June 14, 1960 R. GOLLUB 2,941,173

CONTROLLABLE INDUCTOR

Filed Sept. 7, 1954

Fig. 1.

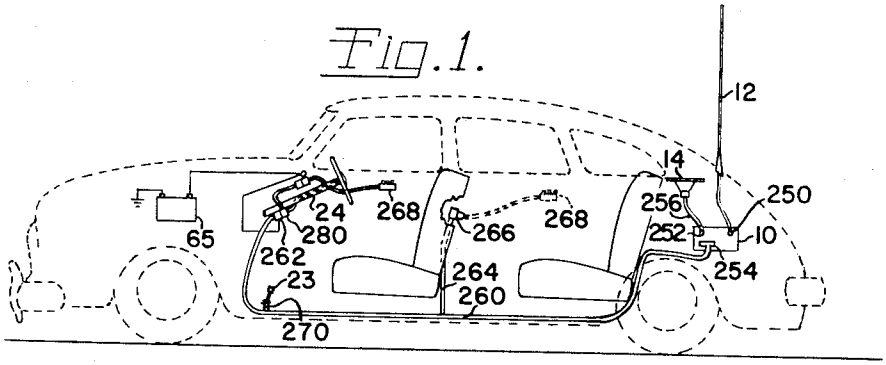


Fig. 2.

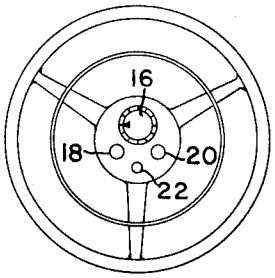
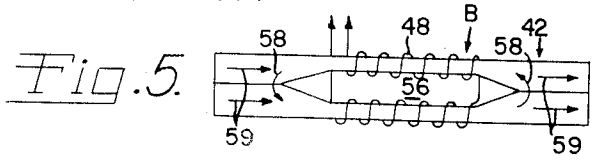


Fig. 3

Fig. 4.

Fig. 5.



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CONTROLLABLE INDUCTOR

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3 Claims. (Cl. 336—155)

The present invention relates to electrical control apparatus and more particularly to electrically controllable inductors.

The present invention is described as embodied in a remotely controllable radio receiver system of a type utilizing a controllable inductor to regulate the frequency to which the radio is tuned.

An advantage of the radio control system described is that it is well adapted for use with superheterodyne receivers and enables remote control of the tuning of the radio frequency and oscillator circuits in such a receiver while providing automatic tracking of the tuning frequencies of these circuits.

Among the advantages of the apparatus described are those resulting from the fact that the controllable inductor used provides improved control characteristics and enables tuning over a wide frequency range. Controllable inductors customarily include a control winding wound on a magnetically saturable core with a signal winding wound on a portion of the core so that changes in the degree of magnetic saturation of the core regulate the inductance of the signal winding which is connected into a circuit to be controlled. A control current is passed through the control winding in order to control the magnetic saturation of the core. As the control current is increased the magnetic saturation of the core increases, reducing the permeability of the material associated with the signal winding and hence reducing its inductance. When the control current is reduced, the inductance of the signal winding increases.

In present day controllable inductors one of the problems encountered is that the core material retains a substantial degree of residual magnetism in the absence of any control current, thus preventing the inductance of the signal winding from rising to as high a value as could be obtained if the core material became fully unsaturated. Considerable efforts have been made in the past in order to neutralize this residual magnetism and thus obtain wider ranges of inductance change. I have found that a substantial reduction in the residual flux and an improvement in the control characteristics of controllable inductors is obtained by the use of non-magnetic shims located in the path of the control flux.

In the controllable inductor described, a plurality of separate signal windings each with its own individual signal core portion are all controlled by the same control winding on a common control yoke. In this inductor non-magnetic electrically conductive shims are sandwiched between each side of all the signal core portions and the control yoke.

Other aspects and advantages of the present invention will be understood from the following description of a remote control receiver incorporating the invention and adapted for installation in an automobile, when considered in conjunction with the accompanying drawings, in which:

Figure 1 is a diagrammatic view of an automobile

showing the arrangement of a radio receiver embodying the present invention;

Figure 2 is an enlarged front view of the steering wheel showing the controls for the radio mounted in the center of the steering wheel;

Figure 3 shows, partly diagrammatically and partly in perspective, an electrically-controllable inductor which forms part of the auto radio receiver shown in Figure 1, the shielding structure being omitted to show the construction;

Figure 4 is an elevational view of the inductor of Figure 3, the control winding being shown diagrammatically and in section; and

Figure 5 is an enlarged view of one of the three variable-inductance signal circuits of the inductor of Figure 3.

