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SIGNAL COLLECTING SYSTEM FOR RADIO RECEIVERS

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Circuit elements 1, 5 and 6 form a primary circuit tuned to a frequency below the signal frequency.

Circuit elements 1, 2 and 3 form a secondary circuit tuned to the signal frequency.

Fig. 1.

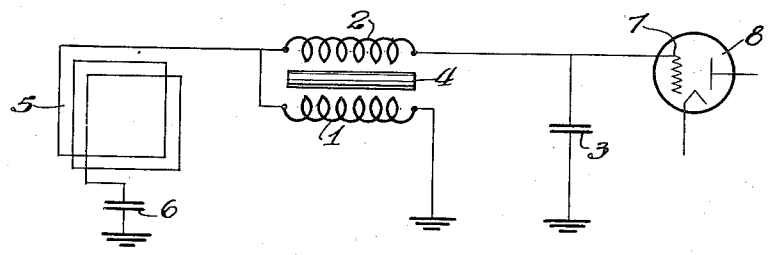
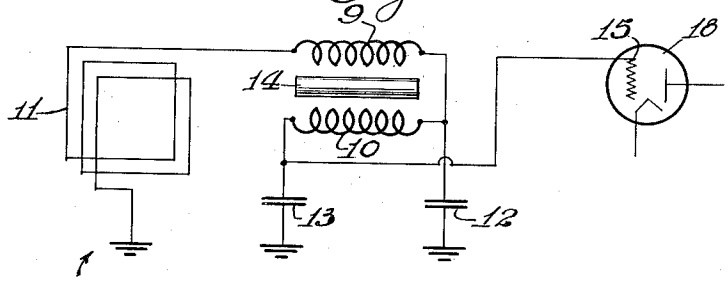


Fig. 2.



Circuit elements 9, 11 and 12 form a primary circuit tuned to a frequency below the signal

Circuit elements 10, 12 and 13 form a secondary circuit tuned to the signal frequency

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SIGNAL COLLECTING SYSTEM FOR RADIO RECEIVERS

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8 Claims. (Cl. 250—40)

This invention relates to high-frequency circuits, such as those employed in radio receiving systems. More particularly, the invention relates to the portion of such systems which constitutes means for collecting the high-frequency signals radiated from relatively distant transmitting stations. This invention incorporates an improved signal-collecting means.

Signal-collecting systems generally include a resonant circuit tunable over a desired range of frequencies and classifiable as series or parallel resonant circuits depending upon how the signal voltage is generated in or applied to the circuit. Collector systems of the series type usually employ a so-called loop antenna or its equivalent to intercept the signals. It is to this type that the present invention is addressed.

In their practicable forms, series collector systems have heretofore been tuned by variation of the circuit capacitance. In the present application, and in my co-pending applications, Serial Numbers 319,671, 319,672, 319,673 and 319,674, all filed February 19, 1940, to which I shall refer in greater detail later in this specification, I disclose highly advantageous and commercially practicable series collector systems tuned by variation of the circuit inductance, preferably by the employment of a ferromagnetic core of suitable characteristics movable relatively to an inductance coil in series with the loop or other exposed inductive element of the system. This method of tuning has the additional advantage of providing means for controlling the high-frequency resistance of the system in substantially any desired manner as the system is tuned over the frequency range.

Resonant circuits tuned by inductance variation by means of ferromagnetic cores movable relatively to the inductive element in the circuit, and possessing the advantage of simultaneous control of the circuit resistance are disclosed by Polydoroff in United States Reissue Patent No. 21,282, in which a resonant circuit having an inductance coil and capacitor is adjusted over a range of frequencies by movement of a compressed comminuted core relatively to the inductance coil. This method of tuning is called permeability tuning. An improved form of such a system is disclosed in my United States Patent No. 2,051,012. Both Polydoroff's original system and my improved system readily cover an adequate range of frequencies and may be ganged to provide multiple unit systems.

