a plurality of windings only the terminals of which are electrically connected to connect the several windings in parallel with their magnetic flux mutually aiding, and an adjustable magnetic core cooperating with said windings, the arrangement being such that the operating range of said circuit is extended beyond that obtainable with a single coil winding having substantially the same inductance as the plurality of parallel coil windings.

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