

Nov. 3, 1959

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2,911,529

ADJUSTABLE CONTROLLABLE INDUCTOR APPARATUS

Filed Jan. 31, 1957

4 Sheets-Sheet 1

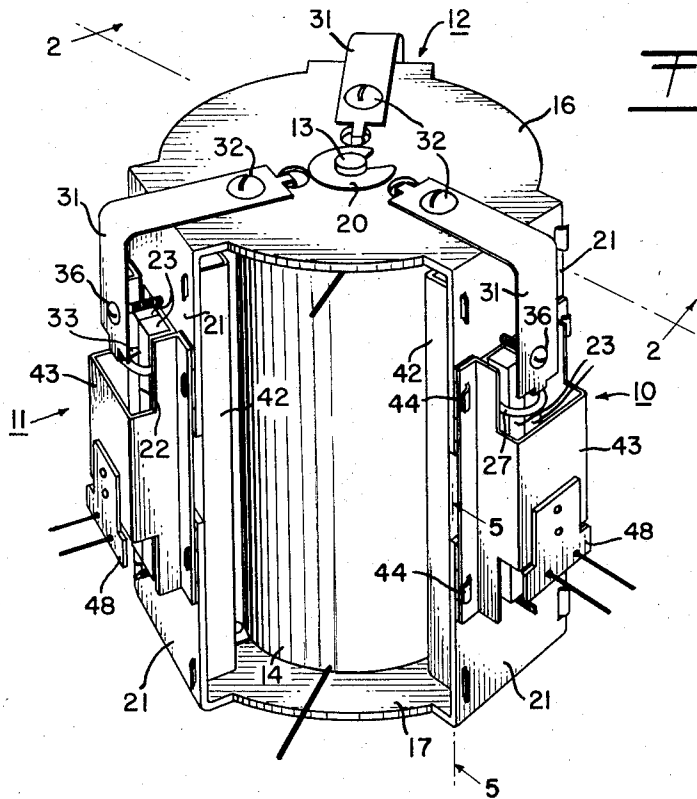


FIG. 1.

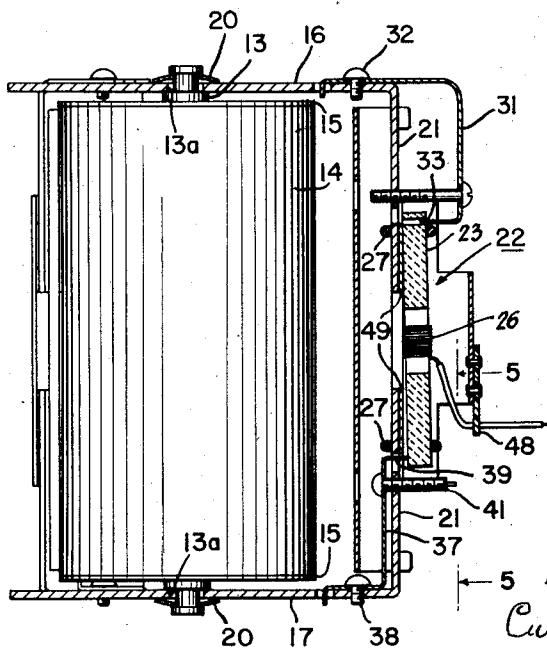


FIG. 2.

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4 Sheets-Sheet 2

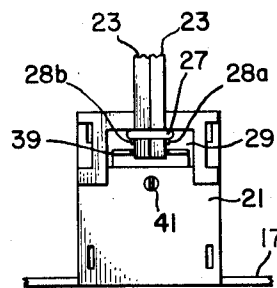
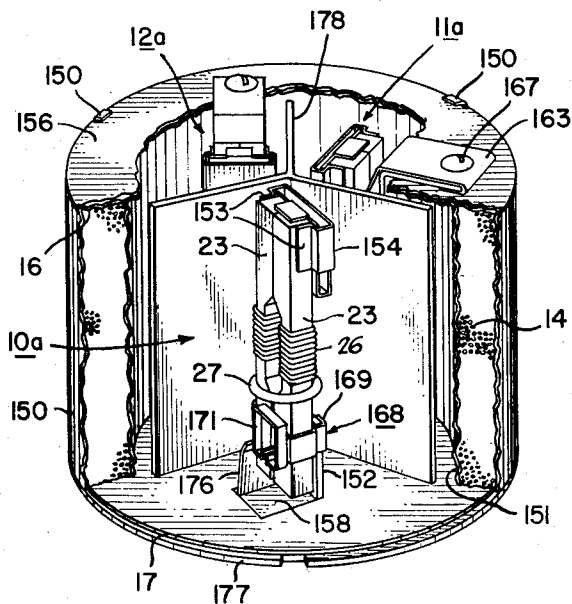
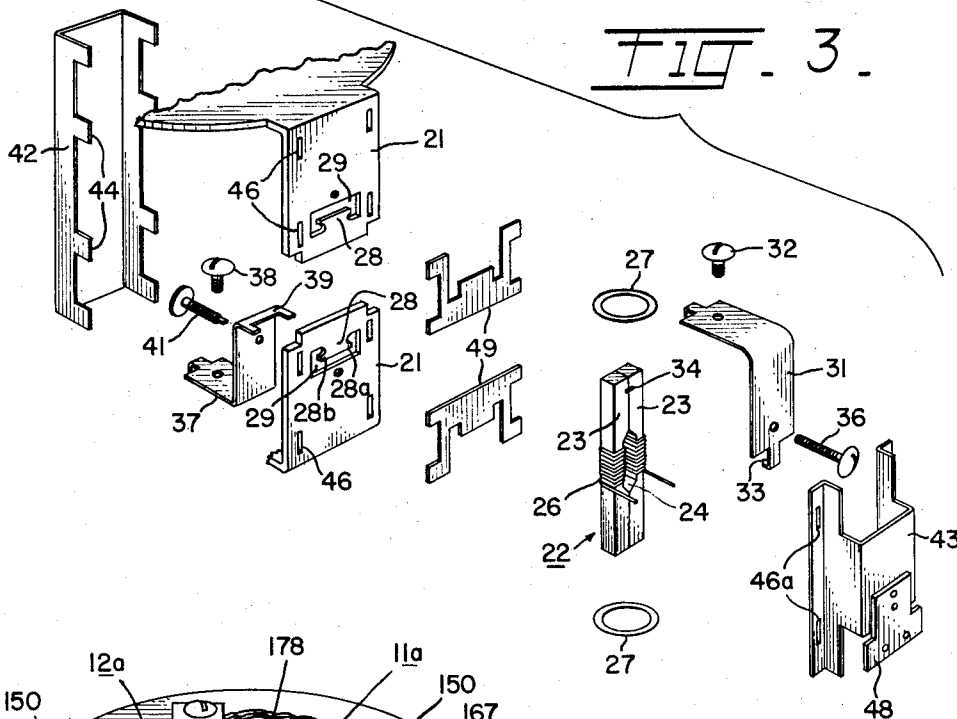


FIG. 5.

Fig. 7.

