March 24, 1936. W. VAN B. ROBERTS 2,034,773

TUNABLE RADIO FREQUENCY CIRCUITS

Filed March 9, 1933

Fig. 1

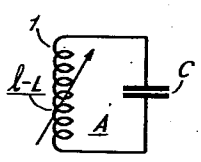


Fig. 3

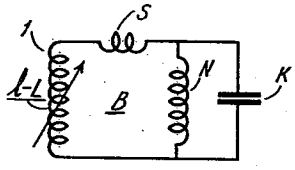


Fig. 2

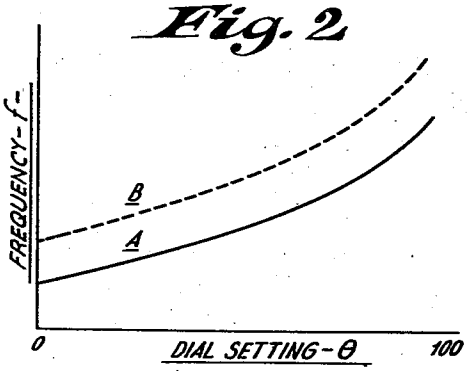


Fig. 4

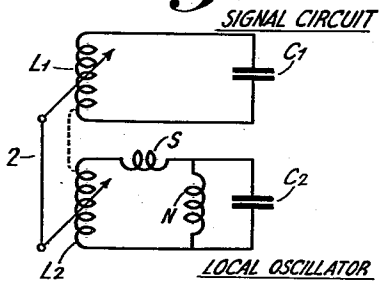


Fig. 4a

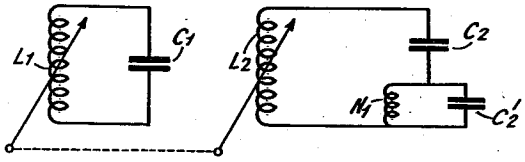


Fig. 5

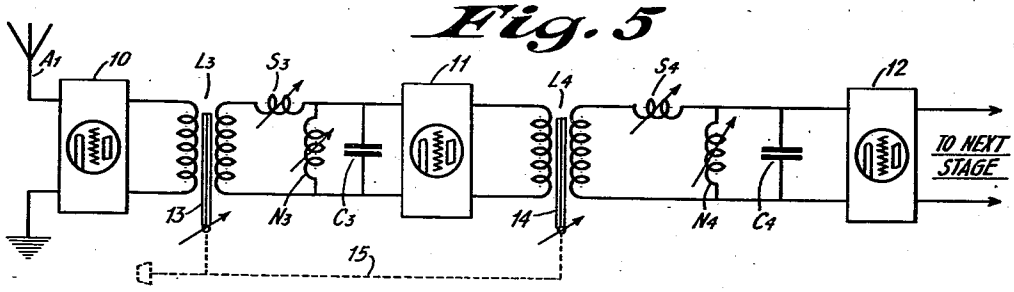


Fig. 6

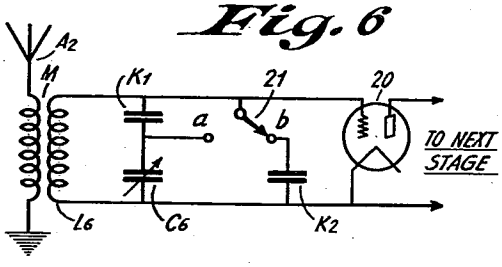


Fig. 7

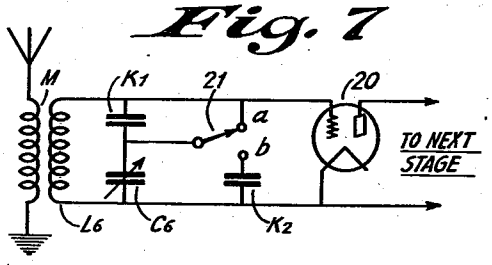
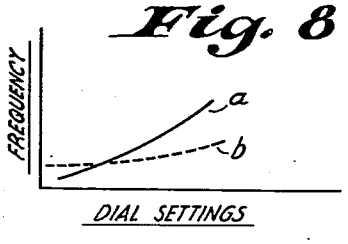


Fig. 8



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TUNABLE RADIO FREQUENCY CIRCUITS

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Application March 9, 1933, Serial No. 660,124

6 Claims. (Cl. 250—20)

My present invention relates to tunable radio frequency circuits, and more particularly to tunable circuits including fixed tuning adjustment reactance elements.

