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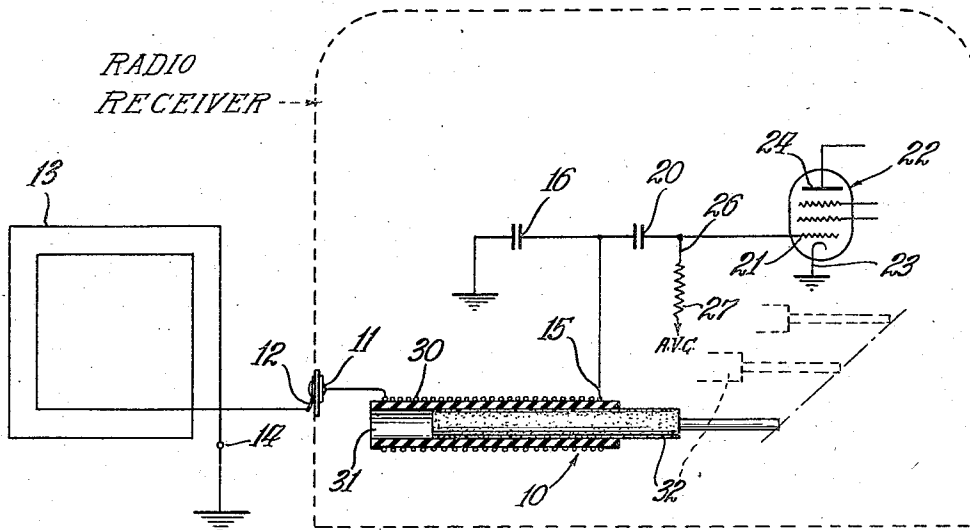
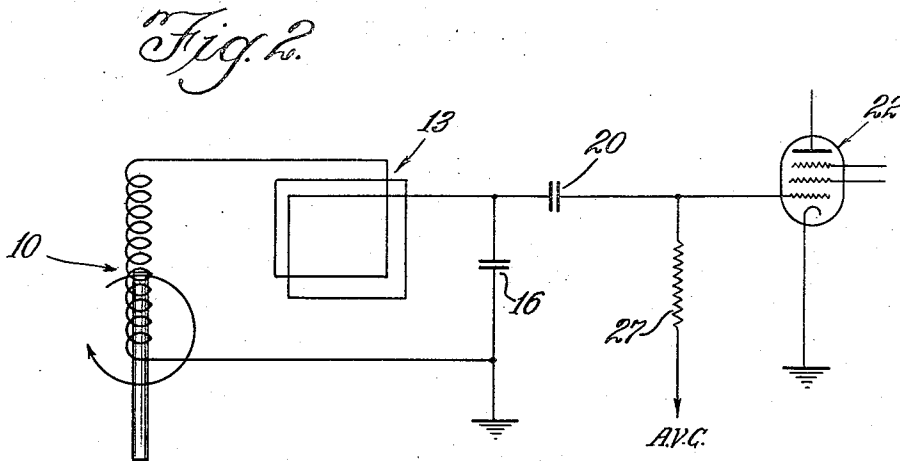


Fig. 1.



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LOOP ANTENNA SYSTEM

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2 Claims. (Cl. 250—40)

This invention relates to a signal collecting system for radio receivers and more particularly to a loop antenna system for use in a ferro-magnetically controlled tuning system.

The use in high frequency circuits of cores of finely divided ferro-magnetic particles moulded into suitable shape is well known. Because of the high efficiency of transformers and coils provided with such cores as well as the compact and small size thereof, such devices have come into great and wide-spread use. Thus Patents Nos. 1,940,228 and 2,051,012 both show such systems and the resonance control of circuits of this character is generally referred to as permeability tuning.

As is well known, it is highly desirable to provide antenna tuning in order to maintain a high level of antenna efficiency as well as provide a high signal to noise level ratio. Because of its desirable characteristics, a loop antenna is frequently used. The efficient utilization of a loop antenna with a permeability tuning means for such a loop is the problem toward which this invention is addressed.