In general, the signal voltage generated in a collector system is directly proportional to the frequency of the signal. Thus a signal at the upper end of the broadcast range will provide approximately three time as much signal voltage in the collector system as a signal at the lower end of this range. Various expedients have been employed in broadcast receivers in an effort to compensate for this inherent deficiency of the collector system.

As is well known, the effective high-frequency resistance of a permeability-tuned circuit increases as the core is advanced into the winding to tune the circuit to lower frequencies. Depending upon the materials employed and the process of producing the core, this increase in resistance may be controlled, and, if desired, may be made quite small. It is impractical, however, to attempt to entirely compensate for the lower voltages generated by the signal at the lower frequencies, by employing a very low-loss core material and construction. As stated by Jacob in United States Patent No. 2,153,622, a series resonant circuit may be arranged to produce constant gain by employing a ferromagnetic core which will maintain the ratio of inductive reactance to resistance in the circuit, that is the circuit Q, substantially constant. In carrying out my invention I prefer to employ such a core, and to secure compensation for the lower voltages generated by the lower frequency signals by utilizing a network which has two resonant frequencies, one of which corresponds to the frequency of the desired signal, and the other of which, although also varying, is maintained below the frequency of the signal. The system thus incorporates a pair of inductively coupled resonant circuits, each having variable effective total inductance and fixed capacitance, one of which includes an exposed inductive element and is maintained resonant to a frequency lower than that of the selected signal.

An object of my invention is to provide an improved signal-collecting means for radio receivers.

An additional object is to provide a signal-collecting means which may be successfully employed in the most compact forms of radio receivers, and which may be placed in close proximity to the receiver chassis without serious detriment.

Still another object of the invention is to provide a signal-collecting circuit whose performance characteristics may be readily controlled with respect to variation with frequency.

It is also an object of the invention to provide a signal-collecting circuit which may be tuned

by inductance variation, for example by means of a movable ferromagnetic core, and in which the advantages of this method of tuning may be realized.

It is a principal object of my present invention to provide a signal-collecting system in which the total gain is high and in which the delivered voltage is substantially independent of the frequency of the intercepted signal.

These and other objects and advantages are realized in accordance with the invention in a manner which will be readily understood from the following description taken in connection with the drawing, in which:

Fig. 1 is a schematic diagram of a basic arrangement in accordance with the invention; and

Fig. 2 is a modified arrangement according to the invention.

In the arrangement according to Fig. 1, windings 1 and 2, which are constructed as the primary and secondary, respectively, of a high-frequency transformer, are connected in series and are shunted by a capacitor 3 to form a resonant circuit tunable over a range of frequencies by motion of ferromagnetic core 4 relatively to windings 1 and 2. Transformer 1—2 is preferably shielded but in any event is not exposed to the passing radio signals. A loop or other suitable inductive element 5 is arranged to intercept the passing signals and is connected between the junction of windings 1 and 2, and through capacitor 6 to ground. Resonant circuit 1—2—3 is connected in the conventional manner to input electrode or grid 7 of vacuum tube 8, which may be the first vacuum tube in a radio receiver, and which may be arranged to act as a high-frequency amplifier, as a detector or as a modulator in a superheterodyne system.

Primary 1, loop 5 and capacitor 6 form a series resonant circuit whose constants are preferably so chosen as to produce resonance at or near the lower frequency end of the frequency range to be covered, with ferromagnetic core 4 fully inserted into secondary 2. To this end, the inductance of loop 5 is preferably made considerably greater, and the inductance of primary 1 is preferably made considerably smaller, than the inductance of secondary 2, the capacitance of capacitor 6 being chosen to produce low-frequency resonance with inductors 1 and 5.

Movement of ferromagnetic core 4 relatively to windings 1 and 2 varies their effective inductance, and the coupling between them, and additionally, as is well known, simultaneously varies their effective resistances. Depending upon the relative inductances of primary 1 and secondary 2, the variation of the inductance of primary 1 and of the mutual inductance of the transformer 1—2 produced by motion of ferromagnetic core 4 will result in a considerable variation in the resonant frequency of circuit 1—5—6.