The automobile radio receiver shown in the drawings is divided into a number of separate components with plugs and sockets at convenient points in the system. The receiver chassis **10**, which is located in a convenient place in the automobile, for example in the rear trunk as shown in Figure 1, includes all of the circuit elements, except the antenna **12**, the loudspeaker **14**, and the remote control circuits, which are shown in Figure 1 and which are described in detail and claimed in my copending divisional application Serial No. 544,155, filed October 14, 1955.

As shown in Figure 2, controls for the radio are positioned on the hub of the steering wheel. These include a manual station selector **16**, which may be adjusted by the driver to tune the receiver to various stations, a combined on-off switch and volume control **18**, a tone control **20**, and an automatic station selector push-button switch **22**. Momentary closure of switch **22** causes the receiver to tune itself to a radio station on an adjacent frequency. A foot switch **23** near the driver's position controls the receiver in the same manner as the switch **22**. The connections from the controls on the steering wheel extend down inside of the steering column **24**.

In the receiver chassis **10** is a radio frequency amplifier input circuit and output circuit (Figure 3), an oscillator circuit, discriminator and rectifier circuits, and a controllable current source. Also included are intermediate frequency, detector, and audio output circuits as described in said divisional application. A frequency control network is provided to stabilize the oscillator and is connected to a control amplifier, as described in said divisional application, so as to tune automatically the radio frequency circuits by regulating the control current through a winding **37**. An automatic carrier-seeking control is provided so that whenever the control button **22** or **23** is depressed the receiver will automatically tune to another station.

In order remotely to control receiver **10**, an electrically-controllable inductor is provided having three radio-frequency control circuits A, B, and C, with the control winding **37** associated therewith for regulating their inductances in accordance with the position of the station selector **16**.

In one embodiment of the present invention, the controllable inductor circuits A, B, and C (see also Figures 3, 4, and 5) include ferrite core portions **40**, **42**, and **44** respectively, with signal windings **46**, **48** and **50** wound thereon. The core portions **40**, **42**, and **44** are bridged across between the legs of a U-shaped magnetic control core portion **52** having the control winding **37** in two series connected portions and one portion being around each of the two legs **54–1** and **54–2** of the control yoke.

The control winding portions are connected in flux aiding relationship on the control yoke **52** so that any control current flowing through winding **37** regulates

the degree of magnetic saturation of signal core portions 40, 42, and 44.

As shown in detail in Figure 5, each of the signal core portions, for example the core portion 42 comprises two elongated bars of ferrite or ferromagnetic ceramic placed longitudinally adjacent one another. This 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 56 is formed by trapezoidal recesses in the adjoining sides of the two bars. The signal winding 48 associated with core 42 is in two halves extending through the opening 56 and connected in series, so that their magnetic fields are in aiding relationship around the opening 56 to induce flux flowing around opening 56, as indicated by arrows 58. Whereas, the control flux, in flowing between the legs 54–1 and 54–2, follows paths extending substantially the full length of the core 42 as indicated by the arrows 59 so that the control and signal flux fields are not mutually coupled. The signal flux 58 is alternating in direction, while the control flux 59 may be a generally unidirectional flux whose value is varied only as necessary to regulate the degree of magnetic saturation of the core 42 and particularly the saturation of the edges of core 42 adjacent the hole 56 on which the two halves of winding 48 are wound. The permeability of the ferrite material in the core 42 decreases rather strikingly with an increase in the degree of its magnetic saturation produced by the control flux 59, and thus the inductance in the control circuit B is changed in accordance with the control current in winding 37. Similarly, the inductance in control circuits A and C is controlled by the control current in winding 37, because their cores 40 and 44 are bridged across between the yoke legs 54–1 and 54–2 and are subjected to the substantially same degree of saturation as core 42. Thus, the inductance values of windings 46, 48, and 50 "track" each other.