A practical requirement for a loop antenna system is that it should have a more or less uniform output over the tunable range thereof. Precise uniformity may be expensive and difficult to achieve so that in practice some departure is tolerated. This requirement is present because of the high gain level at which modern receiver circuits are generally operated. Hence, in order to maintain this gain level, it is necessary that the loop antenna system feed in carrier signals at a substantially high level. By itself, a loop cannot do this unless elaborate and impractical accessories are provided. In combination with an antenna circuit tuning means, however, it is possible to obtain satisfactory loop performance.

The ordinary loop antenna has resistance, capacitance and inductance as substantial factors in its operation as part of a resonant circuit. If such a loop is tuned with a condenser, thus making capacitance a variable, then the inductance of the loop should be as large as possible, consistent with minimum capacitance of the entire circuit. Irrespective of design, all loops have a voltage drop characteristic with drop in tuned frequency. With condenser tuning, it has proven impossible to compensate in the antenna circuit for this loop characteristic and thus such systems inherently lose signal voltage with frequency drop.

Apart from a natural desire to extend the advantages of permeability tuning in a radio re-

ceiver to loop antenna circuits, it is apparent from the above considerations that there are real advantages in tuning by operating upon the antenna system inductance rather than capacitance. In inductance tuning, the inductance itself does not remain constant over the frequency range but rather varies inversely with the square of frequency. This is important for its effect upon the Q of the antenna system. With inductance tuning, it is possible to maintain a satisfactory Q value over the tunable range or even increase it at the low frequency end providing that other factors hereinafter given are properly considered. This, of course, reflects in a satisfactory signal output characteristic over the tunable range.

As a practical matter, if a ferro-magnetic core is to be utilized as part of an inductance tuning expedient in a loop antenna system, it will be necessary to concentrate the tuning function in an inductance coil and operate upon the loop itself indirectly because of its functional relationship as part of a resonant antenna circuit. Obviously, providing a loop antenna with inductance tuning means would be impractical both from a manufacturing angle and sales angle. Such a tuning means contemplates either a change in the effective loop turns or moving a ferro-magnetic core or both. By providing a separate inductance tuning coil in the antenna circuit, as hereinafter disclosed, highly desirable operation of the system over the entire tunable range is attained.

In general this invention provides a series connected loop antenna and tunable inductance coil whose free outer terminals are shunted by a capacitance of suitable value and constitute the output terminals. This capacitance may be variable within predetermined limits but is merely used for adjusting the tunable characteristics of the system, particularly at the high frequency end, and is not used for tuning purposes itself. In other words, the condenser once adjusted to a particular loop circuit will not ordinarily be operated upon again. The inductance coil is preferably provided with a ferro-magnetic core of finely divided ferro-magnetic particles suitably moulded in a manner well known in the art. The coil itself is preferably cylindrical and has a ratio of length to mean diameter of at least 4 to 1 and preferably somewhat greater as set forth in United States Patent No. 2,051,012. The resistance and Q characteristics of the coil are controlled in the manner set forth in the patent to have characteristics as hereinafter set forth.

It is preferred to have the free loop terminal at the ground or low potential side of the system although this is not essential. The other free terminal will naturally be the high potential side of the system.

An important consideration in the carrying out of my invention is the control of the radio frequency resistance characteristics of both the loop and coil. Thus for any broadcast range coverage, the inductance coil resistance over any frequency range should vary over a certain predetermined resistance range with reference to loop resistance as disclosed hereinafter. An important factor is the relative values of the inductances in the loop and inductance coil. The relationship between the two is of great importance and contributes to the efficient operation of the system as a whole because of the implicit functional relationship to the Q's of the system and components thereof. Preferably, the loop inductance itself and the total antenna circuit inductance should satisfy certain requirements.

The invention will be further described in connection with the drawing wherein:

Figure 1 shows a circuit diagram of a preferred form; and

Fig. 2 shows a modification.