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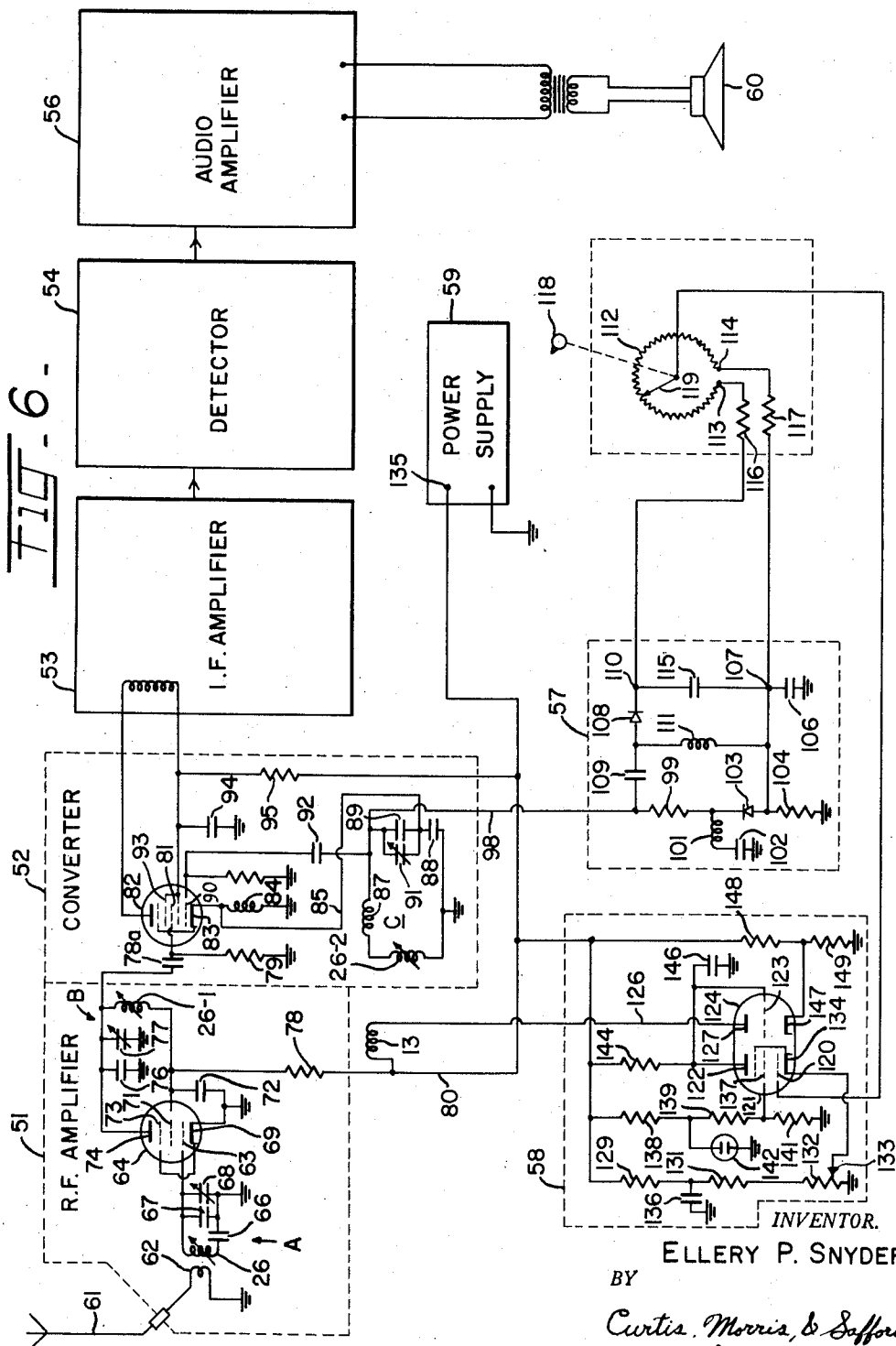
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4 Sheets-Sheet 4

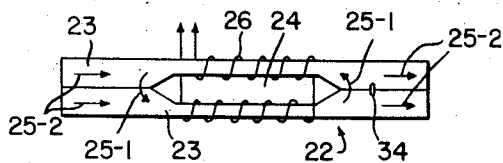
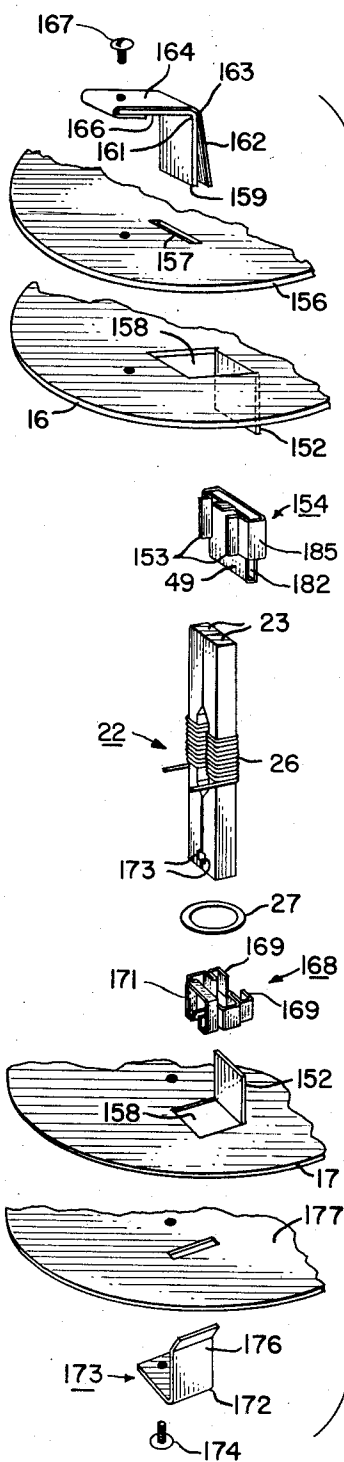


FIG. 4.

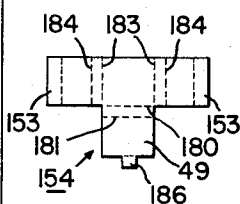


FIG. 13.

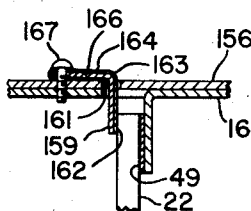


FIG. 10.

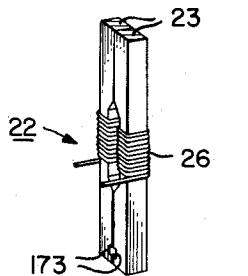


FIG. 9.

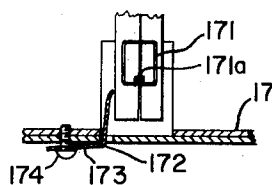


FIG. 11.

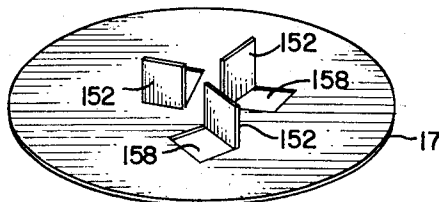


FIG. 8.

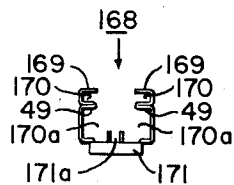


FIG. 12.

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2,911,529

ADJUSTABLE CONTROLLABLE INDUCTOR APPARATUS

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Application January 31, 1957, Serial No. 637,505

19 Claims. (Cl. 250—40)

The present invention relates to improved adjustable controllable inductor apparatus and more particularly to improved controllable inductors having a plurality of controlled signal inductances and providing independent adjustment of the signal inductances as a function of the control current at both the low and high current ends of the control current curves.

Among the many advantages of the improved controllable inductors described herein as illustrative embodiments of this invention are those resulting from the fact that the signal inductance values can be quickly and conveniently adjusted after the controllable inductor is fully installed in an electrical circuit ready for operation. There is no requirement for disassembly or for disturbing any of the parts. The adjusting elements are readily accessible and enable accurate adjustments of the signal inductance values.

A further advantage of the adjustment apparatus of the present invention is that the signal inductance values are adjustable at both the low and the high current ends of the control current curves. Moreover, these adjustments are substantially independent of each other so that the low or the high ends of the curves can be adjusted at will as may be required by the particular circuit installation. In addition, each of the plurality of signal inductance values are separately adjustable.

Advantageously, the adjustments are continuous. That is, the controlled signal inductance values can be incrementally adjusted throughout the range of operation so that accurate precise results are obtained.

In the illustrative embodiments of the invention described herein, three signal inductance windings are controlled by a single control winding. By virtue of the adjustment apparatus described the inductance values of these three signal windings are enabled to follow each other or "track" each other with corresponding characteristics when the control current is changed. Thus, in installations where tracking of the signal winding inductances is required, the three controlled windings are readily adjusted to provide the desired tracking characteristics.

A further advantage of the controllable inductors described herein is their ability to withstand severe shock and vibration stresses without any adverse effects or changes in adjusted values.

Another advantage of the present invention is the provision of improved adjustment apparatus for obtaining proper "tracking" of controlled circuits.

As used herein, the term "controllable inductor" refers to electrical apparatus including a controlled signal winding associated with a magnetically saturable signal core structure so that changes in the degree of magnetic saturation of the signal core alter the effective incremental inductance of the signal winding. In operation this signal winding usually is connected into a circuit which is controlled by varying the effective inductance values of the signal winding in response to variations in the degree of magnetic saturation produced by a control

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flux in the signal core. This control flux is controlled by a control current flowing through a control winding electromagnetically coupled to a flux path which extends through the signal winding core. As the control current is increased, the degree of magnetic saturation of the signal core increases, reducing its permeability and thereby reducing the effective incremental inductance of the signal winding. When the control current is reduced or the magnetic saturation of the signal core is otherwise decreased, the inductance of the signal winding increases.

In controllable inductors of the foregoing type, it is advantageous to have means for adjusting the effective inductance of each signal winding at any given value of control flux. There are several reasons for this. It is commercially impractical to attempt to reproduce the signal core structures and windings during mass production of controllable inductors with such exact precision that each will be affected in exactly the same manner by a control flux and will have exactly the same characteristics.

The slight differences between various signal core structures resulting from mass production are particularly significant in certain integrated applications of multi-element controllable inductors, that is, in inductors having a plurality of signal windings which are controlled by a common control winding. In such integrated circuits a plurality of signal windings are controlled by a single control winding or comparable control flux source and are components of companion or mutually co-operating controlled circuits, such as the co-operating tuned circuits in a radio receiver. In such integrated apparatus it is important that the tuning of the various circuits "track" along together. That is to say, the several circuits should have substantially identically shaped curves of inductance versus control current or other correlated characteristics which follow along together so as to produce the desired mutual co-operation.