In order to reduce substantially any residual magnetism in control core 52 or in signal cores 40, 42, and 44 when the control current in winding 37 is decreased, it is advantageous to use non-magnetic shims 60 to space the ends of the signal cores slightly from the legs 54–1 and 54–2. These shims also provide further magnetic isolation between cores 40, 42, and 44, and legs 54–1 and 54–2 and acts to confine the signal flux 58 to the signal cores. To be most effective in reducing residual magnetism the shims 60 should be at least 10 mils thick. The shims adjacent the sides of the legs 54–1 and 54–2 are preferably considerably thicker than the shims between the ends of these legs and the core 40. In the receiver shown the two shims at the ends of the legs 54–1 and 54–2 are 10 mils thick and those adjacent the sides of the legs are 30 mils thick. The reason for the thinner shims at the ends of the legs 54–1 and 54–2 is that the end core 40 receives less of the control flux than the cores 42 and 44 because it is further from the control winding 37. Also, the core 40 is adjacent the ends of the laminations and so does not have as good magnetic coupling because of any slight irregularities in the ends of the laminations. This ratio in the thickness of the respective shims 60 may be varied where the dimensions of the control and signal cores are changed or a different lamination arrangement is used. If added shielding effect is desired, the shims 60 may be electrically conductive, further preventing any signal flux from entering the control core 52. I find that shims 60 which are of brass 30 and 10 mils thick, respectively, are well suited for a radio receiver as shown, providing reduction in residual magnetism and giving suitable isolation of the signal and control cores, as well as providing optimum control of the inductance in circuits A, B, and C by the control current.

In the receiver shown the control core 52 comprised a stack of 13 laminations of cold rolled carbon steel, for example such as SAE 1010 with a No. 4 temper and maximum Rockwell hardness B65. The laminations are .030 thick making a total stack of .390 inch. The laminations are 1⅝ inches wide and 2 13/16 inches long. The legs 54–1 and 54–2 are .312 inch wide, with a 1 inch spacing between them, and the back of the core 52 is 1 1/16 inch wide. The control winding 37 comprises two bobbins of 20,000 turns each of No. 40 enameled wire connected in series, making a total of 40,000 turns. Each of the signal cores 40, 42, and 44 comprise two rods of ferrite, each ⅛ inch square in cross-section and about 1 3/16 inches long, so as to overlap the core legs by slightly more than 1/16 inch at each side. The shims 60 are slightly larger than the area of the signal cores in contact with the control core. The signal cores may more fully overlap the legs of the control core, as shown in the drawings, when longer rods of ferrite are used, but I find the particular dimensions described quite satisfactory.

The hexagonal opening 56 in the signal cores 40, 42, and 44 is about ⅜ inch long, the thin portions of the signal cores are about ¼ inch long, and the cross-sections of these thin portions are 1/16 by ⅛ inch. The signal windings 46, 48, and 50 each have a total of 120 turns of 7/40 Litz wire, 60 turns being wound around each side of the openings 56. The antenna may be coupled to the core 40 by a winding 73 having about 3 turns through the opening 56 in the core 40.

For best operation the core portion 40 for the input to the R.F. stage 26 is usually placed across the ends of legs 54–1 and 54–2 as isolating it more completely from the oscillator circuit, with the cores 42 and 44 being bridged across the sides of these legs. A shield of electrically-conductive material 61 is fitted between the core 40 and the cores 42 and 44, and an outer parabolic shield 62 is spaced from and curved around the outside of cores 40, 42, and 44. It is soldered to the edges of shield 61 as shown in Figure 4.

The radio-frequency control circuit A is included in the tuned circuit in the input of the radio frequency amplifier, and control circuit C is included in the tuned circuit in the output of this R.-F. amplifier. Control circuit B is in the oscillator tank circuit. The control current in winding 37 regulates the inductance of the circuits A, B, and C and hence controls the frequency to which the receiver 10 is tuned.

The incoming radio signals picked up on the antenna 12 are coupled from a primary winding 73 (see Figure 3) on the core 40 to the winding 46 forming a secondary winding and into the tuned R.-F. input circuit. The primary and secondary windings 73 and 46, respectively, on the core 40 form an antenna coupling transformer having certain advantages discussed hereafter.

For purposes of explanation, it is assumed that the receiver 10 is a broadcast receiver tunable through a range from 530 to 1650 kilocycles, or in other words, a frequency range of somewhat more than 3 to 1. To tune through this range the inductance values in circuits A and B 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 3, 4, and 5; 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 46, 48, and 50.

