June 15, 1943. W. H. GRIMDITCH 2,322,126

LOOP ANTENNA SYSTEM

Filed April 23, 1941 2 Sheets-Sheet 1

Fig. 4.

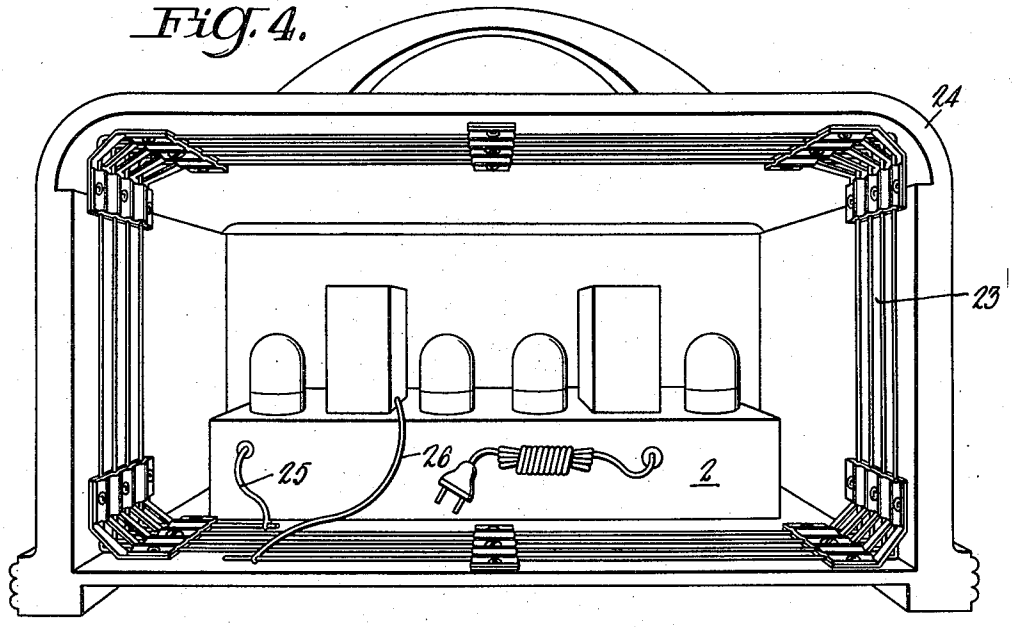


Fig. 1.

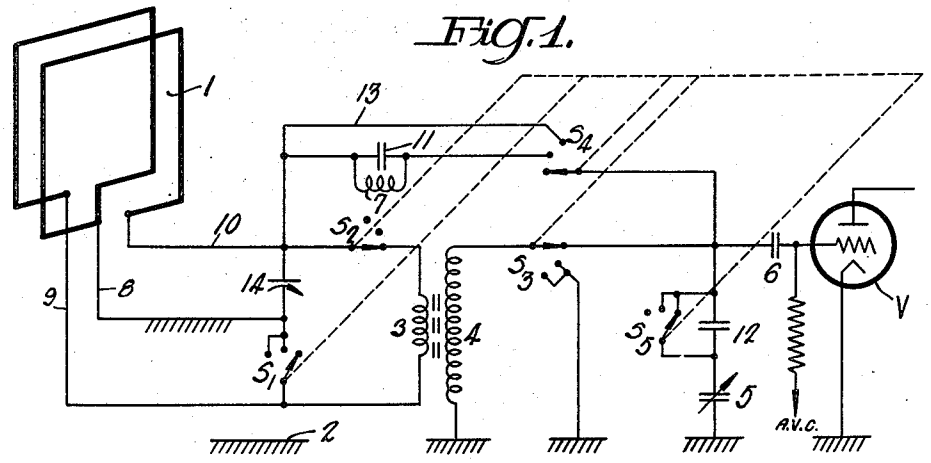
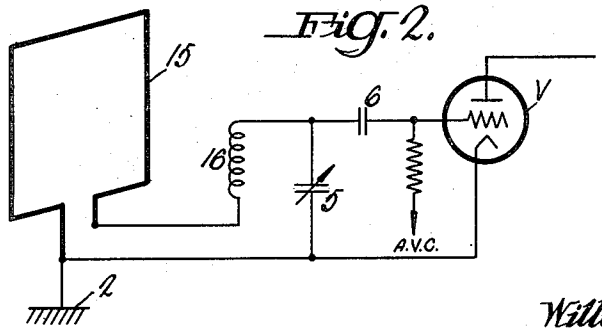


Fig. 2.



