Aug. 22, 1961 W. M. W. QUERFURTH 2,997,584

SATURABLE CORE TUNING INDUCTOR

Filed Feb. 19, 1958

2 Sheets-Sheet 1

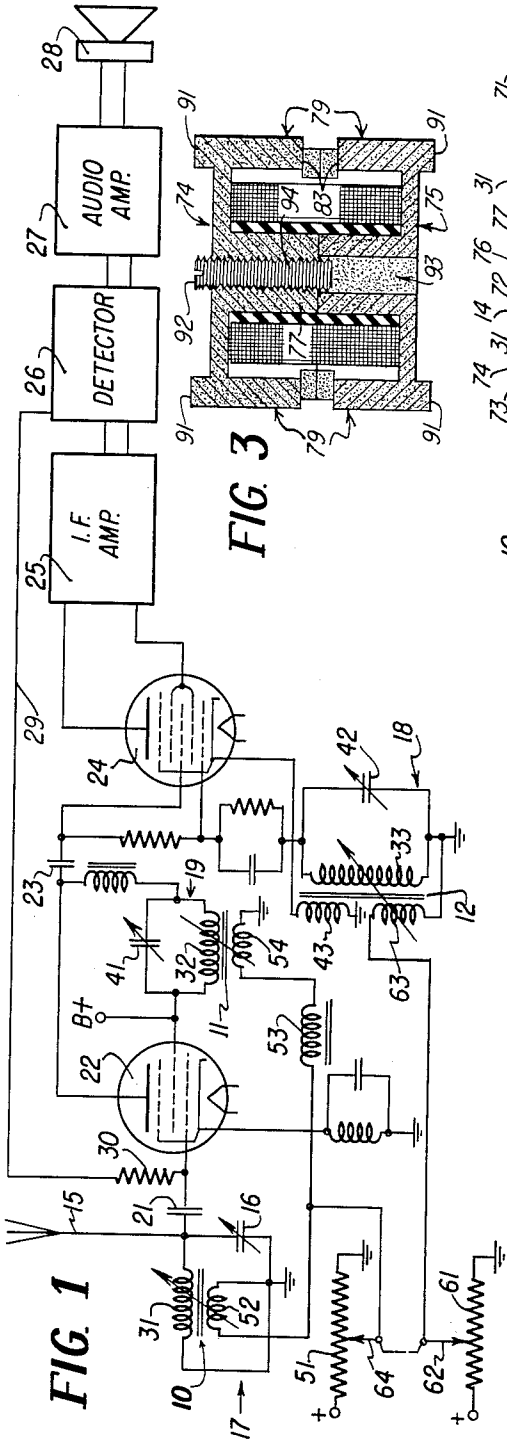


FIG. 1

FIG. 3

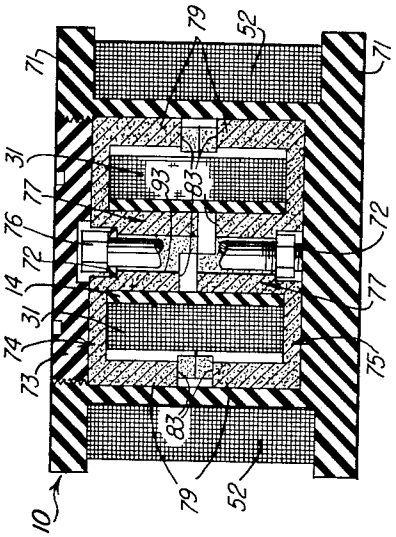


FIG. 2

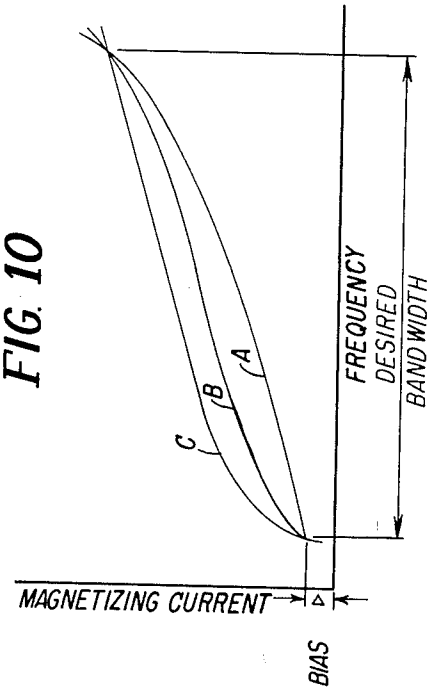


FIG. 10

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Aug. 22, 1961 W. M. W. QUERFURTH 2,997,584