Heretofore, it has been the practice in some instances to use supplemental windings to adjust the effective inductance of each signal winding circuit at preselected control current values, whereby to achieve the desired correlation between the several tuned circuits in the system.

Among the further advantages of the present invention are those resulting from the fact that any requirement for supplemental inductance-modifying circuit components in conjunction with the controllable inductor is eliminated by providing one or more variable air gaps in the magnetic flux path or paths associated with a controllable inductor. These provide adjustment of the effective inductance values of the inductor at a given control flux. A related aspect of the invention contemplates the provision of an improved arrangement for obtaining so-called "three point tracking" between separate tuned circuits in an apparatus utilizing controllable inductors with variable air gaps.

A more complete analysis of the present invention and its various features and advantages will be found in the following description of illustrated embodiments thereof, which is to be read with reference to the accompanying drawings, in which:

Figure 1 is a perspective view, shown on an enlarged scale, of a controllable inductor embodying the present invention;

Figure 2 is an elevational sectional view of the controllable inductor shown in Figure 1, taken on the line 2—2 of Figure 1;

Figure 3 is an exploded perspective view of one of the signal winding assemblies of the controllable inductor of Figure 1;

Figure 4 illustrates an enlarged scale of one of the

signal windings and its associated core and shows the magnetic flux paths associated therewith;

Figure 5 is an enlarged fragmentary elevational view taken along the line 5—5 in Figure 1 and Figure 2 and showing an end portion of one of the signal winding cores held properly seated in position on the pole piece platform;

Figure 6 is a schematic circuit diagram of a radio receiver utilizing the controllable inductors which are described herein as illustrative embodiments of the present invention;

Figure 7 is a perspective view, shown on enlarged scale, of another embodiment of the present invention, with a portion of the control winding and one of the pole pieces being shown broken away to illustrate the internal construction;

Figure 8 is a separate perspective view of one of the pole pieces of the controllable inductor of Figure 7;

Figure 9 is an exploded perspective view of one of the signal winding assemblies in the inductor of Figure 7;

Figures 10 and 11 are partial sectional views of the opposite end portions, respectively, of one of the signal winding assemblies in the controllable inductor of Figure 7, showing the relation of the signal winding assembly to the pole pieces and to the gap adjusting means; and

Figures 12 and 13 illustrate in greater detail the improved holding and supporting clips for the signal core structures of the controllable inductor of Figure 7.

The controllable inductor shown in Figure 1 includes three signal winding assemblies 10, 11, 12 symmetrically disposed and uniformly spaced about a central magnetizable core 13 which is surrounded by a control winding 14. The winding 14 is wound on a suitable bobbin 15, the end portions of which appear in Figure 2. The core 13, winding 14, and bobbin 15 form a central control winding assembly.

These three signal winding assemblies 10—12 are spanned between uniformly spaced portions on the peripheries of a pair of magnetizable plates or pole pieces 16 and 17 which are held in place at opposite ends of the control winding assembly. As shown in Figure 2, these end plates or pole pieces 16 and 17 seat against shoulders 13a formed by annular grooves cut into the end portions of the core 13. The pole pieces 16 and 17 are held in place by any suitable fasteners, such as arcuate retaining rings 20 which snap into these annular grooves.

In order to support the signal winding assemblies spanned between these pole pieces, support platforms 21 (Figure 2) are provided which are integral with the pole pieces and depend from their edges. Each platform 21 is bent at right angles to its associated pole piece, so as to lie in a common plane with its counterpart at the other end of the assembly. Thus, opposed pairs of platforms provide coplanar, spaced supports for the signal winding assemblies 10—12. The platforms 21 also serve as extensions of the pole pieces 16 and 17, cooperating therewith to define magnetic flux paths flowing in parallel from the core 13 through the signal winding assemblies. It is seen that the three signal winding assemblies are substantially identically related both physically and as parts of magnetic circuits with respect to the central control winding assembly 13—15.

As shown in detail in Figures 1—4, each of the signal winding assemblies comprises a core structure 22 in the form of two elongated bars or signal winding core pieces 23 of saturable magnetic material such as ferrite or ferromagnetic ceramic material placed longitudinally adjacent one another. The ferrite material may be similar to that disclosed by Snoek in U.S. Patents Nos. 2,452,529; 2,452,530; and 2,452,531.

A generally elongated hexagonal signal winding opening 24 (see Figures 3 and 4) is formed by trapezoidal recesses in the adjoining sides of the two bars 23, A

signal winding 26 associated with the core 22 is formed in two halves. Each half is wound around one of the bars and extends through the opening 24. The halves of the signal winding are connected in series so that their magnetic fields are in aiding relationship around the opening 24 to induce a flow of magnetic flux around the opening as shown schematically by the arrows 25—1 in Figure 4.

The control flux, on the other hand, in flowing from the center core 13 through the core structure 22 follows parallel paths extending substantially the full length of the core 22 as indicated by the arrows 25—2, so that the control and signal flux fields are not mutually coupled. The signal flux 25—1 is alternating in direction, but the control flux is a generally unidirectional flux whose value is varied only as necessary to regulate the degree of magnetic saturation of the core 22 and particularly the saturation of the core pieces 23 traversed by the signal winding flux 25—1.

By virtue of the fact that the effective permeability of the ferrite material in the core 22 decreases with an increase in the degree of its magnetic saturation produced by the control flux, the inductance of the signal winding 26 is changed in accordance with the amount of control current flowing in the control winding 14. Because the three signal windings assemblies 10—12 are bridged across between the pole pieces 16 and 17 and are subjected to substantially equal amounts of control flux, the inductance values of the three signal windings change correspondingly as the control current is changed.

Among the advantages of the illustrative embodiment of the present invention, are those resulting from the fact that provision is made for quickly and conveniently adjusting the effective inductance value of each individual signal winding for any given control flux. Thus, in accordance with the invention each signal winding can be adjusted precisely to the same or to predetermined different inductance values, as desired. For purposes of adjustment, variable air gaps are provided in the portions of the core structure traversed by the flux paths, as explained in detail further below.

The end junctions between each pair of core pieces 23 constitute air gaps which are altered or varied to change the effective inductance of the respective signal winding associated therewith. Advantageously, means are provided for varying one of these air gaps in each of the signal winding cores to give an adjustment of the signal winding inductance.

As shown in Figures 1—3 and 5, such adjusting means includes a structure in which the two core pieces 23 of each core 22 are held together near their ends by resilient rings 27 of rubber or resilient plastic material. Each ring 27 also passes around a suitably slotted tab (see Figure 3) defined by a C-shaped opening 29 in the support portions 21 of the pole pieces 16 and 17. Thus, the rings 27 hold the core structure resiliently in position with respect to the pole pieces, and also draw the legs 23 toward each other.

In order to control a first air gap in series with the signal winding flux 25—1, an L-shaped strip 31 of resilient, non-magnetic material, such as brass or beryllium copper, is attached at one end to the pole piece 16 by a screw 32 or similar attachment. The other leg of the L-shaped strip is spaced from and parallel to the platform 21, and terminates at its free end in a wedge-shaped tooth 33 which extends into slots 34 formed in the facing surfaces of the core legs 23. An adjusting screw 36 extends through the resilient strip 31 and is threaded into the platform 21. By turning the screw 36 further into the platform, the free leg of the strip 31 is drawn toward the platform, forcing the tooth 33 further into the slots 34 of the signal core structure. This wedge action separates the core pieces against the restraining force of the resilient band 27, and thereby opens up the air gap between their adjacent end portions. Rotation of the ad-

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justing screw 36 in the opposite direction allows the tooth 33 to be withdrawn by the resilient force of the strip 31, thereby permitting the two legs to be drawn more closely together by the resilient ring 27. The effect of this adjustment of the air gap reluctance in series with the signal flux is analyzed and described in greater detail further below.

In order to adjust a second effective air gap in series with the path followed by the control flux, a second adjusting strip 37 of resilient, non-magnetic material is attached to the other end plate 17 by a screw 38 and extends beneath the platform 21 parallel thereto and spaced slightly therefrom. At its free end, this strip 37 is bent laterally and is notched so as to present a recessed seat portion 39 which extends through the opening 29 and seats against the underside of the core 22. The recessed seat assures proper centering of the core 22 on the end of the strip 37.

A second adjusting screw 41 passes through the strip 37 from the underside and is threaded into the underside of the adjacent platform 21. The screw head is arranged to engage the underside of the strip 37 and draws it toward the platform. For ease of adjustment, the outwardly projecting end of the screw 41 is flattened to be turned by a pair of pliers, and adjustment of this screw raises the end of the core 22 away from the platform 21, thereby altering the air gap between the signal core structure and the pole piece extension 21.