Referring now to Fig. 1, an inductor 10 is shown having one terminal 11 connected to terminal 12 of a loop antenna 13. The free loop terminal 14 is here shown as grounded. The free inductor terminal 15 has a capacitance 16 between it and ground. Thus terminals 14 and 15 form the output terminals of the entire antenna system. The capacitance 16 forming part of the antenna system may either be a real condenser or may be the capacitance existing between the inductor and ground or may even be the capacitance between the load into which the system feeds and ground.

As shown here, the system may be connected to its load—a radio receiver, for example—by any suitable means such as, for example, a coupling condenser 20 disposed between terminal 15 and control grid 21 of a vacuum tube 22. Tube 22 may be a simple amplifier or a detector tube to combine radio frequency impulses with local oscillations in a superheterodyne circuit or may be a mixer tube wherein the functions of an oscillator and first detector are combined. The cathode 23 of vacuum tube 22 completes the load circuit back to ground either through a direct connection as shown or condenser. The output of tube 22 is fed into plate circuit 24 and thence is treated in the usual fashion well known in the radio art. If desired, an automatic volume control lead 26 may be connected through a suitable resistance 27 to the control grid of tube 22.

Inductor 10 consists of a coil of wire 30 wound on an insulating form 31 within which is movably disposed a core 32. Core 32 is moulded of finely divided iron or other ferro-magnetic particles in accordance with the teachings of Patent No. 1,982,689.

As set forth in said patent, the fineness of the ferro-magnetic particles and density of moulding depends upon the frequencies and range over which the inductor is to be used. Also the thickness of insulating form 31, the closeness of wire turns to each other, size of wire and manner of winding are all important factors in the design thereof. Since these various factors and their effects are now well known in the art, no further details in regard to obtaining the characteristics desired herein will be given, although

the desired characteristics themselves will be pointed out. Core 32 may be moved in and out of inductive relationship with winding 30 by suitable means such as a ganged control of a plurality of tunable elements in cascaded circuits of a radio receiver.

Loop antenna 13 may be either of the shielded or unshielded type and within the limits of desired characteristics may have any desired construction. Loop 13 is made of wire having such size and character and the construction is such that the ohmic resistance of the loop rises with frequency over the tunable range. This rising characteristic with frequency increase or conversely a dropping characteristic with frequency drop should be as great as possible. This makes it easier to design a suitable inductor. At the present time, it is possible to design a loop for broadcast reception whose resistance over the range of about 1600 kilocycles, hereinafter abbreviated to kc., to 500 kc. will vary as much as 5 to 1. A smaller ratio may be used if desired. The manner in which such a characteristic may be obtained is well known in the art and is disclosed for example in Bureau of Standards Circular No. 74, entitled Radio Instruments and Measurements.

Loop 13 has fewer turns of wire than would be the case with the same loop for condenser tuning. The number of turns of a loop are a function of the loop area, the tunable range, proximity to ground, nature of load into which the antenna system feeds, and the nature and details of the tuning means for the antenna circuit. With everything else the same, however, the loop turns in the system disclosed herein will be substantially less than those for a condenser tuned system. The actual number of loop turns may vary within wide limits but as the inductor characteristics must be functionally dependent upon loop characteristics, it is evident that the loop limits will be determined in large measure by limitations in inductor design.

The reduction in the number of loop turns of a loop antenna as described above markedly raises the operating efficiency of the loop. Inductance of a loop varies as the square of the number of turns so that a reduction in the number of turns causes a disproportionate drop in the self-inductance of the loop. The operation of such a loop by itself promotes a higher signal to noise ratio, particularly in view of the resistance characteristics of a permeability tuned system.

As pointed out originally, all loop antennae lose in efficiency as signal collectors with a drop in signal frequency. In order to compensate for this and to provide an antenna system which operates satisfactorily as a whole over the tunable range, it is necessary to design the inductor with relation to the resistance, inductance and capacitance characteristics of the loop in such a manner that the characteristics hereinafter described are obtained.

The inductor, as a discrete electrical element in a high frequency circuit, exhibits certain phenomena with frequency changes. Thus the radio frequency resistance of the wire decreases with frequency because of a reduction in skin effect as well as other reasons, assuming the core is out. In other words, the inductor coil behaves like a loop in that respect. However, as the core is inserted into the inductor coil to increase the inductance, the coil exhibits an increased resistance to high frequencies. By controlling the

inductor structural details, it is possible to control the rising resistance characteristics as the core moves into the coil.