In the embodiment of the receiver 10 shown, the oscillator is arranged to oscillate at a frequency 455 kc. above the carrier signal. Thus, in tuning through the broadcast range the oscillator frequency changes from approximately 985 kc. to 2105 kc., or in other words, a range of something more than 2 to 1, requiring an inductance change of about 5 to 1. As mentioned above, both circuits A and B must be varied over an inductance range of approximately 10 to 1. The inductance in circuit B also varies over a range of 10 to 1, but by using

the pair of padding inductance windings in series and parallel therewith, respectively, the total effective change in the inductance of the resonant tank circuit is adjusted to the required range of about 5 to 1, as explained in greater detail in said divisional application. By using the proper values for these padding inductances, the frequency of the oscillator is caused to "track" 455 kc. above the frequency to which the tuned input and output circuits of the R.-F. amplifier are adjusted.

The inductance of the circuits A, B, and C is varied and precisely controlled at any desired value, for tuning to various stations, by regulating the control current through the control winding **37** so as to tune the resonant frequency of the R.-F. amplifier and the oscillator frequency as mentioned above. Advantageously, in the circuit shown the frequency of the oscillator is controlled by circuit B and this frequency is monitored by circuits including the discriminating and rectifying circuit. The inductance of circuits A and C are forced to follow or "track" with the value of circuit B, which is sensed and controlled as desired, and thus circuit B acts as the "bell wether" for the station selecting circuits as a whole.

Among the important advantages of the remote station selecting control circuits described, is that the frequency of the oscillator is continually sensed or measured by the discriminator and rectifier circuit. Any changes in the oscillator frequency for any reason, cause a different signal to be fed to the controllable current source, thus changing the current through the control winding means **37** to bring the oscillator frequency back to the desired frequency. Moreover, the station selecting circuits are made substantially independent of any tendency toward hysteresis effect in the controlled inductance values in circuits A, B, and C, for the control circuits operate in such a way that any given setting of the station selection control **16** always corresponds to a given frequency of the oscillator. Thus, regardless of from which direction the tuning knob **16** is tuned toward a given position, as it reaches that position the operation of forces the inductance in circuits A, B, and C to change to the proper value to tune the receiver to the frequency corresponding with that position on the dial **16**. The magnitude of the control current automatically adjusts itself to overcome any tendency toward magnetic hysteresis in the control flux.

Among the advantages of the circuit described are that they provided remote control of the receiver; that they eliminate all moving parts; and that they provide a receiver of longer life and one which is more rugged in operation because of the elimination of the moving parts.

There are certain important fundamental differences in the operation of a receiver wherein the condenser values are fixed and the inductance values are changed from the operation of an ordinary receiver in which the inductance values are fixed and the condensers are changed in value. Some of these differences are not at all apparent and are rather surprising in their results, as will be pointed out in the following description. In the ordinary superheterodyne receiver in order to increase the frequency, the capacitance is decreased while the inductance remains constant. Thus, as the frequency is increased, the impedance of the resonant circuits involved is increased due to the fixed inductances involved. The increase in impedance tends to cause regeneration problems. Moreover, it decreases the effective gain at the higher frequencies because of the presence of shunt or stray capacities to ground which are present in any circuit. Also, the losses in the fixed inductances increase, so that the "Q" drops and, thus, the band-width drops.

In contrast to this, in the present circuit with increasing frequency the effective impedance of the tuned circuits preferably remains constant. In addition, due to the decrease in inductance (which also means a decrease in various losses in the inductance) there is a corresponding increase in the "Q" of the circuits being used. The result is that the effective band-width of the receiver is constant over the full range of reception, and moreover the effective gain of the receiver is constant because the impedance remains constant with increasing frequency.

The reason that the band-width is constant is that it is proportional to the ratio of the frequency and Q. That is: $BW \alpha F/Q$. As the frequency rises, the Q is correspondingly increased so that the ratio remains approximately constant, and hence the band-width is approximately constant throughout the full range of operation of the receiver.