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Filed Feb. 19, 1958 2 Sheets-Sheet 2

FIG. 4

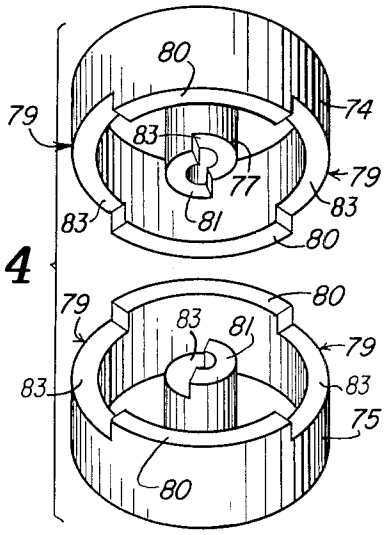


FIG. 5

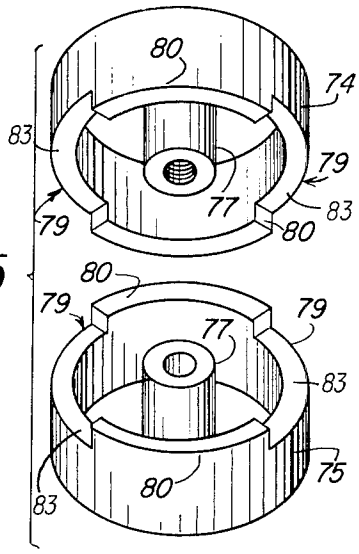


FIG. 6

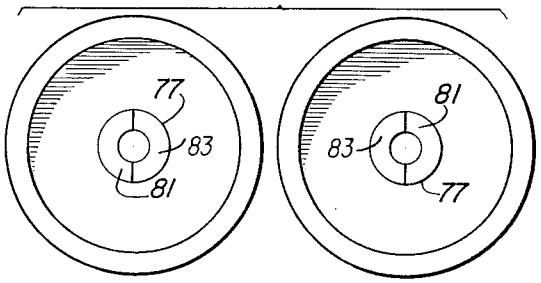


FIG. 7

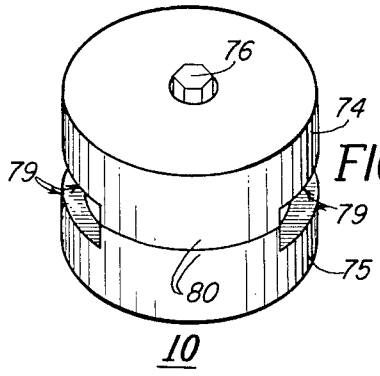


FIG. 8

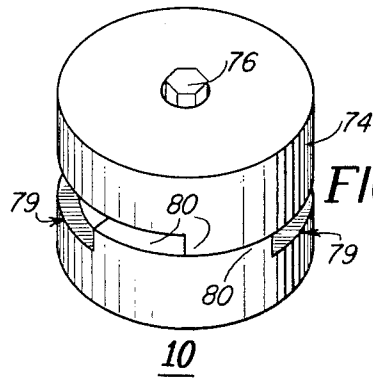
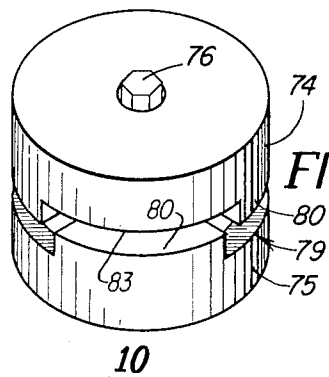


FIG. 9



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SATURABLE CORE TUNING INDUCTOR

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Filed Feb. 19, 1958, Ser. No. 716,108
6 Claims. (Cl. 250—40)

This invention relates generally to inductors, and more particularly to a saturable core reactor of an adjustable type which may be used to provide tracking of a plurality of tunable electric circuits, such as those of a radio receiver.