The effects of varying these air gaps in the inductor flux paths is analyzed in the following manner:

In general, the inductance L of a signal winding 26 can be represented by the expression:

$$(1) \quad L = \frac{n^2}{R}$$

where n is the number of turns of the winding and R is the reluctance of the magnetic circuit 25-1 traversed by flux induced by current flowing in the winding. Also,

$$(2) \quad R = R_f + R_g$$

where R_f is the reluctance of the core structure associated with the winding and R_g is the reluctance of any air gap in the core structure, that is, of any gap in series with the magnetic circuit.

Accordingly, the effective winding inductance L_{eff} can be expressed as

$$(3) \quad L_{eff} = \frac{n^2}{R_f + R_g}$$

Neglecting fringe effects, the reluctance of an air gap is directly proportional to the width of the gap measured in a direction parallel to the direction of the flux passing across the gap and inversely proportional to the cross sectional area of the gap as measured perpendicular to the flux. This is expressed:

$$(4) \quad R_g = K \frac{\Delta}{2}$$

where Δ is the width of the gap, a is the cross sectional area of the gap, and K is a constant of proportionality.

Then if the inductance of a winding with no gap be expressed as

$$(5) \quad L_0 = \frac{n^2}{R_f}$$

it follows that

$$(6) \quad L_{eff} = \frac{n^2}{\frac{n^2}{L_0} + K \frac{\Delta}{a}}$$

This simplifies to:

$$(7) \quad L_{eff} = \frac{1}{\frac{1}{L_0} + K \frac{\Delta}{a}}$$

In other words, the effective inductance of such signal

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winding is a function of its inductance with no gap in the core structure, modified by the effect of the gap, and this effect is such as to decrease the effective inductance upon widening of the gap and vice versa.

In the controllable inductors described herein as embodying the present invention, two variable air gaps are provided, as described above. By moving the wedge-shaped tooth 33 between the core pieces, a gap in series with the signal winding flux circuit 25-1 is widened or narrowed, as the case may be. This adjustment has an effect which predominates during the condition of high signal winding inductance, which also corresponds to a condition of low signal core saturation. That is, when a low density of control flux 25-2 is present, the signal flux series gap adjusting screw 36 is most effective in its control action in adjusting the value of signal winding inductance obtained for a given value of control flux 25-2. During conditions of low control flux density, the effective inductance of the signal winding is primarily influenced by the air gap in the signal flux loop (i.e., the gap between the ends of the core pieces 23) and is substantially insensitive to gap changes in the control flux path 25-2.

On the other hand, the condition of low signal winding inductance corresponds to a substantial amount of signal core saturation as produced by a high density of control flux 26-1. At this end of the control curve, the second air gap which is in series with the control flux path (that is, the gap between the core 22 and the platform 21) is predominant in adjusting the values of effective signal winding inductance obtained by a given density of control flux. The first air gap between the ends of the core pieces has only a negligible effect when a substantial amount of signal core saturation is present because the high saturation of the core pieces 23 increases their reluctance to such a relatively high value. Thus, the presence of the gap in series with the signal flux path 25-1 has only a negligible effect at high values of control current in view of the large reluctance already present. Thus, it is seen that the adjustment means of the present invention provide great flexibility of control over signal winding inductance by acting at opposite ends, i.e., at both the high and low ends of the control flux curve.

In order to avoid any undeserved influence on the magnetic circuits in the inductor of Figures 1-3 by the various adjusting elements, it is preferable to have these elements, such as the resilient strips 31 and 37 and the attaching and adjusting screws 32, 36, 38 and 41, made of brass or similar non-magnetic material.

In addition to enabling the adjustment of the first and second air gaps as previously described, the resilient mounting provided by the rings 27 also serves to prevent permanent displacement of the core structure 22 due to shock or vibration. Also, as illustrated in slightly exaggerated form in Figure 5 for clarity, it will be noted that the opposite edges 28a and 28b of the tabs 28 which underlie the end portions of the core 22 extend laterally beyond the sides of the core pieces. Thus, advantageously, any slight sidewise displacement of the signal core structure resulting from sudden shocks does not change the net effective area of signal core material which is in contact with the platform 21. This prevents any undesired circuit relationships due to shock or vibration.

Furthermore, the ends of the core pieces 23 project over the openings 29 beyond the ends of the tabs 28. This advantageously assures that the net effective areas of contact between the signal core material and the platform 21 does not change if the relative lengths of the core pieces and the longitudinal spacing between the opposed ends of respective pairs of the platforms 21 should vary due to changing temperature or as a result of mechanical stress or other dimensional changes.

Advantageously, it is seen that the gap adjustments provided by the apparatus described above are readily

accessible. No disassembly for access to the adjusting elements is required. Thus, the inductances at both the high and low ends of the control flux curve for all three signal windings can quickly and individually be adjusted after the parts are completely assembled and the controllable inductor is fully installed ready for use. Each individual signal winding is thus properly adjusted after installation and after all connections to the controllable inductor have been completed.

In setting up a tunable resonant circuit to enable controlling the resonant frequency across a predetermined range or band of frequencies, in accordance with prior art practice the first step is to determine the proper size of condenser to resonate with each winding at the center of the frequency band when the winding L_{eff} is at an intermediate value. For example, assume that a superheterodyne radio receiver is being tuned by an inductance winding. It is then customary to vary the winding so as to produce its maximum and minimum inductance values, and to bring the resonant frequency of the circuit into correspondence with the desired "end points" of the frequency band by means of so-called trimming and padding circuit elements suitably connected in series or parallel with the original circuit components. In this way, so-called "three-point" tracking is obtained, whereby the resonant frequency coincides or tracks with the desired values at three points across the range. These points are, respectively, near each end of the range and near the center of the range. Under these circumstances, the tuning of the circuit usually follows the desired control curve closely enough throughout the remainder of the range so as to give acceptable correspondence between actual and desired characteristics.

Among the many advantages of the improved controllable inductor of the present invention are those resulting from the fact that it enables easy adjustment in obtaining three-point tracking of tuned circuits utilizing such inductors. In operating these improved controllable inductors, the low frequency end of the tuning range or band corresponds to a condition of high signal winding inductance which, in turn, corresponds to low density of control flux. Thus, a signal circuit is adjusted at the low frequency end of the range by suitable adjustment of the gap in series with the signal flux path. In the embodiment of Figures 1-3, this series gap in the signal flux path comprises the gap between the ends of the core pieces 23 of each signal core 22.

The adjustment at the high frequency or high control flux end of the curve is obtained by adjusting a gap in series with the control flux path which extends through the control winding core and through the signal winding cores. In the embodiment of the invention shown in Figures 1-3, this gap comprises the gap between the core structure 22 and the platform 21, adjustable by means of the screw 41.

Advantageously, it is seen that the adjustment provided by the variable gap structures of the present invention greatly simplifies the three-point alignment procedure. This desirably results because the necessary adjustments can be made by incremental variation of the gaps with all of the circuit components and with the controllable inductor completely installed ready for use, rather than by inserting different sizes of padding or trimming components or by tediously calculating the exactly correct size thereof. All of these advantages in use and operation provide important savings in time and labor.

In a typical inductor of the type shown in Figures 1-5, the control winding 14 is formed of 25,000 turns of #40 wire. The three signal windings 26, 26-1, 26-2 are formed of 100 turns of #35 wire. The core pieces 23 are each one inch long, and are $\frac{1}{8}$ of an inch wide and $\frac{1}{8}$ of an inch thick. The hexagonal signal opening 24 is $\frac{1}{8}$ of an inch across at its maximum width. From the foregoing exemplary dimensions, it will be understood that the various figures of the drawings are drawn

on a considerably enlarged scale for purposes of clarity. Actually, a completely assembled improved controllable inductor can be encompassed within a circular cylindrical space about 3 inches long and about $2\frac{1}{2}$ inches in diameter.

An advantageous feature of forming the signal winding 26 in two halves which are wound in series aiding relationship is that it insures that almost all of the signal winding flux is confined to the ferrite core pieces 23. As a result, a simple copper shield can desirably be used around the signal winding assemblies for purposes of isolating them from each other and from other nearby circuit components without adversely affecting the "Q" of the coil. For example, two rectangular U-shaped shields 42 and 43 of copper, aluminum, or other conducting non-magnetic material behind and in front of the platforms 21, respectively. These shields are held in place by tabs 44 extending from the edges of the lower shield 42 and passing out through slots 46 in the platforms 21 and through corresponding aligned slots 46a in the upper shield 43. The outer shield 43 further provides a convenient mount near one end for an insulating terminal strip 48 at which connections can be made to the signal winding. Non-magnetic E-shaped spacers or shims 49 preferably are provided between the ends of each signal core structure 22 and the underlying platforms 21 for the purpose of reducing substantially any residual magnetism in the control core 13 or in the signal cores 22 when the control current in the control winding 14 is decreased. These shims 49 also aid in further isolating the signal and control magnetic circuits from each other.