One of the main objects of my present invention is to provide a novel method of, and means for, adjusting the ratio of minimum to maximum inductance of a tunable high frequency circuit arranged for tuning variation by a variable inductance.

Another important object of the present invention is to provide a method of, and means for, securing a substantially constant frequency difference between a pair of tunable oscillation circuits, both including like variable tuning inductances, over a predetermined tuning range, the method comprising the utilization of fixed trimmer inductances in at least one of said circuits, and said constant frequency difference being zero, or a value greater than zero, the latter as in the case of superheterodyne receivers.

Another important object of the present invention is to provide a tuning means for a resonant radio frequency circuit which can readily be changed from a condition which covers a wide range of frequencies to a condition which covers only a narrow band of frequencies with the same range of adjustment of the tuning mechanism.

Still other objects of the invention are to generally improve the tuning efficiency of resonant radio frequency circuits, particularly those tunable by means of variable tuning inductances, and additionally to provide such tuning arrangements in an economical manner with regard to manufacture and assembly.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims, the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawing in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawing,

Fig. 1 shows a conventional tunable high frequency circuit,

Fig. 2 graphically illustrates the object of the present invention,

Fig. 3 shows a circuit of the type of Fig. 1 embodying the present invention,

Fig. 4 shows a modified form of the invention applied to a superheterodyne receiver, and whose operation is illustrated in Fig. 2,

Fig. 4*a* shows a modification of the arrangement shown in Fig. 4,

Fig. 5 shows another modification of the invention applied to a cascaded tuned radio frequency amplifier receiver,

Figs. 6 and 7 show alternative embodiments of the basic principle of the present invention applied to a band spreader device for tunable radio frequency circuits and

Fig. 8 graphically illustrates the operation of the arrangements of Figs. 6 and 7.

Referring now to the accompanying drawing, wherein like reference characters designate similar circuit elements in the different figures, there is shown in Fig. 1 in conventional manner a resonant high frequency circuit consisting of a variable tuning inductance coil l and a shunt fixed condenser C. The coil l is shown adjustable by means of the arrow passing through it, and it is to be understood that this variable, or adjustable, inductance coil l may be any conventional variometer, or a variable inductance of the type wherein the coil is provided with a magnetic core which is movable with respect thereto to vary the inductance value of the coil. Such a movable core inductance coil is shown in my copending application Serial No. 657,769, filed February 21, 1933. Regardless of the construction of the variable tuning inductance l, the resonant oscillation circuit A may be used for most purposes where such a circuit is required, such as for a tunable radio frequency amplifier circuit of a radio receiver.

The adjusting dial, or knob, of the variable inductance l when set to different angular positions results in an adjustment of the frequency to which the circuit A is resonant. In Fig. 2 the full line A represents a tuning characteristic of circuit A; "Frequency", as ordinates, are plotted against "Dial setting—θ" as abscissæ. In other words, the variable inductance l tunes the circuit A according to an arbitrary law such as illustrated by the solid curve A of Fig. 2. Now, let it be assumed that the coil l has a minimum value l and a maximum value L, and let the dotted line B in Fig. 2 illustrate curve A displaced upwards by a given frequency. There arises, then, the problem whether the resonant circuit A can be designed so that the same variable inductance l will tune the circuit according to the dotted curve B of Fig. 2 with a good degree of approximation. In Fig. 3 there is shown the method of solving this problem. In this figure the fixed condenser K is chosen to shift the tuning frequency range of the circuit, while the trimmer inductances s and N are connected respectively in series and shunt with the coil l to maintain the new tuning law substantially the same as the original tuning law.

The quantitative relations between the circuit elements shown in Fig. 3 are somewhat involved, and make it desirable to employ mathematical formulæ in illustrating the laws governing the phenomena taking place in the network. Particularly, these formulæ lay down rules of design

whereby any one skilled in the art may construct the present invention.