Saturable core reactors have previously been used to provide control of tuned circuits in radio receivers and transmitters. Such units are advantageous in that they may be remotely controlled and several tunable circuits may be controlled in unison to vary their resonant frequencies. It is necessary, however, that some means of adjusting the saturable core reactors be provided in order to obtain and maintain a desired frequency relationship between the different tunable circuits. Saturable reactors presently used have been difficult to manufacture with the close tolerances required and it has been difficult to adjust the incremental permeability thereof to provide the required frequency relationship.

The term incremental permeability when used herein means the permeability of the core at a given increment of magnetizing force. The term initial permeability means the permeability of the core at zero magnetizing force. The term starting permeability means a particular incremental permeability at which the frequency of a tuned circuit including the reactor is at one of the limits of a desired bandwidth.

It is an object of this invention to provide a simple and inexpensive adjustable saturable core reactor.

Another object of the invention is to provide an improved saturable core for a reactor, the initial and incremental permeability of which may be readily adjusted.

A further object of the invention is to provide improved tunable circuits having adjustable core inductors which may be readily adjusted to provide a desired frequency relationship so that they may then be tuned in unison to provide tracking.

One feature of the invention is the provision of an improved core for a saturable reactor including a pair of cup-shaped core elements each having a rim and a central stud and which may be mounted face-to-face to form a chamber having a central post around which an inductance coil may be positioned. The core elements are provided with recessed portions which may be located either in the rims of the cups or in the studs or in both, so that the cross-sectional area of the flux path may be varied by turning the core elements relative to each other, thereby facilitating adjustment of the incremental permeability of the reactor. If both the stud and the rim have slots, the initial permeability of the reactor may be kept substantially constant when the core elements are turned to adjust the incremental permeability. However, the reactor may be provided with a slug in the stud to permit adjusting the initial permeability of the reactor independently of the incremental permeability.

Another feature of the invention is the provision of a saturable core reactor as described in the preceding paragraph mounted within a spool of insulating material around which a magnetizing coil may be wound so that the inductance of the reactor may be varied by varying the current in the magnetizing coil.

A further feature of the invention is the provision of an improved saturation tuning system for a radio receiver in which various tunable circuits include saturable core reactors having turnable cup-shaped core elements with slotted portions therein, so that a desired frequency relationship between the tunable circuits may be obtained by turning a core element to the proper setting.

Another feature of the invention is the provision of an improved saturable core reactor including a pair of cup-shaped core elements each having a rim and a central stud with recesses therein, and in which the cross-sectional area of the flux-path in the core is quite small so that the magnetizing force required to produce saturation is relatively small.

The invention is illustrated in the drawings in which:

FIG. 1 shows a part of the circuit of a radio receiver including saturable core reactors in accordance with the invention;

FIG. 2 is an enlarged cross-sectional view of an assembled saturable reactor having a cup-core whose incremental and initial permeability may be adjusted by turning one of the cups;

FIG. 3 is a cross-sectional view of a cup-core similar to that shown in FIG. 2 but having an adjustable slug for controlling initial permeability independently of incremental permeability;

FIG. 4 is a perspective view of the pair of cup-shaped core elements shown in assembled relation in FIG. 2;

FIG. 5 is a perspective view of the cup-shaped core elements shown in assembled relation in FIG. 3;

FIG. 6 is a plan view showing still another form of the cup-shaped core elements;

FIGS. 7, 8 and 9 are perspective views showing cup-shaped core elements in different positions of adjustment; and

FIG. 10 is a graph showing various frequency characteristic curves of a tuned circuit having an adjustable core saturable reactor associated therewith.

The invention provides an improved adjustable saturable reactor which is especially suited for use in radio receivers and may provide, for instance, remotely controlled circuits for tuning a trunk-mounted automobile radio receiver. The saturable reactor includes a pair of core elements made of material having variable permeability and low retentivity. The core elements are each formed in the shape of a cup having a rim and a central stud, and the pair is assembled with the rims of the cups and the ends of the studs in physical contact. A sleeve made of non-permeable material is placed around the central post formed by the stud portions, and a spool of non-permeable material surrounds the outside of the assembled core. A coil forming an inductance element is wound around the internal sleeve, and a magnetizing coil conducting energizing current is wound around the external spool. Slots or recesses are provided along the junction of the rim portions of the cup or at the junction of the stud portions or in both places. Accordingly, the amount of contact area between the core elements depends upon their relative position, and by turning one of the core elements with respect to the other, the amount of contact area may be varied. The contact area in turn controls the incremental permeability of the entire core assembly, and consequently it controls the inductance of the coil and ultimately the frequency change characteristic for a tuned circuit in which the inductance coil is used. This may be used in a multiple tuned circuit receiver to set the value of a tuned circuit so that its frequency characteristic bears a desired relationship to the frequency characteristic of other tuned circuits. The resonant frequency of a tuned circuit may be controlled by changing the level of the energizing current in the magnetizing winding, and when several reactors are used in different tuned circuits, the desired frequency relationship between the circuits can be maintained when the level of the energizing current in the magnetizing winding is varied. The initial permeability of the reactors may be