The passing signal generates a voltage in loop 5 and the resulting current, which will normally be greatest at the low-frequency end of the range through circuit 1—5—6, develops a voltage across primary 1. The signal voltage delivered across capacitor 3 to the input terminals of vacuum tube 8 is due to the voltage developed across primary 1, the voltage induced in secondary 2, which varies with the position of ferromagnetic core 4, and to the resonant gain of circuit 1—2—3, which is controllable by virtue of the resistance-varying characteristic of ferromagnetic core 4. By appropriate choice of constants and by appropriate choice of the material and construction of ferromagnetic core 4, it is therefore possible to secure high resonant gain in the system, and to achieve any reasonable desired relation between the frequency of the selected signal and the voltage delivered to vacuum tube 8. In preferred embodiments of the invention, appropriate constants for which will later be given, the system is so adjusted that the voltage delivered to vacuum tube 8 is substantially independent of the frequency of the signal, depending only upon the strength of the signal.

The operation of the system in accordance with the present invention differs from that of the system described in my co-pending application, Serial Number 319,672, filed February 19, 1940, above referred to, in that in the former I employ a single exposed inductive element and two circuits of variable frequency, whereas in the latter I employ two exposed inductive elements and two circuits one of which has variable frequency and the other of which has substantially fixed frequency. Additionally, although in both systems I employ three inductive elements, and inductive coupling between two of them, in the present system I vary the coupling between two unexposed elements whereas in the system of the co-pending application I maintain fixed coupling between two exposed elements.

As to my other co-pending applications above referred to, that of application Serial Number 319,671, filed February 19, 1940, employs only two inductive elements, one exposed and one unexposed, that of application Serial Number 319,673, filed February 19, 1940, employs a regenerative coupling from the plate or output circuit of the associated vacuum tube, and that of application Serial Number 319,674, filed February 19, 1940, employs only a single resonant circuit directly responsive to frequencies within or near the range of frequencies to be covered, and with appropriate constants secures resonance to the signal frequency in an associated portion of the system by varying reflected capacitive reactance.

Still referring to Fig. 1, it may be shown from the equations of the equivalent circuit that the quality factor in the system is

$$Q=\frac{X_2-A^2(X_5-X_6+X_1)}{R_{10}+A^2R_9} \tag{1}$$

in which the X terms are the reactances of the correspondingly numbered components, R_9 and R_{10} are the effective resistances of the primary and secondary portions of the system, respectively, and

$$A^2=\frac{X_m^2}{(X_5-X_6+X_1)^2} \tag{2}$$

where X_m is the mutual reactance corresponding to the coupling between windings 1 and 2. It may also be shown that the effective voltage is

$$E'=EA \tag{3}$$

where E is the voltage generated in the loop 5, and that the two resonant frequencies of the system are given by

$$w^2=(2\pi f)^2=\frac{-b+\sqrt{b^2-4ac}}{2a} \tag{4}$$

in which

$$a=L_1L_5+L_1L_2-L_m^2 \tag{5}$$

$$b=\frac{L_2}{C_6}+\frac{L_5}{C_3}+\frac{L_1}{C_3} \tag{6}$$

$$c=\frac{1}{C_3C_6} \tag{7}$$

where the L and C terms are the inductances and capacitances, respectively, of the correspondingly numbered components. The plus sign in Equation 4 gives the variable frequency of circuit 1—2—3, and the minus sign of Equation 4 gives resonant frequency of circuit 1—5—6. Since L_1, L_2 and L_m are varied by movement of ferromagnetic core 4, the resonant frequency of circuit 1—5—6 also varies in the same sense as, although more slowly than, the resonant frequency of circuit 1—2—3. This is a particular and highly advantageous feature of the system according to the invention, and it is by virtue of this feature that I am enabled to deliver to vacuum tube 8 a resonant voltage which is substantially independent of the frequency of the selected signal, or, if desired, to secure any other reasonable desired relation of the delivered voltage to the frequency of the signal.