In Figure 6 there is shown a superheterodyne radio receiver utilizing the improved controllable inductor of the present invention. The receiver shown includes a radio frequency amplifier stage 51, an oscillator and frequency converter stage 52, a tuned intermediate frequency amplifier 53, a detector stage 54 and an audio amplifier 56 which is transformer coupled to a loud-speaker 60. A frequency control network 57 is provided to stabilize the oscillator 52 and is connected to a control amplifier 58 so as to tune the radio frequency stages 51, 52 automatically by regulating the control current through the control winding 13. The circuit also includes a conventional power supply section 59. In Figure 6, certain stages (53, 54, 56 and 59) are shown in block form, for the details thereof are not necessary to an understanding of the invention. A complete radio receiver of this same general type is shown in detail and claimed as to certain features in a copending application of Carl G. Sontheimer, Serial No. 445,146, filed July 22, 1954, and which is assigned to the same assignee as the present invention.

The tunable signal winding 26 of signal winding assembly 10 in Figures 1-3 is included in the input section "A" of the radio frequency amplifier stage 51 in Figure 6, while the tunable signal winding 26-1 of signal winding assembly 11 is included in the output section "B" of the same stage 51. The tunable signal winding 26-2 of signal winding assembly 12 is included in the oscillator tank circuit "C." The control current in the control winding 13 regulates the inductance of these three windings 26, 26-1, 26-2 and, hence, controls the frequency to which the receiver is tuned.

The incoming radio signals picked up on the antenna 61 are coupled from a primary winding 62 (which can conveniently be wound on the core 22 of winding 26) to secondary winding 26. The winding 26 forms part of a tuned input circuit connected between the common return ("ground") circuit of the receiver and the grid 63 of a pentode 64. The tuned input circuit "A" is formed by the winding 26 having one end coupled to ground through a condenser 66 and its other end connected to the grid 63, with a fixed condenser 67 in parallel with a padding condenser 68.

The pentode 64 has a cathode 69 connected to ground,

a screen grid 71 connected through a condenser 72 to ground, a suppressor grid 73 connected to the cathode 69, and a plate 74 connected to the tuned plate load circuit "B." The plate load circuit "B" includes the variable inductor 26-1, and a condenser 76 which is connected to ground and shunted by an adjustable condenser 77. The other end of the inductor 26-1 is coupled to ground through the condenser 72, and is connected to a power supply lead 80 through a filter resistor 78.

The amplified radio frequency signal is coupled from the plate 74 through a coupling condenser 78a and across a grid resistor 79 to a grid 81 of an oscillator convertor tube 82. The tube cathode 83 is coupled to ground through a radio frequency choke 84 and is also connected to a lead 85 to the oscillator tank circuit "C."

The oscillator tank circuit "C" comprises a parallel resonant circuit whose inductance is supplied primarily by the variable inductor 26-2. The inductor 26-2 is connected in series with a fixed padding inductance element 87 between ground and a coupling condenser 92 leading to a grid 90 of the tube 82. The other side of the parallel resonant tank circuit "C" includes a condenser 88 connected between the common ground and the tube cathode 83, and a condenser 89 connected in parallel with an adjustable condenser 91 between the condenser 88 and the coupling condenser 92.

The screen grids 93 of the tube 82 are coupled to ground through a condenser 94 and are connected to the power supply lead 80 through a filter resistor 95.

The inductance of the three controlled circuits A, B, C is varied and precisely controlled at any desired value, for tuning to various stations, by regulating the control current through the control winding 13 so as to tune the resonant frequency of the radio frequency amplifier and the oscillator. Advantageously, in the circuit shown, the frequency of the oscillator 52 is controlled by the winding 26-2, and this frequency is monitored by circuits including the discriminating and rectifying circuit 57 associated with the control amplifier 58. The inductances of the other two circuit windings 26 and 26-1 are forced to follow or "track" with the value of the winding 26-2 through the medium of the controlling winding 13.

The oscillator signal appearing across the oscillator tank circuit C is fed through a lead 98 to the top of a series discriminator circuit formed by a resistor 99 in series with an inductor 101, and a grounded condenser 102. The inductor 101 and the condenser 102 are tuned to have a series resonant frequency somewhat above the maximum desired oscillator frequency. In the particular circuit shown, with a maximum oscillator frequency of about 2105 kc., this discriminator circuit may be tuned about 50 or 100 kc. higher, as for example to 2150 kc. Thus, the series discriminator including elements 99, 101 and 102 has a negative output slope for, as the oscillator frequency increases, the impedance of the discriminator decreases. Consequently, the magnitude of the rectified signal, which is fed from the junction of the resistor 99 and the inductor 101 is decreased. This output is fed through a rectifier 103 and appears across a resistor 104 in parallel with a condenser 106, connected between ground and output terminal 107 of network 57. Since the rectifier 103 is arranged to pass only the negative half cycles of the output from the discriminator, the potential of the terminal 107 is always negative with respect to the common ground circuit. The terminal 107 has its greatest negative voltage when the oscillator is at its minimum frequency; this voltage being equal to the amplitude "Y" of the oscillations in the tank circuit C times 2, and as the oscillator frequency increases, the terminal 107 becomes less negative, approaching nearly zero when the oscillator is at its maximum frequency.

A rectifier 108 is coupled to the lead 98 through a high pass filter including a condenser 109 between the lead 98 and the rectifier 108 and an inductor 111 between the terminal 107 and the rectifier 108. The high pass filter

is arranged to have a cut-off frequency far below the minimum oscillator frequency. Thus, regardless of the oscillator frequency, the full amplitude "Y" of the oscillations in the tank circuit C is fed to the rectifier 108, which is arranged to pass only positive half cycles. Thus, a positive voltage is fed to an output terminal 110 of the circuit 57. This positive voltage appears across a condenser 115 and is always equal in magnitude to $Y\sqrt{2}$, so that the terminal 110 is always $Y\sqrt{2}$ volts above the terminal 107.

To summarize the operations of the discriminator and rectifier circuit 57, the terminal 107 is at a large negative voltage when the oscillator is at minimum frequency, and the potential of this terminal 107 gradually moves up and almost reaches zero voltage when the oscillator is at maximum frequency. The terminal 110 is always $Y\sqrt{2}$ volts above the terminal 107. Thus, the terminal 110 is at a small positive voltage when the oscillator is at minimum frequency and gradually moves up to a large positive voltage when the oscillator is at maximum frequency.

A circular potentiometer 112 is connected between the terminals 107, 110. Accordingly, some point along the potentiometer is at zero or "ground" potential because the terminal 107 is always below and the other terminal 110 is always above zero. The position of this zero point depends upon the oscillator frequency at the time. When the oscillator is at minimum frequency, the zero voltage point on the potentiometer 112 is near the left terminal 113. As the oscillator frequency increases, this zero voltage point shifts along the potentiometer toward its right terminal 114. The potentiometer 112 is in series between two resistors 116 and 117, so that every point along the potentiometer 112 will adjust to zero voltage, thus providing a range of adjustment corresponding with full scale width of the potentiometer control knob 118. It can be seen that the position of the zero voltage point depends on the relative voltages between the terminals 107 and 110 and ground, and both of these voltages are proportionately affected by any change in oscillator amplitude "Y." Thus, the position of the zero voltage point on the potentiometer 112 is independent of the oscillator amplitude and depends only upon the oscillator frequency. A given point on potentiometer 112 always corresponds with the same oscillator frequency.

The manual control knob 118 is connected to an adjustable contact 119 on the potentiometer 112. If the adjustable contact 119 is at a position along the potentiometer which differs from the zero voltage point, this difference or "error" voltage is fed to the grid 120 of a pentode 121 in the D.C. control amplifier circuit 58. The output from the plate 122 of the pentode 121 is direct coupled to the grid 123 of a triode 124 to control the current flow through the control winding 13, which is connected by a lead 126 between the plate 127 of the triode 124 and the power supply lead 80.

To compensate for fluctuations in the voltage from the power supply 59 (or from a battery where the radio is battery operated) a voltage-dropping network is provided, including two fixed resistors 129 and 131, and a potentiometer 132. The potentiometer 132 is used to adjust the mid-point of the operating range of the controllable inductors. The adjustable contact 133 of the potentiometer 132 is connected to the cathode 134 and is moved to a position along the potentiometer 132 giving the best compensation and the best operating range. With the tube used in the embodiment described, the contact 133 should be adjusted to bias the cathode 134 about 1.0 volt positive with respect to the common "ground" when normal voltage is available. This 1.0 volt adjustment is such that with zero voltage applied to the grid 120, the current through the control winding 13 tunes the receiver to the middle of the broadcast fre-

quency band. Moreover, the 1.0 volt bias adjustment gives excellent compensation over a full 10% fluctuation in supply voltage, for as the supply voltage drops, lowering the temperature and the work function of the cathode 134, the voltage from the power supply terminal 135 also drops so that the cathode bias is correspondingly reduced to compensate for the work function reduction.