controlled separately from the incremental permeability thereof to ensure that the desired frequency characteristics are obtained exactly.

In FIG. 1 there is shown a part of the circuit for a radio receiver adapted to be installed in the trunk of an automobile and remotely controlled. The receiver circuit includes saturable core reactors 10, 11 and 12 in accordance with the invention which provide the tuning system for the receiver. The antenna 15 picks up radio frequency signals which are applied to the radio frequency amplifier stage 22 by the capacitor 21. The frequency of the signals applied to the radio frequency amplifier stage 22 is controlled by the tuning circuit 17, and the frequency of the output of the radio amplifier stage 22 is controlled by the tuning circuit 19. The amplified signals are applied by the capacitor 23 to the converter stage 24 where the signals are heterodyned and converted to an intermediate frequency. The frequency of the oscillator signal utilized in the heterodyning action is controlled by the tuned circuit 18. The heterodyned signals are then applied to an intermediate frequency amplifier stage 25, and the audio frequency component of the signals is detected in a detector stage 26. The resulting audio frequency signal is then amplified in the stage 27 and applied to a loudspeaker 28 which converts the signal to sound energy. An automatic gain control voltage is developed at the detector stage 26 and is applied by a line 29 and a resistor 30 to the radio frequency amplifier stage 22 in a well-known manner.

The resonant frequency of each of the tuned circuits 17, 18 and 19 is controlled by the saturable core reactor included therein. The tuned circuit 17 for the antenna 15 includes a capacitor 16 and a coil 31 coupled in parallel. The coil 31 forms a part of the saturable core reactor 10, and its inductance value may be varied by changing the amount of current in the magnetizing coil 52. This is accomplished by changing the setting of the slider 64 on the potentiometer 51, and since the potentiometer 51 may be located at a remote position, this method of tuning is particularly well suited for use with trunk-mounted radio receivers where the receiver proper is carried in the trunk of a vehicle and only the potentiometer need be mounted on the dashboard.

The tuned circuit 19 for the radio frequency amplifier stage 22 is similar to the tuned circuit 17, with a capacitor 41 and an inductance coil 32 being coupled in parallel. The coil 32 is provided by saturable reactor 11, the magnetizing coil 54 of which is coupled to the slider 64 of the potentiometer 51 by the radio frequency choke coil 53.

The tuned circuits 17 and 19 should be set to resonate at the same frequency, and this frequency relationship should be maintained to provide tracking when the frequencies are changed by adjusting the potentiometer 51.

The tuned circuit 18 for the converter stage 24 includes a capacitor 42 coupled in parallel with an inductance coil 33 which forms a part of the saturable core reactor 12. The magnetizing winding 63 of the reactor 12 is coupled to another potentiometer 61 through the slider 62. The reactor 12 also includes a tertiary winding 43 connected to the cathode of the converter stage 24. The sliders 62 and 64 are mechanically interlocked so that as the slider 64 is moved the slider 62 moves proportionately causing the tuned circuit 18 to track with the other circuits.

A saturable core reactor 10, which may be used to provide all of the reactors used in the tuning system of FIG. 1, is shown in assembled relation in FIG. 2. The reactor includes a spool 71 made of non-permeable material such as plastic and has an internal chamber 72 therein. The spool is provided with a threaded plug 73 which may be removed to provide access to the chamber 72. The magnetizing coil 52 is wound on the exterior of the spool, and the chamber 72 receives the cup-shaped core members 74 and 75 which may be secured together by a bolt 76 or other suitable fastening means to form the core of the reactor. The core members 74 and 75 include tubular stud portions 77 which form a central post around which the sleeve 14 of non-permeable material is mounted. The hollow interior 93 of the post receives the bolt 76. An inductance coil 31 forming an element of the tuned circuit 17 is wound around the sleeve 14. The peripheral rim portions 79 of the core elements extend around the outside of the coil 31. Thus, the coil 31 is completely surrounded by permeable material both internally and externally so that the core provides a continuous flux path around and through the coil. A plurality of slots or recesses 83 are provided along the junction of the rim portions and the stud portions so that the flux path in the core is limited to the abutting segments between the slots.