Equation 1 shows that as X_1+X_5 approaches equality with X_6, the numerator of the fraction becomes equal to X_2. At the same time, however, the quantity A becomes very large. Maximum circuit Q is achieved when $(X_5-X_6+X_1)$ is slightly negative, hence X_6 is preferably made greater than X_1+X_5. Under these conditions, and assuming that for all frequencies the quantity A is large enough to make X_2 and R_{10} negligible, the quality factor of the system may be stated as

$$Q=\frac{X_5-X_6+X_1}{R_9} \qquad (8)$$

The effective Q of the secondary circuit may therefore be varied without appreciably affecting the performance of the system. However, the loop corresponding to X_5 and the primary corresponding to X_1 should be carefully constructed to have low losses if highest resonant gain through the system is desired.

As the system is tuned toward the lower frequency end of the frequency range, the difference in resonant frequency between circuit 1—2—3 and circuit 1—5—6 becomes smaller, and the advantage of low-loss constructions for loop 5 and primary 1 becomes more pronounced. It is to be remembered that the term R_9 includes not only the effective resistances of loop 5 and primary 1 but also the reflected effect of ferromagnetic core 4. If constant resonant gain is desired, therefore, Q as given by Equation 8 is to be maintained constant by the employment of a ferromagnetic core 4 which will cause R_9 to vary proportionately to $(X_5-X_6+X_1)$.

Referring again to Equation 4 the resonant frequencies of the system are determined in part by inductance L_5 of the loop which is not variable. For this reason, ferromagnetic core 4 will necessarily have a considerably higher effective permeability, in order to tune over the desired frequency range, than would be required if secondary 2 were the only inductance in the resonant circuit. It is readily possible, with present ferromagnetic materials and core constructions to secure adequate effective permeability. The core should be such that it produces a high Q at all frequencies in combination with secondary 2 alone.

In a successful embodiment of the invention according to Fig. 1, loop 5 was a close wound solenoid comprising 25 turns of No. 28 plain enamelled wire on a wood frame 5¾ x 11¼ x 1 inches and had an inductance of 380 microhenries. Secondary 2 was a progressive universal winding 1 5/16 inches long on a tube of 0.220 inch diameter and comprised 250 turns of 7/44 single-silk enamelled Litz wire. This winding had an inductance of 200 microhenries, a Q of 110 at 600 kilocycles and a Q of 80 at 1560 kilocycles. Primary 1 was a small universal coil of 0.063 inch axial length wound directly on the secondary tube 1/16 inch beyond the high-potential or grid end thereof and comprised 50 turns of 7/44 single-silk enamelled Litz wire. This winding had an inductance of 63 microhenries and a Q of 130 at 1560 kilocycles. To secure proper phase relations, the inside terminal or start of primary 1 was connected to ground and the outside terminal or finish was connected to the loop end or start of the secondary 2, and the two windings were positioned with their turns running in opposite directions. Ferromagnetic core 4 was 0.200 inch in diameter and 1.375 inches long and consisted of a mixture of 94% hydrogen iron dust and 4% tin-hydrogen iron dust, sifted through a 400-mesh screen, insulated with 0.5% varnish, hot molded at 180° F. with 3% powdered Bakelite binder and cured at 290° F. for three hours. Core 4 was arranged to enter the grid end of secondary 2. Capacitor 3 was of 35 micromicrofarads and capacitor 6 was of 157 micromicrofarads. The frequency range of the system was 550 to 1560 kilocycles.

With the constants above given, the arrangement according to Fig. 1 provides much greater resonant gain than can be secured with the conventional condenser-tuned loop circuit, particularly at the higher frequencies. Additionally, and by virtue of the coupled circuit arrangement, when employed in connection with a receiver of the usual superheterodyne type, the system according to the invention provides greatly superior rejection of signals at the intermediate frequency of the receiver, and of the image-frequency signals.