Moreover, due to its own heat storage capacity, the temperature of the cathode 134 tends to lag behind rapid changes in the heater voltage. In order to delay the changes in cathode temperature, a large electrolytic condenser 136 is connected to ground from the junction of the resistors 129 and 131 so that the time-constant formed by the resistor 129 and the condenser 136 is effectively equal to the thermal time lag of the cathode 134.

In case the particular pentode 121 being used is sensitive to voltage fluctuations of its screen 137, this screen is connected to another voltage-dropping network including three resistors 138, 139, 141 in series between the power supply terminal 135 and the common ground circuit. To isolate the screen from any voltage fluctuations at the terminal 135, the junction of resistors 138 and 139 is connected to a neon voltage regulating tube 142 having its other terminal grounded. The plate 122 of the pentode 121 is connected through its plate load resistor 144 to the power supply terminal 135 and is coupled to ground through a fairly large condenser 146, which reduces the frequency response and stabilizes the control amplifier 58 so that it is essentially a direct current amplifier.

The cathode 147 of the triode 124 is biased to the proper operating range by a third voltage-dropping network including resistors 148 and 149 connected between the power supply terminal 135 and ground, with the cathode 147 being connected to their junction. Preferably, the resistors 148 and 149 are made as small as operation will permit in order to secure more gain in the control amplifier 58.

In analyzing the operation of the station-selecting circuits, assume that the contact 119 has been at a position along the potentiometer 112 corresponding to a radio station to which the operator has been listening. The operator, wishing to listen to another station on a higher frequency, moves the contact 119 counterclockwise along the potentiometer 112. This feeds a negative voltage to the grid 120 of the pentode 121. The voltage of the pentode plate 122 increases and biases the grid 123 more positive so that an increased current flows through the triode 124 and through the control winding 13. This increase in control current increases the saturation of the three cores 22 associated with windings 26, 26-1, 26-2 and thus reduces the inductance in circuits A, B and C, and hence raises the frequency to which the receiver is tuned.

This increase in frequency immediately causes the discriminating and rectifying circuit 57 to shift the voltage of both of the terminals 107 and 110 in the positive direction, causing the voltage of the new point on potentiometer 112 to which the contact 119 has been moved to shift up toward zero voltage with respect to the common ground circuit. The voltage fed to the grid 120 moves back toward zero, preventing any further change in the current through the control winding 13 and thus holding the receiver tuned to the new frequency. Of course, when the contact 119 is moved clockwise along the potentiometer 112, the operation of the control circuit is the opposite of that described above, and the receiver is tuned to a lower frequency.

For purposes of explanation, it is assumed that the receiver in Figure 6 is a broadcast receiver tunable through a range from 530 to 1650 kilocycles; a frequency range of somewhat more than 3 to 1. To tune through this range, the inductance values in the circuits A, B, C must

change by a ratio of approximately 10 to 1. This is well within the available range of inductance variations obtainable by using apparatus as shown in Figures 1-3; this apparatus can readily produce inductance changes of 100 to 1 and often produces inductance changes of 200 to 1 or more in the signal windings.

In the embodiment of the receiver shown, the oscillator converter stage 52 is arranged to oscillate at a frequency 455 kilocycles above the carrier signal. Thus, in tuning through the broadcast range, the oscillator frequency changes approximately from 985 kilocycles to 2105 kilocycles or a range of something more than 2 to 1, requiring an inductance change of about 5 to 1 in circuit C. As mentioned above, both of the other signal winding circuits A and B must be varied over an inductance range of about 10 to 1. The inductance of the winding 26-2 in circuit C also varies over a range of 10 to 1, before it is adjusted, but by taking advantage of the mechanically adjustable magnetic circuit air gaps as heretofore described, the effective change in the inductance of the resonant tank circuit C is adjusted to the required range of about 5 to 1. By properly adjusting the air gaps as previously explained, the frequency of the oscillator is caused to track the desired 455 kilocycles above the frequency to which the tuned input and output circuits A and B of the radio frequency stage 51 are adjusted.

In Figures 7-11, there is shown another embodiment of the improved controllable inductor of the present invention, which has the advantage of being substantially immune to influences of stray flux from any origin. In this embodiment, the relative locations of the control winding and the signal winding structures in Figures 1-3 are interchanged. In the construction shown in Figures 7-11, the control winding 14 is wound on a bobbin 151 which is large enough to accommodate three signal winding assemblies 10a, 11a, 12a inside of it in place of the central core 13 of Figure 1. As before, a pair of end plates or pole pieces 16 and 17 of soft iron or similar magnetizable material serve both as core elements for carrying the magnetic control flux circuit as well as providing support means for the signal winding assemblies. These end plates are identical, and are held in place by spring clips 150.

The end plates 16 and 17 have three rectangular tabs or support platforms 152 (see Figure 8) which are struck out of the plates at uniformly spaced positions 120° apart and extend inwardly toward each other within the bobbin 151. Opposed pairs of these tabs are aligned in coplanar relation to serve as mounting support platforms for the signal winding assemblies 10a, 11a, 12a.

With this arrangement, it can be seen that the three signal winding assemblies 10a-12a in effect form a three-section "core" for the control winding 14. They provide three parallel and substantially identical flux paths between the pole pieces 16 and 17 for carrying control flux generated by the flow of current through the winding 14. As in the other embodiment, the pole pieces 16, 17 are common to the three flux paths. In order to provide adjustment of a gap in series with the signal flux path 25-1, one end of each ferrite core structures 22 is supported from one of the tabs 152 by a spring clip 168. This clip has a pair of opposed cooperating arms 169 which are generally E-shaped as seen axially of the core 22. An opposed pair of recesses 170 in these arms define a first socket for embracing the end of the support tab 152. A second socket for holding the end of the signal core 22 and mounting it on the adjacent support tab 152 is defined by a second opposed pair of recesses 170a. As shown in Figure 13, the arms 169 are formed from a resilient strip of non-magnetic material such as brass or beryllium copper with both ends bent into an E-shape to form the pairs of recesses 170 and 170a. The projecting lug between the recesses 170 and 170a forms a non-magnetic spacer or shim 49 for the same purposes as the shims 49 shown in Figures 2 and 3.

The clips 168 not only engage the ends of the signal core pieces so as to hold them in position, but they also have a supplementary U-shaped spring portion 171 which provides a spring force tending to separate the two adjacent ends of the core pieces. As best seen in Figures 7 and 11, the opposed ends of the U-portion 171 have laterally projecting teeth 171a (Figure 13) that extend into slots 173 near the ends of the core pieces 23, exerting a separating force thereon. These core pieces are resiliently restrained by a resilient ring 27, but are normally maintained somewhat separated by the action of the U-portion 171.

As shown most clearly in Figures 9 and 11, the U-portion 171 may be formed by a bight in the strip which is bent to form the clip.

To adjust the gap spacing thus provided between the ends of the core pieces 23, a flat strip of non-magnetic material bent into an L-shaped control lever has one leg 173 adjustably fastened to the adjacent end plate 17 by an adjusting screw 174. The other leg 176 of the lever extends through the opening 158 left by striking out the tab 152 and lies in a plane generally perpendicular to the tab 152. This leg 176 lies adjacent to the side face of one of the core pieces 23 and its end is bent over as seen in Figures 9 and 11, so as to press against the end of the core piece 23. Upon tightening the adjusting screw 174, this core piece is forced toward the other core piece by the lever leg 176, thereby reducing the gap between the two core pieces. This provides inductance adjustment for the signal winding structure at the low control current end, i.e., low control flux end of the control curve as previously described. Preferably, the end plate 17 is surmounted by a suitably slotted insulating plate 177 through which the control lever 173 passes.

In this embodiment of the invention, a second variable air gap is provided in series with the individual control flux paths passing through the cores 22. This second gap is adjusted by means of an L-shaped movable supplementary pole member of the type described and claimed in a copending application of P. H. Lee, Serial No. 656,559, filed on May 2, 1957, and assigned to the assignee of the present invention. This supplementary pole piece is described in detail further below.

At one end, the ferrite core pieces 23 are held between the projecting arms 153 of a spring clip 154. This spring clip 154 is bent up from a T-shaped sheet (Figure 13) of non-magnetic resilient material, such as brass or beryllium copper. The bottom arm of this T-shaped piece is bent up along two parallel folds 180 and 181 to form a first U-shaped socket 182 adapted to embrace and firmly grip onto the adjacent support platform 152. The two side arms 153 are bent toward each other along pairs of parallel folds 183 and 184 so as to form side closures 185 for the socket 182. Then the ends of the arms 153 are bent out into parallel relationship to define a second socket for gripping the end of the core 22 and for pressing the core pieces 23 firmly against each other. A finger 186 is bent out and forms an end abutment for this second socket firmly folding the ends of the core pieces properly aligned. It will be appreciated that the side 49 of the socket 182 forms a non-magnetic shim between the core 22 and the adjacent support platform 152.