The incremental permeability of the core may be adjusted to obtain a desired frequency change characteristic for the tuned circuit 17, by varying the contact area between the abutting segments. This is done by loosening the bolt 76 and turning one of the core elements 74 and 75 with respect to the other until the proper setting is obtained. The relative disposition of the slots with respect to each other may be predetermined such that the initial permeability of the core may be maintained nearly constant when one cup is turned. This separate control over initial permeability is facilitated by having the magnetizing coil 52 wound about the outside of the rims 79 so that the core presents two parallel paths to the saturating flux generated by the core. As may be seen in FIG. 2, the path through the rims has a lower reluctance than the path through the studs so that saturating flux is mainly restricted to the rims. However, the path presented to the flux generated by the inductance coil 31 is a loop as previously mentioned. Thus, incremental permeability may be adjusted by varying the contact area between the rims 79 while initial permeability is controlled separately by varying the stud portion of the loop path to compensate for the rim adjustment.

The core elements 74 and 75 of FIG. 2 are shown in perspective in FIG. 4. These elements are made of a material having a variable permeability with low retentivity and coercive force such as compositions known as ferrite. The magnetic field which builds up around the inductance coil 31 is largely confined to the flux path presented by the core members. As previously mentioned, recesses are provided in the rim portion 79 and the stud portions 77 so that only the abutting segments 80 and 81 can come into physical contact. When the segments 80 are aligned, the segments 81 are offset. Since saturating flux is concentrated in the rims 79, most of these flux linkages are made through the rim segments 80. The maximum cross-sectional area of this flux path through the core is obtained when segments 80 are aligned with each other as shown in FIG. 7. When one of the members 74 and 75 is turned relative to the other to a position such as that illustrated in FIG. 8, the area of contact between the abutting segments 80 is reduced whereas the contact area between segments 81 increases. The reluctance of the flux path through the air gaps provided by the recesses in the rims is much greater than that through the segments 80, and therefore the flux in the rim is largely restricted to this reduced contact area, thereby increasing the flux density therein. This means that the core is more nearly saturated and its permeability is reduced. The initial permeability remains comparatively unaltered, however, because this property is controlled to a greater extent by the contact area between the stud segments 81 which increases to offset the decreasing contact area between rim segments 80.

If the core elements are turned to the position illustrated in FIG. 9, the rim segments 80 are completely offset from each other and the rim flux path is interrupted by a continuous air gap which minimizes the magnetizing force on the cup members and produces a much lower level of core saturation.

The inductance value of the alternating current carrying coil 31 decreases as the incremental permeability of the core decreases. It follows, then, that the permeability

of the core may be adjusted by turning the core elements relative to one another to vary the area of contact between the abutting segments 80 until a desired inductance value for the coil has been obtained. This operation is known as setting the starting permeability of the core. The magnetizing force required to establish the starting permeability is supplied by the current in the magnetizing coil. This biasing current may be a direct current or an alternating current having a direct current component. Of course, the biasing magnetizing force may be supplied by using a permanent magnet instead of a coil, or a coil and a permanent magnet may be used together. Once the starting permeability is set, the inductance of the coil 31 is varied to change frequency by changing the current level in the magnetizing coil such as by adjusting the potentiometers 51 and 61 of FIG. 1. If an alternating current is used in the magetizing coil there will be a modulation of frequency.

FIG. 5 shows another embodiment of the invention in which the members 74 and 75 are similar to those shown in FIG. 3 except that the stud portions 77 are not provided with a recess or slot. The slots are provided only in the rim portions 79 so that only the abutting segments 80 may be variously positioned to control the incremental permeability of the core. Projections 91 on the rims 79 are provided to help concentrate more of the saturating flux in the rims as opposed to the stud. FIG. 3 shows the cups 74 and 75 of FIG. 5 in assembled relation. The incremental permeability is adjusted by turning one cup relative to the other. This embodiment particularly lends itself to the provision of a control for adjusting initial permeability independently of incremental permeability. This may be accomplished by turning the threaded slug 92 to move it in or out of the hollow interior of the post formed by studs 77. Only the cup 74 is threaded so that the slug may extend into cup 75 without interfering with the turning movement of the cups. The slug 92 may be made of the same ferrite material used for the cups.