The Q -or efficiency of the inductor alone may be varied as desired. Since both inductance and resistance are Q determinants, with frequency variations as a third factor, it is possible to have a ferro-magnetic inductor whose Q by itself may rise, fall or be substantially constant over the frequency range.

I have determined that in order to attain desirable operation of a loop antenna and variable inductor it is necessary to control the high frequency resistance characteristics of the entire system and also control the resistance characteristics of the inductor alone with variation in tuned frequency. For best operation it is desirable to maintain the total high frequency resistance of the system substantially constant over the tunable range although a variation of as much as 25% may be tolerated. Since the loop preferably has a dropping resistance characteristic with drop in frequency, this means that the resistance of the remainder of the system must have a rising characteristic with frequency drop. The simplest solution is to endow the inductor with such a rising characteristic and this is accordingly done in a manner well known in the art. It is preferred to have the rise as gentle as possible. The actual resistance characteristics of the inductor as a whole are closely bound up with the inductance variation of the inductor and this, of course, is directly controlled by the effective permeability of the core in the coil. I have determined that the ratio of maximum to minimum coil resistances should be less than the effective permeability of the core and, in fact, this ratio of resistances approaches the effective core permeability as a practical limit.

The same considerations apply to the Q of the component parts of the system and the total Q . In practice it may be difficult to raise the Q as the frequency drops. In other words, if the Q of the inductor at the high frequency end of the range is quite high, it may be rather difficult to obtain a sufficiently fast rising Q characteristic in the inductor alone with frequency drop to raise the system Q at the low frequency end of the range with conventional loop construction. This is principally due to an excessive resistance rise. As a rule, the costs of such an inductor may be high and commercial requirements both of cost and characteristics are satisfied when the inductor permits a moderate rise such as about 50 or 100% in the Q of the system as the frequency drops. This is particularly true of the broadcast range with its comparatively extensive coverage.

Thus it follows that the ratio of maximum coil resistance (when the core is all the way in) to minimum coil resistance should be as low as possible for conventional loop design. Where the loop resistance goes through a very large range of values; i. e., where the arithmetical difference in the maximum and minimum resistances are large, then as will be apparent from equations given later, the resistance ratio of the coil may be greater. It is also understood that the resistance values in ohms of the loop and coil at the high frequency end are of the same order, although one may be two or three times the other. In practice, the minimum coil resistance is generally larger than the maximum loop resistance. Hence, a resistance variation of one or the other

will have a substantial effect on the total resistance of the system.

The relative proportions of inductance in the loop and inductor as well as total inductance are also important. In general, for all kinds of tuning a good signal to noise ratio is obtained if the total inductance of the entire antenna system is kept relatively low. Hence, while this invention has as an important factor the relative disposition of inductance in both the inductor and loop, in so far as this reactance element may be separately treated, and not with the total inductive reactance in the entire antenna circuit, nevertheless from a practical operating angle, it has been found that the total inductive reactance does have an effect on the relative intensities of signal and noise impulses transmitted to the system output terminals. For this reason the total maximum inductance of the system must be considered.

The relative values of loop and minimum coil inductances may vary with the loop value either being larger or smaller. The permeability of the core, determining the tunable range, will generally determine this relationship. Where the core construction is such that the inductance range of the inductor is large, then it is possible to have the minimum coil inductance less than that of the loop. Naturally, the maximum inductor inductance will be greater than that of the loop for ordinary broadcast purposes.

In short wave reception however, it may be necessary to maintain the inductance of the coil below that of the loop over the tuning range, assuming that the same loop is used as for ordinary reception (550 kc. to 1600 kc.) and different inductor coils are switched in. Of course, if loop switching is utilized as part of the frequency range changeover, then the relative distribution of inductance may remain substantially as first indicated. But for ordinary broadcast frequencies of 550 kc. to about 1600 kc. the ratio of loop inductance to coil inductance may be about 2.75 or less with present types of loops. The variation in this ratio is a function of the ratio of maximum to minimum coil inductances. This latter ratio of course is directly controlled by the permeability of the core when inserted into the coil.