Still referring to Fig. 1, the coupling between primary 1 and secondary 2 may be reduced substantially to zero by positioning the coils at right angles to one another. This provides an alternative arrangement in which the resonant frequency of circuit 1—5—6 is not appreciably varied by movement of ferromagnetic core 4 but nevertheless operates as in the previously described arrangement to greatly increase the delivered signal voltage at the lower frequency end of the frequency range.

Referring now to Fig. 2, a modified arrangement according to the invention employs a transformer having a primary 9 and a secondary 10 and a loop or other exposed inductive element 11 similar to those above described in connection with Fig. 1 but differently connected. In this arrangement capacitor 12, which corresponds to capacitor 6 in Fig. 1, is connected between one end of primary 9 and ground, loop 11 being connected from the other end of primary 9 directly to ground. The junction of primary 9 and capacitor 12 is connected through secondary 10 and capacitor 13 to ground, grid or input electrode 15 of vacuum tube 18 being connected to the junction of secondary 10 and capacitor 13. Reactance X_{12} of capacitor 12, and therefore the signal voltage developed across it, rises as the signal frequency decreases. Since this voltage is effectively applied to the tunable resonant circuit 10—12—13, a very effective compensation for the lower voltages generated in the loop 11 at the lower frequency end of the range can be secured. This arrangement is therefore recommended

when high sensitivity of the receiver at the low-frequency end of the range is to be secured at the expense of some loss of sensitivity at the high-frequency end of the range. The relation between delivered signal voltage and frequency will, as in the case of Fig. 1, be additionally affected by the resonant gain of circuit 10—12—13 which may be made substantially uniform by construction of ferromagnetic core 14 to produce substantially constant Q for the complete system, as above explained in connection with Fig. 1.

In accordance with the present invention I secure high resonant gain and a delivered signal voltage substantially independent of the frequency of the selected signal by the employment in a signal-collecting system of a first resonant circuit including a loop or other exposed inductive element, a capacitor and the primary of a high-frequency transformer, and a second capacitor, the mutual inductance of the transformer being effectively in both circuits, by tuning this system by movement of a suitable ferromagnetic core relatively to the windings of the transformer to produce resonance with the desired signal in the second circuit solely by variation of its effective inductance, and simultaneously to appropriately vary the mutual inductance of the transformer and the effective resistance of the entire circuit, and by arranging the first resonant circuit so that for all positions of the ferromagnetic core it is resonant to a frequency lower than that of the selected signal and near the low-frequency end of the frequency range. By alteration of the degree of coupling I may vary the frequency of the first resonant circuit as the system is tuned over the range, or I may maintain the frequency of the first resonant circuit substantially fixed at a low value.

Having thus described my invention, what I claim is:

1. A signal-collecting system for radio receivers and the like tunable over a range of frequencies, including a high-frequency transformer comprising primary and secondary windings having a common terminal and a ferromagnetic core movable relatively thereto, a capacitance effectively in series with said secondary winding and forming a secondary resonant circuit tunable by movement of said core to any desired signal within said range, an inductive element exposed to said signals, and a second capacitance effectively in series with said exposed element and said primary winding and forming a primary resonant circuit which is turned by motion of said core to a frequency lower than the frequency of said signal.

2. In a radio receiver having a first vacuum tube, means for delivering to the input terminals of said vacuum tube a voltage proportional to the strength but independent of the frequency of a desired signal, including a high-frequency transformer comprising primary and secondary windings having a common terminal and a ferromagnetic core movable relatively thereto, a capacitance effectively in series with said secondary winding and forming a secondary resonant circuit tunable by movement of said core to any desired signal, an inductive element exposed to said signals, and a second capacitance effectively in series with said exposed element and said primary winding and forming a primary resonant circuit which is tuned by motion of said core to a frequency lower than the frequency of said signal.

3. A signal-collecting system for radio receivers and the like tunable over a range of frequencies, including a high-frequency transformer comprising primary and secondary windings having a common terminal and a ferromagnetic core movable relatively to said windings, a capacitance effectively in series with said windings and forming a secondary resonant circuit tunable by movement of said core to any desired signal within said range, an inductive element exposed to said signals and connected to said terminal, a second capacitance effectively in series with said exposed element and said primary winding and forming a primary resonant circuit which is tuned by motion of said core to a frequency lower than the frequency of said signal.