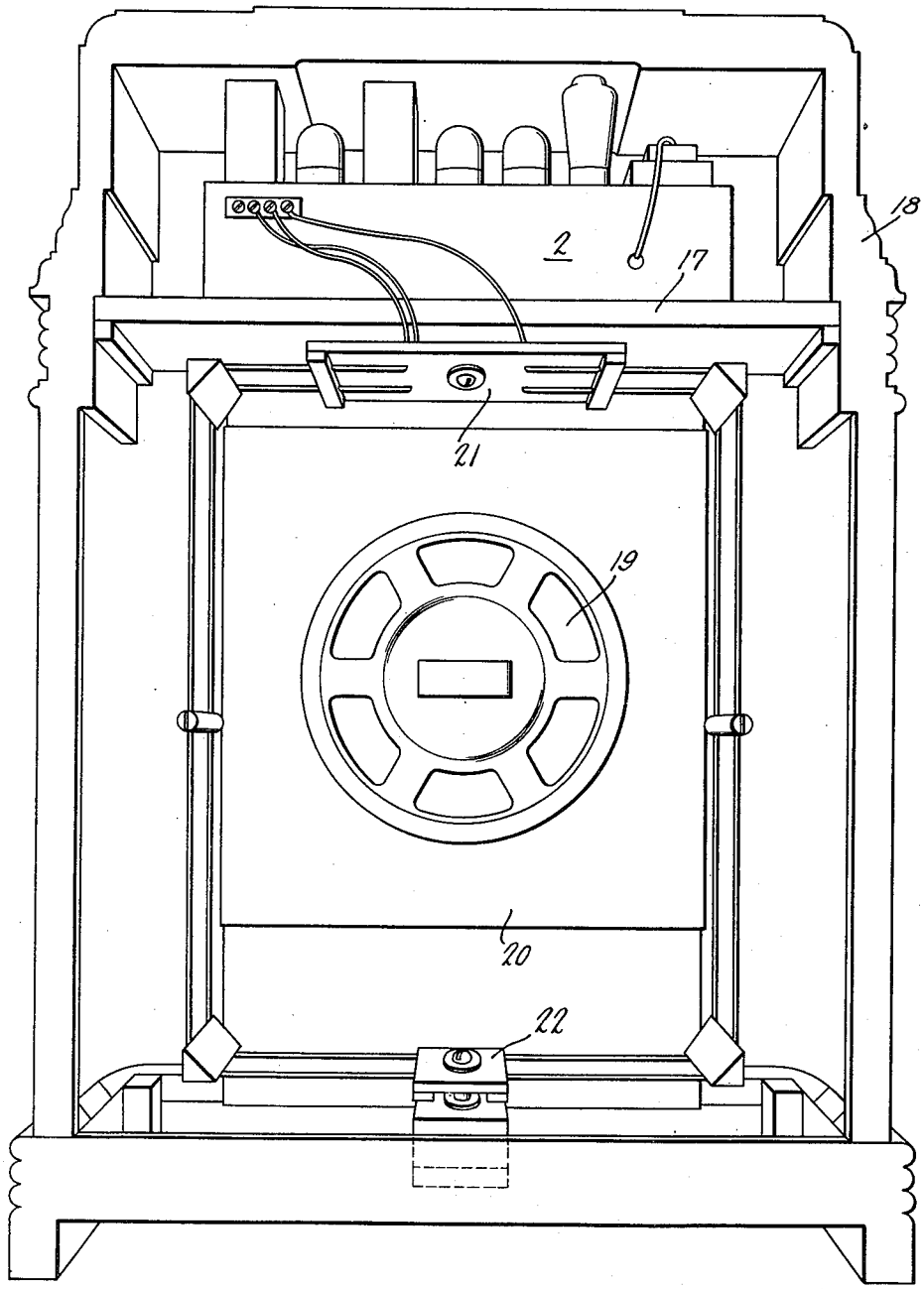
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Filed April 23, 1941 2 Sheets-Sheet 2

Fig. 3.



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Patented June 15, 1943

2,322,126

UNITED STATES PATENT OFFICE

2,322,126

LOOP ANTENNA SYSTEM

William H. Grimditch, Rydal, Pa., assignor to Philco Radio and Television Corporation, Philadelphia, Pa., a corporation of Delaware

Application April 23, 1941, Serial No. 389,987

8 Claims. (Cl. 250—40)

This invention relates to improvements in loop antenna circuits for radio receivers, and more particularly to a balanced low-impedance loop antenna circuit having substantial advantages both from electrical and mechanical points of view.

The invention contemplates the provision of a loop antenna of large cross sectional area, of few turns, wound with wire of relatively large diameter, and having a low impedance between its terminals. In the preferred embodiment of the invention the loop circuit is balanced with respect to the receiver's chassis, and no external ground connection is used. As will be shown later, in such a circuit the ratio of the desired magnetic to the undesired electrostatic (noise) pickup is substantially greater than in the high-impedance type of loop antenna heretofore employed in radio receivers adapted to receive signals in the broadcast and high frequency bands.