It is understood that the extent of the frequency range may be varied within limits. This however is well known and understood in the art. Obviously, the relationships set forth above may be reversed to some extent. However, as a rule an antenna system is designed for a desired frequency range with the loop antenna size predetermined. The inductance and resistance variation of the loop may be controlled by the number and spacing of turns and size of wire used. Then the remaining portions of the circuit must be adapted to the loop so as to form a uniformly efficient operating system.

The modified system shown in Fig. 2 differs from Fig. 1 in that the position of the loop and coil with respect to ground are reversed. The general design factors remain the same. Some differences may result however because of the presence of new circuit elements created by the electrostatic elevation of the loop with respect to ground. The mere fact that the loop is at different potential with respect to ground and the fact that both terminals are connected through reactances to ground will result in a variation of its electrostatic elevation with frequency. This type of connection has some advantages due to its apparent rise in elevation but

has some disadvantages also, particularly as regards noise and losses if disposed in proximity to metal, as a radio chassis.

The design of a loop and an inductor of the type contemplated herein as individual articles so that certain desired individual characteristics are obtained is a procedure guided by theoretical and empirical considerations, all well known in the art. The correlation of these characteristics may be more generally applied in view of the following mathematical analysis.

Thus

$$\frac{F_H^2}{F_L^2} = \frac{L_1 + L_{2ma}}{L_1 + L_{2mi}} \quad (1)$$

where F_H and F_L are respectively the highest and lowest frequencies of the range considered, L_1 is the loop inductance and L_2 is the coil inductance. The subscript *ma* and *mi* merely refer to maximum and minimum values at the low and high frequency ends of the range.

If a ferro-magnetic core of effective permeability p is inserted into the coil, then

$$pL_{2mi} = L_{2ma} \quad (2)$$

Let

$$N = \frac{F_H}{F_L} \quad (3)$$

then

$$N^2 = \frac{L_1 + pL_{2mi}}{L_1 + L_{2mi}} \quad (4)$$

Let

$$T = \frac{L_1}{L_{2mi}} \quad (5)$$

then

$$T = \frac{p - N^2}{N^2 - 1} \quad (6)$$

The above equations give the upper limit of L_1 and also shows the relationship between L_1 and L_2 .

If the output of the antenna system is to remain substantially constant over the frequency range (this is measured in grid microvolts at the first tube divided by field strength at the loop measured in microvolts per meter) then the Q of the entire system must vary inversely as the frequency varies—the induced loop voltage drops off directly with frequency.

Therefore

$$\frac{Q_H}{Q_L} = \frac{F_L}{F_H} = \frac{1}{N} \quad (7)$$

Q_H and Q_L are the overall Q 's of the system at high and low frequencies respectively.

$$Q_H = \frac{(L_{1H} + L_{2H})\omega_H}{R_{1H} + R_{2H}} \quad (8)$$

and

$$Q_L = \frac{(L_{1L} + L_{2L})\omega_L}{R_{1L} + R_{2L}} \quad (9)$$

where the subscripts H and L refer to high and low frequency conditions and R_1 and R_2 are loop and coil resistances respectively. Since the loop inductance L_1 is constant, L_{1H} and L_{1L} are equal. The omega refers to the product of $2\pi F$.

Making the substitutions from Equations 2 and 5 and bearing in mind that L_{2mi} is equal to L_{2H} then

$$\frac{Q_H}{Q_L} = \frac{(L_{1H} + L_{2H})(R_{1L} + R_{2L})}{(R_{1H} + R_{2H})(L_{1L} + L_{2L})} \quad (10)$$

By means of Equations 3, 5 and 6, the above Equation 10 may be reduced to

$$\frac{Q_H}{Q_L} = \frac{R_{1L} + R_{2L}}{N(R_{1H} + R_{2H})} \quad (11)$$

From Equation 7, it follows that

$$R_{1L} + R_{2L} = R_{1H} + R_{2H} \quad (12)$$

In other words, the sum of the loop and coil resistances over the frequency range should remain constant. Because a ferro-magnetic coil increases its resistance as the core goes in, it follows that the loop or rest of the circuit must decrease its resistance with frequency drop, occurring when the core goes into the coil. In practice the total resistances may vary as much as 25% and even more over the range of tuning.