The end plate 16 underlies a plate 156 of insulating material which has three slots 157 formed therein adjacent to the support tabs 152 and aligned with the edge of the tab opening 158, opposite to the tab 152.

One leg 159 of the adjustable L-shaped supplementary pole member 161 of magnetizable material extends through the slot 157 parallel to the tab 152 and spaced therefrom, so as to be positioned near to the end portion of the core 22 (see Figure 10). One leg 162 of an L-shaped spring 163 of non-magnetic material urges the supplementary pole leg 159 away from the core 22. This spring leg 162 forms an obtuse angle with the other leg

164 of the spring 163, whereas the legs 159 and 165 of the magnetizable pole member are substantially at right angles to each other. The end of spring leg 164 is folded around the end of the corresponding leg 165 of the supplementary pole member 161, and they are adjustably fastened to the top of the upper plate 156 by a second adjusting screw 167. Accordingly, the spring leg 162 presses against the flat face of the core structure 22 and exerts a force tending to raise the leg 166 and thereby urges the supplementary pole leg 159 away from the core structure. By tightening the screw 167, the pole leg 159 is forced toward the core structure.

The pole member 161 serves as a supplemental pole piece which is movable toward and away from the core 22 to provide a variable air gap in series with the control flux path.

It will be appreciated that there are two parallel magnetic circuit paths from the pole piece 16 into the core 22. One path is through the support platform 152 and the other is through the supplementary pole member and across an air gap into the core 22. It is the path through this latter member 161 which provides the adjustable gap effectively in series with the control flux path.

This, then, enables convenient adjustment of an air gap in the control winding magnetic circuit through the structure 22 so as to give an inductance adjustment at the high control flux density end, i.e., at the high control current end of the control current curve similar to the manner previously described for the first embodiment.

In the assembled inductor, the three signal circuit assemblies 10a, 11a, 12a preferably are separated from each other by a minimum spacing of about $\frac{1}{16}$ inch between the closest parts. Also, they are shielded from each other by a symmetrical, Y-shaped shield element 178 (Figure 7) of electrically conductive non-magnetic material, such as copper or aluminum. The shield 178 is located at the center of the assembly with its three uniformly spaced branches extending radially outwardly between the three signal winding assemblies. Further shielding is obtained for the three structures by the wires in the control winding.

From the foregoing, it will be understood that the embodiments of the present invention described above are well suited to provide the advantages set forth, and since many possible embodiments may be made of the various features of this invention and as the apparatus herein described may be varied in various parts, all without departing from the scope of the invention, it is to be understood that all matter hereinbefore set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense and that, in certain instances, some of the features of the invention may be used without a corresponding use of other features, all without departing from the scope of the invention.

I claim:

1. A controllable inductor for controlling the inductance of a plurality of signal windings simultaneously comprising magnetizable components including saturable magnetic material defining a plurality of substantially identical magnetic flux paths in magnetic circuit in parallel relationship with one another, a plurality of signal windings electromagnetically coupled one to each of said flux paths, a variable magnetic flux source associated with said components for establishing substantially identical variable magnetic fields through said flux paths whereby to control the effective inductances of said signal windings simultaneously as respective functions of the strengths of said magnetic fields, means defining an air gap in each of said magnetic flux paths, resilient means associated with the gap-defining means of at least one of said flux paths for changing the dimensions of the gap of said one flux path, and a movable lever and an adjusting screw for said lever, said lever and adjusting screw being associated with said gap-defining means and opposing the

action of said resilient means for varying at least one of said air gaps independently of another whereby to adjust the effects of said magnetic fields on the effective inductance of the said signal winding for adjusting the effective inductance of the said signal winding relative to another.

2. A controllable inductor having a control winding, a plurality of signal windings, a plurality of signal winding cores each including saturable magnetic material and each defining a closed-loop magnetic flux path, magnetizable core means defining with said signal winding cores a plurality of parallel magnetic flux paths, said magnetizable core means being common to all of said parallel flux paths, each said signal winding being electromagnetically coupled to the closed loop path of a respective one of said signal winding cores and said control winding being electromagnetically coupled to all of said parallel flux paths, means defining an air gap in each of said closed-loop flux paths, and manually-adjustable means associated with said air-gap defining means for varying at least one of said air gaps independently of another, thereby to adjust the inductance of one of said signal windings relative to that of another.

3. A controllable inductor comprising a control winding, a pair of pole pieces at opposite ends of said winding, a plurality of signal winding cores extending between said pole pieces in symmetrical relation to said pole pieces and to said control winding, a plurality of signal windings, one of said signal windings being wound on each signal winding core, said pole pieces and said signal winding cores co-operating to provide a plurality of parallel paths for control flux induced by current flow through said control winding, and said pole pieces constituting flux path portions which are common to all of said parallel flux paths, each said signal winding core comprising a plurality of permeable members arranged to define a closed loop signal flux path magnetically coupled to the signal winding thereon, and means mechanically interacting with two of said permeable members in at least one of said signal winding cores for varying the spacing between said two members for adjusting a variable air gap in each said closed loop signal flux path, thereby to adjust the inductance of one of the signal windings relative to another.

4. In a controllable inductor, a control winding, a pair of pole pieces magnetically coupled to said control winding, a plurality of separate signal cores each comprising a plurality of permeable members arranged in contiguous relation to each other to define closed-loop signal flux paths in each of said signal cores, a plurality of signal windings each coupled to a different one of said closed-loop signal flux paths, said signal cores defining a plurality of control flux paths extending between said pole pieces, first adjustable means associated with at least one of said control flux paths and defining a variable air gap in said one control flux path for varying the reluctance thereof between said pole pieces, and second adjustable means associated with a pair of adjacent permeable members in at least one of said signal cores for altering the spatial relationship therebetween whereby to alter the reluctance of the closed-loop flux path through said pair of permeable members without appreciably affecting the control flux path through said one signal core.

5. In an adjustable, controllable inductor, signal winding core means comprising a plurality of pairs of magnetically saturable core elements defining a closed-loop flux path having air gaps therein at the junctions between said elements, a plurality of signal windings having two portions wound one on each of said elements in series aiding relationship with respect to said flux paths, a resilient member holding a pair of said elements resiliently in position with respect to each other, and a wedge-shaped movable member engageable with at least one of said pair

of elements and operable to alter the spatial relationship between said core elements.

6. A controllable inductor comprising a control winding, a pair of pole pieces at opposite ends of said winding, a plurality of signal winding cores extending between said pole pieces in symmetrical relation to said pole pieces and to said control winding to provide a plurality of flux paths between said pole pieces, said pole pieces and said signal winding cores co-operating to provide parallel paths for flux induced by current flow through said control winding and said pole pieces constituting flux path portions which are common to all of said parallel flux paths, means associated with said pole pieces and said signal winding cores for altering the reluctance of one of said flux paths relative to another, a plurality of saturable magnetic members, each of said signal winding cores including at least two of said saturable magnetic members and defining a closed-loop magnetic flux path, means holding the saturable members of each signal winding core resiliently in their respective positions, and separating means comprising a wedge co-operable with two adjacent ones of said members of at least one signal winding core for forcing said members apart, whereby to alter the reluctance of the closed-loop flux path of said one signal winding core.

7. A controllable inductor comprising a control winding, a pair of flat, circular pole pieces at opposite ends of said control winding, a plurality of uniformly spaced platforms of magnetizable material extending from each of said pole pieces toward the opposite pole piece, each of said platforms on one pole piece being aligned with a corresponding platform on the opposite pole piece to provide spaced, co-planar pairs of supports of signal winding assemblies, each said platform having a C-shaped slot therein, a signal winding assembly mounted on each of said pair of supports and extending therebetween, each said signal winding assembly comprising: (1) a winding core including a pair of elongated bars of saturable magnetic material placed longitudinally adjacent to each other on corresponding pairs of said platforms and extending over the respective slots at each end, said bars having recesses in the adjoining sides thereof to define a signal winding opening intermediate the ends of said core, (2) a pair of windings wound one on each said bar and connected together in series aiding relationship to form a signal winding, (3) a resilient ring at each end of said core extending around said bars and around the portion of the adjacent platform encompassed by said C-shaped slot whereby resiliently to hold said core on said platforms and said bars together, (4) a strip of resilient, non-magnetic material attached at one end to one of said pole pieces and extending parallel to the associated platform to a point overlying the adjacent end portion of said core, (5) a wedge-shaped portion at the free end of said strip, (6) first adjustable means for flexing said strip to force said wedge-shaped portion into and out of separating engagement with said bars whereby to open and close a gap between said bars, (7) a second resilient strip of non-magnetic material attached at one end to the other of said pole pieces, said second strip extending parallel to and beneath the associated support platform and terminating beneath said slot therein, the free end of said second strip being bent to extend through said slot into engagement with said core, and (8) second adjustable means for flexing said second strip to move the free end thereof toward and away from the associated platform whereby to raise and lower said core off of and onto said platform to provide a variable air-gap between said last-named platform and said core.