4. A signal-collecting system for radio receivers and the like tunable over a range of frequencies, including a high-frequency transformer comprising primary and secondary windings having a common terminal and a ferromagnetic core movable relatively to said windings, a capacitance effectively in series with said windings and forming a secondary resonant circuit tunable by movement of said core to any desired signal within said range, an inductive element exposed to said signals and connected between the other terminal of said primary and ground, a second capacitance effectively in series with said exposed element and said primary winding and forming a primary resonant circuit which is tuned by motion of said core to a frequency lower than the frequency of said signal.

5. In a radio receiver tunable to signals over a range of frequencies and having a first vacuum tube, means for delivering to the input terminals of said vacuum tube a voltage proportional to the strength but independent of the frequency of a desired signal, including a high-frequency transformer comprising primary and secondary windings having a common terminal and a ferromagnetic core movable relatively to said windings, a capacitance effectively in series with said windings and forming a secondary resonant circuit tunable by movement of said core to any desired signal within said range, an inductive element exposed to said signals and connected to said terminal, a second capacitance effectively in series with said exposed element and said primary winding and forming a primary resonant circuit which is tuned by motion of said core to a frequency lower than the frequency of said signal.

6. In a radio receiver tunable to signals over a range of frequencies and having a first vacuum tube, means for delivering to the input terminals of said vacuum tube a voltage proportional to the strength but independent of the frequency of a desired signal, including a high-frequency transformer comprising primary and secondary windings having a common terminal and a ferromagnetic core movable relatively to said windings, a capacitance effectively in series with said windings and forming a secondary resonant circuit tunable by movement of said core to any desired signal within said range, an inductive element exposed to said signals and connected between the other terminal of said primary and ground, a second capacitance effectively in series with said exposed element and said primary winding and forming a primary resonant circuit which is tuned by motion of said core to a frequency lower than the frequency of said signal.

7. In a radio receiver tunable to signals over a range of frequencies and having a first vacuum tube, means for delivering to the input terminals of said vacuum tube a voltage proportional to

the strength but independent of the frequency of a desired signal, including a high-frequency transformer comprising primary and secondary windings having a common terminal and a ferromagnetic core movable relatively to said windings, a capacitance effectively in series with said windings and forming a secondary resonant circuit tunable by movement of said core to any desired signal within said range, an inductive element exposed to said signals and connected to said terminal, a second capacitance effectively in series with said exposed element and said primary winding and forming a primary resonant circuit which is tuned by motion of said core to a frequency lower than the frequency of said signal, said secondary having an inductance value intermediate those of said primary and said inductive element.

8. In a radio receiver tunable to signals over a range of frequencies and having a first vacuum tube, means for delivering to the input terminals of said vacuum tube a voltage proportional to the strength but independent of the frequency of a desired signal, including a high-frequency transformer comprising primary and secondary windings having a common terminal and a ferromagnetic core movable relatively to said windings, a capacitance effectively in series with said windings and forming a secondary resonant circuit tunable by movement of said core to any desired signal within said range, an inductive element exposed to said signals and connected between the other terminal of said primary and ground, a second capacitance effectively in series with said exposed element and said primary winding and forming a primary resonant circuit which is tuned by motion of said core to a frequency lower than the frequency of said signal, said secondary having an inductance value intermediate those of said primary and said inductive element.

WILLIAM A. SCHAPER.

Certificate of Correction

Patent No. 2,244,177. June 3, 1941.

WILLIAM A. SCHAPER

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Page 1, second column, line 3, for the word "time" read *times*; page 2, second column, line 68, Equation 4, for "$-b+$" read $-b\pm$; page 4, first column, line 54, claim 1, for "turned" read *tuned*; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 29th day of July, A. D. 1941.

[SEAL]

HENRY VAN ARSDALE,
Acting Commissioner of Patents.