At the low frequency end of the range, the loop resistance will be a minimum and the coil resistance will be a maximum. In actual value, the minimum loop resistance will always be less than the maximum coil resistance. The resistance values of the loop and coil at the high frequency end of the range will generally be of the same order.

Assuming the maximum loop resistance and minimum coil resistance to be approximately of the same order and assuming a five to one ratio of maximum to minimum loop resistances, then the maximum coil resistance will come out to be about two times the minimum coil resistance. This value is easily attained in present day practice for a frequency range of about three to one and a satisfactory Q value at the high frequency end. The effective permeability of the inductor core will always be greater than the square of the ratio of frequencies over which the inductor can operate. Hence it follows that the limit of the resistance ratios of the coil is of the same order as the square of the ratio of frequencies. Usually the resistance ratio

$$\frac{R_{2L}}{R_{2H}}$$

is less than

$$\frac{F_H^2}{F_L^2}$$

in practice, a good resistance ratio may be roughly inversely proportional to the frequency ratio.

As an actual example of a system designed to cover a range of 1500 kc. to 540 kc. we may make the following calculations.

From Equation 3, $N=2.75$.

A core having a permeability of 10.5 would give T a value of 414. A coil having a minimum inductance of 50 microhenries may be used. Then the loop inductance will be 20.6 microhenries (Equation 5).

The loop to which this calculation is applied has a Q of 50 at the high frequency end of the range.

The loop resistance R_{1H} comes out to 3.9 ohms from the formula

$$R = \frac{2\pi F_H L_{1H}}{Q_H}$$

The inductance coil Q_{2L} in this case was 80 so that the resistance R_{2H} comes out to 5.92 ohms.

The total circuit resistance is 9.82 ohms and inductance is 70.6 microhenries. The entire circuit Q_H comes out to 68. For constant gain, this Q_H must be multiplied by the frequency range 2.78 and gives a circuit Q_L of 189. To determine the Q_{2L} ; the coil inductance at low frequency, we must know what the Q_{1L} and R_{1L} values are. In this instance, the loop was designed so that Q_{1L} was 90. R_{1L} comes to be .78 ohm.

Since the total resistance of the system is 9.82 ohms, it follows that R_{2L} should be 9.04 ohms. The Q_{2L} , the Q for the coil at the low frequency end of the range, works out to be 197. Actually,

it may be difficult to maintain all the factors as required for constant gain so that in commercial production some variation is to be expected.

This application is a continuation-in-part of my application Serial No. 319,671 filed February 19, 1940.

What is claimed is:

1. An antenna system comprising a grounded loop antenna and an inductance coil in series therewith, a capacitance across the free terminals thereof with the free terminals forming the output of the system, a ferro-magnetic core movable in said coil for tuning said system over a range of frequencies, said loop having substantially less turns than a similar loop having condenser tuning, said loop having a dropping high frequency resistance characteristic with drop in tuned frequency, said coil having a rising high frequency resistance characteristic with drop in tuned frequency, the maximum loop resistance and minimum coil resistance being of substantially the same order.

2. An antenna system comprising a loop antenna and an inductance coil in series and together having a pair of free terminals, a capacitance across the free terminals thereof with the free terminals forming the output of the system, a ferro-magnetic core movable in said coil for tuning said system over a range of frequencies, said loop having substantially less turns than a similar loop having condenser tuning, said loop having a dropping high frequency resistance characteristic with drop in tuned frequency, said coil having a rising high frequency resistance characteristic sufficient to compensate for the loop dropping characteristic to maintain the total high frequency resistance characteristic of the entire system at a substantially constant value throughout the tunable frequency range thereof, the maximum loop resistance and minimum coil resistance being of substantially the same order.

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