Another advantage of the control circuit is that it is not the absolute values of the inductances which are important in the operation, but rather their normalized values, that is, the ratio of the incremental inductance at any point to the incremental inductance when the control current is zero. This is particularly helpful in the antenna circuit because it enables the use of a wide variety of antennas, the only requirement being that the total volume and shape of the antenna loop winding **73** be maintained the same. Thus, any configuration of antenna may be used and will produce results superior to those in the ordinary receivers used today.

Although the present receiver is described as tunable over a range from 530 to 1650 kc., the inductance values of the control circuits A, B, and C are capable of variations over ranges of 100 to 1 or even 200 to 1. Thus, it is apparent that the controllable inductor of the present invention is capable of use for tuning a receiver over a far wider range than is done today with mechanically variable condensers.

As described in greater detail in said divisional application, all of the connections to the receiver chassis **10** are made through three sockets; an antenna lead-in socket **250** (Figure 1), a loudspeaker outlet **252**, and a control and power socket **254**. The antenna is mounted on the automobile near the receiver chassis **10**; for example, it may be fastened on the rear bumper or on the rear of the car near the top of the trunk, as shown in Figure 1, with its lead-in wire adapted to be plugged into the socket **250**. The loudspeaker **14** is located remotely from the chassis **10**; for example, under a grill in the rear window ledge with its leads **256** plugged into the socket **252**.

A seven-wire control and power cable **260** extends between a plug which connects in the receiver socket **254** and a socket **262** which engages a plug **280** adjacent the steering post **24** and the floorboards.

To permit control of the radio from the rear seat, a branch cable **264** extends from the cable **260** to a socket **266**, secured to the back of the front seat, so that an extension control unit **268** can be plugged into it when desired.

Also, a socket **270** may be provided under the floorboards near the driver's position into which is plugged a lead from the automatic station changing foot switch **23**.

The power for the receiver is supplied by the automobile battery **65** through a lead passing to the ignition switch and then to the socket **262**. The leads from the controls on the steering wheel pass down inside of the steering column **24** some going directly to the plug **280**.

From the foregoing description it will be understood that the present invention provides an electrically controllable inductor having many advantages as discussed above, and it is understood that the controllable inductor described can be adapted to a wide variety of different applications and that various changes or modifications may be made therein, each as may be best suited to the particular application desired and that the scope of the present invention is intended to include such modifications or adaptations, as defined by the following claims limited only by the prior art.

What is claimed is:

1. A controllable inductor comprising a generally U-shaped control yoke with a pair of spaced legs, a first

signal core bridged across between the sides of said legs, a second signal core bridged across between the ends of said legs, each signal core including a transverse opening elongated in a direction generally toward said legs and dividing each signal core into a pair of opposed edge portions, a signal winding wound on each of said signal cores, each signal winding including turns wound through the opening and around the opposed edge portions of its respective signal core, a pair of non-magnetic electrically-conductive shims at least 30 mils thick between each of said legs and said first signal core, and a pair of non-magnetic electrically-conductive shims at least 10 mils thick between the ends of said legs and said second signal core.

2. An electrically controllable inductor having a control winding, control core means defining part of a control flux path, said control winding being wound around said core means and electromagnetically coupled to said control flux path whereby current in said control winding produces control flux changes in said control flux path, a plurality of signal core means defining individual signal flux paths, said signal core means being spaced different distances from said control winding, said signal core means being at least partially included in said control flux path and each including saturable magnetic material, a plurality of signal windings, each of said signal windings being wound around a portion of a respective one of said signal core means and electromagnetically coupled to one of said signal flux paths, and a plurality of non-magnetic shims positioned between each of said signal core means and said control core means, the shims between the control core means and the signal core means spaced more remote from said control winding being thinner.

3. An electrically controllable inductor including control core means having a plurality of spaced regions and defining part of a control flux path extending therethrough between said spaced regions, a control winding being electromagnetically coupled to said control flux path whereby current in said control winding produces control flux changes in said control flux path, a plurality of signal core means extending between said two spaced regions and being spaced different distances from said control winding, each of said signal core means defining an opening therein and defining an individual signal flux path extending around the opening, said signal core means at least partially completing said control flux path between said spaced regions and including saturable magnetic material, a plurality of signal windings at least one being on each of said signal core means passing through the respective openings thereof, and a plurality of non-magnetic shims between each of said signal core means and the spaced regions of said control core means, the shims between the more remote signal flux paths and the control core means being thinner.

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