One condition that must be fulfilled in employing the invention shown in Fig. 3 is that the ratio of the slope at the right end of the dotted curve B of Fig. 2 to the slope at the left end must be the same as the ratio of slopes at the ends of the solid curve A. But the slope,

$$\frac{dL}{d\theta}$$

is proportional to the

$$(\text{circuit inductance})^{-3/2}\times\frac{d\ (\text{circuit inductance})}{d\theta}$$

For the solid line curve A, the slope is therefore proportional to

$$L^{-3/2}\frac{dL}{d\theta}$$

where L is the inductance of the variometer *l*. Therefore, the ratio of the slopes at the two ends of the solid curve A is:

$$l^{-3/2}\left(\frac{dL}{d\theta}\right)_{\theta=100}+L^{-3/2}\left(\frac{dL}{d\theta}\right)_{\theta=0} \quad \text{(1)}$$

Now, the circuit inductance in Fig. 3 is

$$\frac{N(s+L)}{N+s+L}$$

and, therefore,

$$\frac{d\ (\text{circuit inductance})}{d\theta}=\frac{N^2}{(N+s+L)^2}\frac{dL}{d\theta} \quad \text{(2)}$$

Therefore, the ratio of slopes at the ends of the dotted curve B is

$$\frac{\left[\frac{N(s+l)}{N+s+l}\right]^{-3/2}\frac{N^2}{(N+s+l)^2}\left(\frac{dL}{d\theta}\right)_{\theta=100}}{\left[\frac{N(s+L)}{N+s+L}\right]^{-3/2}\frac{N^2}{(N+s+L)^2}\left(\frac{dL}{d\theta}\right)_{\theta=0}} \quad \text{(3)}$$

Equating these two ratios of slopes, we have

$$\left(\frac{l}{L}\right)^{-3/2}=\frac{\left[\frac{N(s+l)}{N+s+l}\right]^{-3/2}\frac{N^2}{(N+s+l)^2}}{\left[\frac{N(s+L)}{N+s+L}\right]^{-3/2}\frac{N^2}{(N+s+L)^2}} \quad \text{(4)}$$

Now, let l/N, and s/L and s/N be negligibly small, and rearrange thus:

$$\left(\frac{l}{L}\right)^{-3/2}=\frac{\left[\frac{s+l}{1+s/N+l/N}\right]^{-3/2}\left(1+\frac{s}{N}+\frac{l}{N}\right)^{-2}}{\left[\frac{s+L}{1+s/N+L/N}\right]^{-3/2}\left(1+\frac{s}{N}+\frac{L}{N}\right)^{-2}} \quad \text{(5)}$$

Now, drop out the negligibly small terms, and the equation is:

$$\left(\frac{l}{L}\right)^{-3/2}=\frac{(s+l)^{-3/2}}{(s+L)^{-3/2}\left(1+\frac{L}{N}\right)^{3/2}\left(1+\frac{L}{N}\right)^{-2}} \quad \text{(6)}$$

The last equation can be rewritten:

$$\left(\frac{l}{L}\right)^{-3/2}=\frac{l^{-3/2}(1+s/l)^{-3/2}}{L^{-3/2}(1+s/L)^{-3/2}\left(1+\frac{L}{N}\right)^{-1/2}} \quad \text{(7)}$$

Dropping s/L, this last equation readily reduces to:

$$\left(1+\frac{L}{N}\right)=(1+s/l)^2 \quad \text{(8)}$$

Equation (8) is the relation required between *s*, N, L and *l* to satisfy the conditions embodied above.

In addition to the dotted curve B having the ratio of slopes at its two ends the same as the ratio of slopes of the ends of the solid curve A, it is desired to embody the condition that the frequency difference be the same at the two ends, and that this difference have a given value. Knowing the frequencies at the two ends of the solid curve A, the same constant amount can be added to each (the desired intermediate frequency in the case of uni-control superheterodyne operation), and there is obtained the required frequencies at the two ends of the dotted curve B. Calling these frequencies f_0 and f_{100}, we must then have:

$$f_0=\frac{1}{2\pi\sqrt{K}\sqrt{\frac{N(s+L)}{N+s+L}}} \quad \text{(9)}$$

$$f_{100}=\frac{1}{2\pi\sqrt{K}\sqrt{\frac{N(s+l)}{N+s+l}}} \quad \text{(10)}$$

These two equations together with the aforementioned Equation (8) completely determine the values of the constants *s*, N and K so as to make the circuits A and B tune with substantially constant difference of frequency. In Fig. 4 is shown such an arrangement. The "Signal circuit" corresponds to circuit A of Fig. 1, and the "Local oscillator" circuit corresponds to circuit B of Fig. 3. The variable inductances L_1 and L_2 are shown uni-controlled by any conventional mechanical arrangement 2, and the condensers C_1 and C_2 have values determined by the signal frequencies, and by Equations 8, 9, 10, respectively. The local oscillator circuit includes the trimmer inductances *s* and N. It should be noted that if f_0 and f_{100} had not been taken as equally different from the frequency limits of the solid curve A, the frequency difference between the dotted and solid curves would have varied with frequency in a linear fashion.

In Fig. 4, then, there has been shown how the invention may be employed in a superheterodyne receiver to maintain the signal and local oscillator circuits differing by substantially constant frequency difference, while employing like variable tuning inductances in both circuits for economical production of receivers.

In Fig. 4*a* there is shown a modification of the arrangement shown in Fig. 4 wherein in the local oscillator circuit L_2C_2, a network, composed of an inductance N_1 shunted by a fixed condenser C_2', is connected in series between the condenser C_2 and the inductance L_2. It can be mathematically demonstrated that proper choice of the values of C_2N_1 and C_2' will cause the signal and oscillator circuits to have the same frequency difference at at least three different adjustments of the inductances L_1 and L_2, and hence to have nearly constant difference for all values of the adjustment of these variable tuning inductances. It is not believed necessary to give these mathematical formulæ, since they are complicated, and can be readily deduced from the network shown in Fig. 4*a* and the aforesaid tuning requirements. Indeed, the particular networks of fixed reactance elements here disclosed are merely illustrative, as by well known formulæ they may be replaced, by various other equivalent networks. Such formulæ are to be found in K. S. Johnson's book (Transmission circuits for telephonic communication—Appendix D).

In Fig. 5 is shown another useful application of the basic principle described in connection with Figs. 1, 2 and 3. If there are several networks of the type shown in Fig. 1 to be adjusted over

the same given range of tuning frequencies by a uni-control device, manufacturing imperfections may result in the values of variable tuning inductance in the different networks not having exactly the same maximum and minimum values in each network.

For example, in a receiver of the type shown in Fig. 5, the numerals 10, 11, 12 designate amplifier tubes, the grounded antenna circuit A being coupled to the input of tube 10. The output of tube 10 and the input of tube 11 are coupled by a network of the type shown in Fig. 1.

The output of tube 11 and the input of tube 12 are similarly coupled by a network of the same type. The output of tube 12 may be coupled to another amplifier stage, or detected and utilized in any well known manner. The fixed condensers C_3 and C_4 are tuned by the variable inductances L_3 and L_4, and these inductances are varied by appropriately moving the magnetic cores 13, 14 with respect to the coils of the inductances. The cores are arranged in any desired mechanical fashion for uni-control operation by a uni-control tuning means 15, shown in dotted lines. As stated heretofore, there may be employed for the variable tuning inductances a construction disclosed in my aforesaid copending application.

The resonant networks between tubes 10 and 11 and tubes 11 and 12 are adjusted to cover a common range of frequencies, say the broadcast range. Manufacturing imperfections may result in the values of L_3 and L_4 not having exactly the same maximum and minimum values in each network. Suitable values of series fixed inductance s_3, inserted as in Fig. 3, can be made to equalize the minimum value of inductance across the condenser C_3, and then suitable values of shunt fixed inductance N_3 can be found to equalize the maximum effective inductance across the condenser C_3. Similarly, trimmer inductances N_4 and s_4 may be employed in connection with the condenser C_4. Each of the fixed trimmer inductances in Fig. 5 has an arrow through it to designate that their values may be adjusted at the factory, but that after adjustment these values are not to be disturbed by the user of the receiver.

By properly adjusting these fixed trimmer inductances, the tuning of the various networks may be lined up so that each network accurately tunes over the same tuning range. If the inductances L_3 and L_4 are nearly alike, the adjustments of the fixed trimmer inductances are nearly independent. This can be demonstrated mathematically, and it is not necessary to complicate the present specification by such a mathematical demonstration. It is merely necessary to point out that the required values of the fixed trimmer inductances s_4 and N_4 are determined respectively by the minimum values and maximum values of the variable inductances L_3 and L_4 independently.