FIG. 6 shows still another embodiment of the invention in which a slot 83 is provided in the stud portions 77 and not in the rim portion 79. In this embodiment, the rim portions 79 abut against each other along the entire circumference of the core elements, and this construction has the advantage that the inductance coil 31 is more completely shielded inside the core.

The feature of adjustability of the core of the invention provides a means for obtaining desired frequency change characteristics for different tuned circuits such as the tuned circuits 17, 18 and 19 shown in FIG. 1. A family of curves representing various frequency change characteristics for the tuned circuit 17 of FIG. 1 is shown in FIG. 9. Curve A shows the change of resonant frequency of the tuned circuit 17 in response to changing magnetizing current in the saturable reactor 10 when the rim segments are adjusted to have maximum contact area as in FIG. 7. Curve B shows a plot of these same values when the rim segments are adjusted to have about one-half of the maximum contact area as in FIG. 8, and curve C shows the plot when the rim segments have only a slight contact area.

Since the frequency change characteristics represented by the curves A, B and C vary with the incremental permeability of the reactor which depends on the setting of the core elements, it follows that the tuned circuits 17 and 19 can be adjusted to have the same frequency characteristic by positioning the reactor core elements properly. Similarly, a desired frequency characteristic may be provided for the tuned circuit 18 by adjusting the capacitor 42 and the core elements of the reactor 12. These frequency characteristics are selected so that the proper relationship between the resonant frequencies of circuits 17, 18 and 19 is maintained when the sliders 62 and 64 are moved. Since the invention provides means for separately controlling the initial permeability of the core, the

cores may be turned until the desired starting permeability is obtained, and the desired frequency characteristic will automatically follow. If further minor adjustments of frequency are necesary, the capacitors 16, 41 and 42 may be varied slightly. However, the necessity for such capacitive adjustments is minimized by the fact that the starting permeability of the reactor can be adjusted comparatively exactly to provide substantially the exact inductance values required for the desired bandwidth.

While the above-described cup core elements have been shown as used in the tuning circuits of a radio receiver, it is obvious that the core members and the inductance coil enclosed therein may be used as the inductor element of any circuit where it is desirable to have an adjustable inductor. The inductors are simple and may be inexpensively constructed, and yet they are extremely effective in operation. The reactors provide a very simple and convenient way of correcting and adjusting the frequency characteristics of a tuned circuit. At the same time, they have a high Q value which is an important advantage in high frequency applications. The cup-shaped construction of the core also provides an effective shield to protect the inductance coil contained therein from stray external fields. Since the flux linkages within the core are confined to the rather narrow abutting segments, a variation in permeability with a consequent change in the inductance of the coil may be obtained with much less magnetizing force than would otherwise be required. This means that the number of ampere-turns in a magnetizing coil required to change the permeability is reduced.

I claim:

1. An adjustable saturable core reactor including in combination, a spool of insulating material having an enclosed inner chamber, said spool having a removable plug portion for providing access to said chamber, a pair of permeable cup members mounted in said chamber and each having a rim portion and a central stud portion, said cup members being joined rotatably with said stud portions and said rim portions contacting each other, said cup members having a slot therein interrupting at least one of the junctions therebetween so that the area of mutual contact therebetween may be varied to adjust the incremental permeability of said core by rotating one of said members relative to the other, means for controlling the initial permeability of said core separately from the incremental permeability thereof, means for locking said cup members together, an insulating sleeve mounted over said stud portions of said cup members, an inductance coil wound around said insulating sleeve, and a magnetizing coil wound around said spool for controlling the inductance value of said inductance coil by variable saturation of said core.

2. A saturable core for use in an inductor including in combination, a pair of variable permeability core members having a cup-like shape, each of said members including a center stud portion aligned with and contacting the center stud portion of the other of said cup members and a peripheral rim portion contacting the peripheral rim portion of the other of said members, said rim portions being recessed along a part thereof so that as one of said members is rotated relative to the other the cross-sectional area of the flux path through said rim portions is varied to adjust the incremental permeability of said core, and means for adjusting the initial permeability of said core separately from the incremental permeability thereof.