8. A controllable inductor comprising a control winding, means electromagnetically coupled to said control winding and defining a plurality of parallel flux paths for conducting magnetic flux created by current flow through said control winding, each said flux path including a pole piece at opposite ends of said control winding,

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each said flux path also including an elongated core of magnetizable material extending between said pole pieces and having an opening therein, a plurality of signal windings, one wound through each of said openings and electromagnetically coupled one to each said elongated core, a plurality of resilient members holding said cores movably in position with respect to said pole pieces, a plurality of resilient members of non-magnetic material operable by flexing to move one end of each said core toward and away from the adjacent pole piece whereby to provide an independently variable air gap in each said flux path, and manually adjustable means connected to each said last-named resilient members to flex said members for adjusting each of said gaps.

9. A controllable inductor comprising a control winding, means electromagnetically coupled to said control winding and defining a plurality of parallel flux paths for conducting magnetic flux created by current flow through said control winding, each said flux path including a signal core of magnetizable material comprising a pair of elongated bars of saturable magnetic material resiliently held longitudinally adjacent to each other and having recesses in the adjoining sides thereof defining a signal winding opening intermediate the ends of said signal core with a closed-loop flux path defined by said bars around said opening, a plurality of signal windings wound one on each said signal core, and each said signal core having associated therewith a wedge-shaped separator of non-magnetic material which is movable into and out of separating engagement with adjacent end portions of said bars whereby to provide a variable air gap in said closed-loop flux path.

10. A controllable inductor comprising a control winding, means electromagnetically coupled to said control winding and defining a plurality of parallel flux paths for conducting magnetic flux created by current flow through said control winding, each said flux path comprising a core of magnetizable material including a pair of elongated bars of saturable magnetic material held resiliently longitudinally adjacent to each other and having recesses in the adjoining sides thereof to define a signal winding opening intermediate the ends of said core, a signal winding wound on each said core, and spring means associated with each said core and engaging adjacent end portions of said bars and exerting a separating force thereon, and a lever associated with each said core and engageable with the end portion of one of said bars for moving said one bar toward the other bar against the separating force of said spring means whereby to provide a variable air gap in the closed-loop flux path defined by said bars around said opening.

11. A controllable inductor comprising a control winding, means electromagnetically coupled to said control winding and defining a flux path for conducting magnetic flux created by current flow through said control winding, said flux-path defining means including a pair of pole pieces one at each end of said control winding, an elongated signal core of magnetizable material movably attached to and extending between said pole pieces, the opposite ends of said signal core being closely adjacent to respective ones of said pole pieces, a signal winding on said signal core, said pole pieces each having a slot therein underlying the associated end portion of said signal core, the end of said signal core projecting beyond the edge of said pole piece which is adjacent to the slot and terminating at a position over the region within the slot, whereby the end portion of the signal core accommodates relative changes in the spacing between said pole pieces and the length of said signal core without significantly altering the reluctance of said flux path.

12. A controllable inductor as claimed in claim 11 and wherein at least one of said slots is C-shaped, the associated end portion of said signal core overlying the region of said pole piece within said C-shaped slot, said end por-

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tion projecting in length and width beyond the edges of said part of the pole piece within said C-shaped slot.

13. In an electrically controllable inductor, in combination, a control winding, a pair of pole structures electromagnetically coupled to said control winding and defining a plurality of parallel flux paths for conducting magnetic flux created by current flow through said control winding, each said flux path comprising a signal core of magnetizable material including a pair of elongated bars of saturable magnetic material placed longitudinally adjacent to each other and having recesses in the adjoining sides thereof defining a signal winding opening intermediate the ends of said core, a pair of windings for each said signal core wound one on each said bar through said opening and connected together in series aiding relationship to define a signal winding on each said signal core, a shield of non-magnetic, electrically conductive material substantially entirely enclosing each said core for shielding said core and its associated winding from stray magnetic flux, each of said pair of pole structures including a plurality of projecting portions which are substantially coplanar, and a plurality of retaining means of resilient non-magnetic material at least partially surrounding the ends of each of said pairs of elongated bars and surrounding said projecting portions of the pole pieces and retaining said bars adjacent thereto.

14. A controllable inductor as claimed in claim 13 and wherein said pole structure includes at least one L-shaped lever of magnetically permeable material having a first leg extending close to the end portions of a pair of said bars, resilient means urging said first leg away from said end portions, and a second leg including an adjusting screw for adjusting the spacing between said first leg and said end portions.

15. In a radio receiver system, two resonant circuits each tunable across a predetermined band of frequencies while being maintained with a predetermined relationship between the resonant frequencies thereof, a controllable inductor including magnetizable components defining two independent, closed-loop magnetic flux paths, a variable magnetic flux source, magnetizable members co-operating with said components to define therewith two parallel magnetic flux paths for flux originating at said variable flux source, said parallel flux paths extending through said magnetic components, a pair of signal windings electromagnetically coupled one to each of said closed-loop flux paths, said signal windings being connected one in each of said resonant circuits and controlling the resonant frequencies of said circuits as a function of the respective magnetic flux densities in said parallel flux paths, means defining a first variable air gap in each of said closed-loop flux paths, first flexible spring means engaging each of said magnetizable components, a first adjusting screw for flexing said first spring means for adjusting the effective inductance of the associated signal winding at low flux densities in said parallel flux paths, and means defining a variable air gap in each of said parallel flux paths, second flexible spring means engaging each of said magnetizable components, and a second adjusting screw for flexing said second spring means for adjusting the effective inductance of the associated signal winding at high flux densities in said parallel flux paths, whereby to provide adjustability of the resonant frequencies of said circuits at opposite extremes of said bands of frequencies and thereby insure maintenance of said constant frequency difference at said extremes of said frequency bands.

16. In a radio receiver system having a plurality of resonant circuits tunable across predetermined bands of resonant frequencies, a controllable inductor including a plurality of magnetically saturable components defining a plurality of closed-loop magnetic flux paths, magnetizable core means co-operating with said components to define therewith a plurality of parallel magnetic flux paths, a control winding electro-magnetically coupled to all of said parallel flux paths, a plurality of signal windings

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electromagnetically coupled one to each of said closed-loop flux paths, said signal windings being connected one in each of said resonant circuits to control the resonant frequencies of said circuits as a function of the control current through said control winding, means in each of said closed-loop flux paths for varying the reluctance thereof to adjust the effective inductance of the associated signal winding at low current flow through said control winding, and a plurality of adjustable bridges of magnetic material, one of said bridges extending between said core means and each of said saturable components for independently varying the reluctance of said parallel flux paths to adjust the effective inductance of the associated signal winding at high current flow through said control winding, whereby to provide adjustability of the resonant frequencies of said circuits at opposite extremes of said bands of frequencies.

17. A controllable inductance apparatus comprising a plurality of signal windings, signal winding core means including saturable magnetic material defining a plurality of independent, closed-loop magnetic flux paths, said signal windings being electromagnetically coupled one to each said closed loop flux path, magnetizable components linking said core means and defining therewith a plurality of parallel substantially identical magnetic flux paths wherein at least a portion of each said closed-loop flux path is included in one of said control flux paths, a variable magnetic field source associated with one of said components for establishing variable magnetic fluxes in said parallel flux paths whereby to control the effective inductances of said signal windings simultaneously as a function of the strengths of said magnetic fluxes, manually-operable adjusting means individual to each of said closed-loop flux paths for varying the reluctance thereof independently, and means individual to each of said parallel flux paths for varying the reluctance thereof independently, whereby to provide adjustment of the effective inductance of said signal windings.

18. An electrically controllable inductor for control-

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ling the inductance of a plurality of signal windings comprising a cylindrical control winding, a pair of pole pieces adjacent opposite ends of said winding, said pole pieces having peripheral parts extending beyond the perimeter of said winding, a plurality of elongated signal cores extending across from the periphery part of one pole piece to the peripheral part of the other, a signal winding electromagnetically coupled to each of said signal cores, and an adjusting screw associated with an end portion of each signal core for adjusting the spacing of said end portion from the associated peripheral part of one pole piece.

19. An electrically controllable inductor for controlling the inductance of a plurality of signal windings comprising a cylindrical control winding, a pair of pole pieces adjacent to opposite ends of said winding, said pole pieces each having parts extending beyond the perimeter of the winding and bent into coplanar relationship, a plurality of elongated signal cores extending across from said part of one pole piece to said part of the other pole piece coplanar therewith, a signal winding on each signal core, resilient means urging one end of one of said signal cores toward the adjacent part of the pole piece, an adjusting screw associated with said one end and opposing said resilient means for adjusting the spacing of said one end from the adjacent part of the pole piece, thereby to adjust the inductance characteristics of one of said signal windings with respect to another.

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