There are situations where the shunt fixed trimmer inductances N_3 and N_4 may be omitted, and the series fixed inductances may be employed in the cascaded networks. That is if the variable inductances L_3 and L_4 are closely alike, adjustment with the series trimmer inductances s_3 and s_4 will render the cascaded networks capable of tuning extremely closely alike throughout the whole frequency range. Using only the series fixed trimmer inductances a still closer approximation is obtainable by choosing the trimmer inductances $s_3 s_4$ and capacities $C_3 C_4$ to make the circuits "line up" exactly, not at the limits of the range, but at two frequencies somewhat inside the limits. For example, if the tuning range is between 500 and 1500 kilocycles, the cascaded networks can be made to tune exactly alike at say 700 and 1200 kilocycles. In this way no frequency in the entire range is very far from at least one frequency of perfect alignment.

The basic principle of the present invention, as shown in Fig. 3, may be utilized to provide a tuning means which can readily be changed from a condition which covers a wide range of frequencies to a condition which covers only a narrow band of frequencies with the same range of adjustment of the tuning mechanism. Further, to demonstrate the scope of the present invention, the tuning means referred to may consist of a variable condenser instead of a variable inductance, the inductance of the tuned circuit being fixed in this case. Figs. 6 and 7 show alternative embodiments of this specific application.

In both Figs. 6 and 7 the grounded antenna circuit A_2 is coupled to the input electrodes of an amplifier tube 20 by means of a radio frequency transformer M, the secondary coil L_6 of which is connected between the grid and cathode of the amplifier tube. The anode and cathode of the amplifier tube may be coupled to a succeeding amplifier stage of any well known type of receiver. Such a receiver may be of the tuned radio frequency amplifier type, a superheterodyne receiver, or even a super-regenerative receiver. The variable tuning condenser C_6 is connected across the fixed inductance coil L_6. However, a large fixed condenser K_1 is connected substantially in series with the variable condenser C_6, while a small fixed condenser K_2 is arranged for connection substantially in shunt with the variable tuning condenser C_6.

A switch device is employed for selectively connecting and disconnecting the fixed condensers K_1 and K_2. This switching device in Fig. 6 comprises a terminal *a* connected to one side of the tuning condenser C_6 and a second terminal *b* connected to one side of the fixed condenser K_2, and a movable switch arm 21 connected to the grid of tube 20. In Fig. 7 the switch arm 21 is connected to one side of the tuning condenser C_6, the terminal *a* is connected to the grid of tube 20, and the terminal *b* is connected to one side of the fixed condenser K_2.

In both Figs. 6 and 7, when the switch arm 21 is connected to terminal *a* the tuning condenser is directly connected across the inductance coil L_6, and the shunt condenser K_2 is disconnected. Therefore, the range of tuning will be as great as the ratio of the square root of the maximum capacity of the variable condenser to the square root of the minimum capacity of the variable condenser together with tube and coil capacities. With the usual type of variable condenser this range of frequencies would be about 3:1. With the switch arm 21 on terminal *b* the maximum capacity across the inductance coil L_6 is reduced by series condenser K_1, while the minimum capacity is increased by the condenser K_2. By properly choosing the values of K_1 and K_2 the range of variation of circuit capacity may be made as small as desired.

Fig. 8 graphically shows how the frequency of the resonant circuits of Figs. 6 and 7 vary with tuning condenser adjustment according as the switch arm 21 is in position *a* or position *b*. It is obvious that the curves of Fig. 8 must cross each

other, and this position of the crossing may be chosen at will by properly choosing the relative valves of K_1 and K_2. For example, if it is desired in the case of Fig. 6 to have the crossing point occur when the variable capacity has a value C_m, all that is necessary is to make

$$K_2=\frac{C_m^2}{K_1+C_m}$$

The arrangements shown in Figs. 6 and 7 are particularly adapted to amateur reception. The amateur frequency bands are located in harmonic relation with each other. That is to say, each band is at approximately twice the frequency of the preceding one. If now a separate coil is provided for each band, the range of tuning available with an ordinary condenser is at least 2:1 and, hence, is such as to make possible reception of all frequencies between the amateur bands, when desired, by setting the switch arm 21 on position *a*.