3. A saturable core for use in an inductor including in combination, a pair of cup-like members made of variable permeability material each having a circular rim portion and a central stud portion extending axially of said rim portion, said cup-like members being joined with said stud portions and said rim portions respectively engaging each other to provide a magnetic flux loop-path, said rim portions having projecting segments and recessed segments between said projecting segments with said project-

ing segments being in mutual contact with each other, and magnetic means movable axially of said stud portions for controlling the portion of said magnetic flux loop-path through said stud portions to provide a desired initial permeability for said core, one of said cup members being rotatable relative to the other, with both said stud portions and said rim portions respectively maintaining mutual contact throughout a substantial range of rotation of said one cup member so that as said one cup member rotates the mutual contact area of said rim portions varies to control the portion of said magnetic flux loop-path through said rim portions, thereby providing an adjustment for controlling the incremental permeability of said core.

4. A saturable core for use in an inductor including in combination, a pair of variable permeability core members having a cup-like shape, each of said members including a center stud portion aligned with and contacting the center stud portion of the other of said cup members and a peripheral rim portion contacting the peripheral rim portion of the other of said members, said rim portions having projecting segments in mutual contact and recessed segments adjacent said projecting segments so that as one of said members is rotated relative to the other the cross-sectional area of the flux path through said rim portions is varied to adjust the incremental permeability of said core, and said stud portions having means to provide a desired initial permeability for said core.

5. A saturable core for use in an electrical inductor including in combination, a pair of core members each having a cup-like shape, said core members being formed of material the permeability of which varies with the magnetic field applied thereto, each of said members including a center stud portion and a circular peripheral rim portion, said core members being assembled together in axial alignment with said stud portion of one member contacting the stud portion of the other member and said rim portion of one member contacting the rim portion of the other member, said rim portions each having a plurality of projecting segments in mutual contact and recessed segments between said projecting segments, so that as said core members are held in axial alignment and one of said members is rotated relative to the other the cross-sectional area of the flux path through said rim portions is varied to adjust the permeability of said core, and said center stud portions of said core members being shaped so that said stud portions are in engagement for all rotational positions of said core members and the common area of contact therebetween varies with the relative rotational position of said core members to provide a further control of the permeability of said core.

6. In a tuning control for a radio receiver which includes at least two tunable resonant circuits which are tunable over different ranges of frequencies that correspond to the tuning range of the radio receiver, and wherein said two resonant circuits must track each other throughout said ranges of frequencies, the combination therewith of inductor devices of the saturable type with one included in each of said resonant circuits, and with at least one of said inductor devices being mechanically adjustable to establish the required tracking relation between said resonant circuits, said mechanically adjustable inductor device including a saturable core including a pair of core members each having a cup-like shape, said core members being formed of material the permeability of which varies with the magnetic field applied thereto, each of said members including a center stud portion and a circular peripheral rim portion, means holding said core members assembled in axial alignment with said stud portion of one member contacting the stud portion of the other member and said rim portion of one member contacting the rim portion of the other member, an inductance coil positioned within said rim portions of said core members and about said stud portions thereof, said rim portions each having a plurality of projecting segments in contact with each other and recessed segments between said projecting segments, so that as said core members are held in axial alignment and one of said members is rotated relative to the other the cross-sectional area of the flux path through said rim portions is varied to adjust the permeability of said core, and said center stud portions of said core members being shaped so that said stud portions are in engagement for all effective rotational positions of said core members, and magnetizing coil means positioned circumferentially about said rim portions of said members in position to provide saturating flux in said core, said magnetizing coil means when energized for tuning providing varying flux in said members to vary the saturation of said core and thereby vary the inductance value of said inductance coil, said cup members being adjusted to a rotational position relative to each other wherein said stud portions and said rim portions form flux paths through the same which establish a desired initial inductance value of said inductance coil and a desired variation of the inductance value of said inductance coil in response to the action of said magnetizing coil means, and which flux paths further establish a desired frequency change in the one of said resonant circuits in which said mechanically adjustable inductor device is included in response to the action of said magnetizing coil means such that said one resonant circuit tracks with the other of said resonant circuits.

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