However, when receiving messages lying within the amateur bands, the switch is used on position *b*, the condensers K_1 and K_2 being chosen to have such values as will cause the frequencies in the amateur band to be spread out over a considerable portion of the dial adjustment and thus greatly facilitate tuning. When plug-in coils are used for the various bands it is well to choose the inductances so that for each coil the center of the desired band occurs at $C=C_m$=the same for each coil. This avoids the necessity to readjust K_1 or K_2 to center the band on the setting C_m.

While I have indicated and described several systems for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim is:

1. In combination with an oscillation circuit consisting of a fixed condenser and a variable tuning coil which is adapted to vary the resonant frequency *f* of the circuit over a range of frequencies, said above oscillation circuit having a maximum inductance L and a minimum inductance *l*, an auxiliary coil *s* in series with the variable coil, and a second auxiliary coil N in shunt with the variable coil, said shunt coil having a larger inductance than said series coil, said auxiliary coils being chosen to satisfy the relation

$$\left(1+\frac{L}{N}\right)=\left(1+s/l\right)^2$$

whereby the resonant frequency *f'* of the resultant circuit varies in such a way that

$$\frac{df'}{df}$$

is substantially constant between predetermined limits of variation of the variable coil.

2. A superheterodyne receiver for telephone signals, comprising a signal circuit including a fixed condenser and a variable inductance coil, a local oscillation circuit coupled to the signal circuit and including a fixed condenser and a variable inductance coil, said local oscillation circuit additionally including a pair of fixed coils connected respectively in series and shunt with its variable coil, the inductances of said variable coils of said two circuits being equal and said variable coils being equally adjusted by one control means, said fixed and variable coils having such relative values that an intermediate beat frequency of approximately constant value is produced as the signal circuit is tuned to an incoming signal by said control means, the ratio between the capacities of said condensers having a value other than unity.

3. In a heterodyne receiving system, a signal circuit including only a fixed condenser and a variable inductance, a local oscillation circuit coupled to the signal circuit and including a fixed condenser and a variable inductance coil, said local oscillation circuit including additionally a pair of auxiliary fixed inductance coils connected respectively in series and shunt with its variable coil, the inductances of said variable coils being equal and said variable coils being equally adjusted by a common means, said fixed and variable coils having such proportional values that a differential beat frequency of substantially constant value is produced as the signal circuit is tuned, the capacity in the oscillation circuit being different from the capacity in the signal circuit.

4. In a wave signalling system wherein a plurality of oscillatory circuits are simultaneously tunable over a certain frequency range by a unitary frequency control, each of said oscillatory circuits comprising a variable tuning inductance connected in shunt with a fixed condenser, adjusting means connected in each of said oscillatory circuits whereby the rate of change of resonant frequency of each of said circuits may be individually adjusted, said adjusting means in each oscillatory circuit consisting of a pair of auxiliary fixed coils connected respectively in series and shunt with the variable tuning inductance of each circuit.

5. A pair of oscillatory circuits including substantially similar inductive tuning elements, uni-control means for said elements and means for maintaining substantially a predetermined frequency difference between said circuits, said means including in one of said circuits a series connected inductance which is small compared to the maximum value of the tuning inductance and a shunt connected inductance which is large compared with the minimum value of the tuning inductance, said series and shunt inductances satisfying the relation

$$\left(1+\frac{L}{N}\right)=\left(1+s/l\right)^2$$

where L is the maximum value of the tuning inductance; *l* is the minimum value of the tuning inductance; N is the shunt inductance; *s* is the series inductance.

6. Radio communication apparatus comprising a pair of resonant circuits, a fixed capacity and a variable inductance in each of said resonant circuits, said variable inductances having similar characteristics, uni-control connecting means connecting said variable inductances for simultaneous movement, and a pair of additional inductances connected in one of said resonant circuits for insuring that the frequency characteristics of said resonant circuits differ by the same amount throughout the range over which said variable inductances may be adjusted, one of said additional inductances being connected in said resonant circuit in series with the variable inductance and the fixed capacity, and the other additional inductance being connected in said resonant circuit in parallel with said variable inductance and said fixed capacity.

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