One object of the invention is to provide a novel loop antenna structure and circuit having advantageous characteristics for use in radio receivers adapted to receive signals in either the broadcast or short wave bands or both.

A further object of the invention is to provide a loop antenna circuit embodying a loop antenna of low inductance, but of substantial area, whereby the loop is enabled to respond satisfactorily to the magnetic component of the desired signal wave, while being substantially less responsive to nearby noise sources whose effect on the loop is largely of an electrostatic nature.

Another object of the invention is to provide a multiple-wave-band radio receiver operating from a common loop antenna having the advantages hereinbefore enumerated.

Other features and objects of the invention will appear from the following detailed description and the accompanying drawings, in which

Fig. 1 is a circuit diagram of a portion of a multi-band radio receiver embodying the invention;

Fig. 2 is a circuit diagram of a modification;

Fig. 3 is a perspective view of the low impedance loop antenna in cooperative relation with a radio receiver housed in a cabinet of the console type; and

Fig. 4 is a perspective view of the low impedance loop antenna as adapted for use with smaller table model radio receivers.

Reference is now made to Fig. 1 in which there is shown a schematic circuit diagram of one embodiment of the loop antenna circuit in combination with a vacuum tube V, which may be the radio frequency amplifier or first detector of a conventional superheterodyne radio receiver, or the first radio frequency amplifier of a conventional tuned radio frequency receiver. As will be described in more detail hereinafter, the loop antenna 1 may comprise one or more turns of a wire of relatively large diameter. The area, and therefore the perimeter, of the loop itself should also be relatively large, preferably as large as the dimensions of the cabinet will permit. When the loop is to be adapted for limited rotational adjustment, as in Fig. 3, it will be necessary of course to make the dimensions of the loop somewhat smaller than the inside dimensions of the cabinet. Where it is desired to rotate the loop a full 180 degrees its width should be made smaller still. On the other hand, where the loop is to be fixed with respect to the cabinet, as in Fig. 4, the loop dimensions may be substantially the same as the inside dimensions of the cabinet. In general, therefore, the loop is preferably made as large as the design of the cabinet permits.

In order to make the receiver fully self-contained, it is preferred to eliminate the usual ground connection and to connect the "ground" terminal of the loop circuit only to the metal chassis 2 of the radio receiver. Preferably, in order to minimize the electrostatic pickup of the loop, the loop circuit is balanced electrically with respect to the chassis. This may be done by locating the loop antenna symmetrically with respect to the chassis and by connecting the electrical center of the primary loop circuit to the chassis. The latter may be accomplished by connecting the center tap of either the loop 1 or the coil 3 to the chassis 2. In Fig. 1 the former connection was chosen.

With the 3-position ganged switches S_1 and S_5 in the position shown, the circuit is adapted for reception in the broadcast or other relatively low frequency band. Coupling between the loop and the input circuit of the tube V may be by means of a transformer having a low impedance primary winding 3 and a high impedance secondary winding 4. The windings 3 and 4 are preferably so tightly coupled that the leakage inductance of the primary is small compared to the inductance of the loop winding itself. The loop winding 1 should be designed to have as high a Q (ratio of reactance to resistance) as possible, but since there are practical limitations to the maximum Q of the loop it is desirable to design the transformer 3, 4 with as high a Q as possible, and in any event a Q which is

higher than the Q of the loop winding 1. If desired, an iron core may be provide to improve the coupling between the coils. The tuning condenser 5 is connected preferably across the secondary winding 4, rather than across the loop winding 1. The tuned secondary circuit may be coupled to the input of the vacuum tube V by means of a small coupling condenser 6.

With the 3-position switches S_1 to S_5 in their second or intermediate position, the circuit is adapted for tuning over an intermediate band of frequencies, for example from 2.3 to 7.0 megacycles. If the loop 1 comprises two turns, both of which are employed for reception in the broadcast band, it may be found that a single turn, plus a small auxiliary external inductance coil 7, will have sufficient inductance to cover the desired intermediate wave band when tuned directly by the tuning condenser 5. This connection may be effected by the switch S_1 which short circuits that turn of the loop which is common to the lead wires 8 and 9, by the switch S_2 which disconnects the operative turn of the loop from the primary winding 3, and by the switch S_4 which connects the operative turn of the loop, via the lead 10 and the inductance coil 7, to the tuning condenser 5 and the grid of the vacuum tube V. Preferably the unused secondary winding 4 is disconnected from the tuning condenser 5 and shorted to the chassis by the switch S_3. If the operative portion of the loop antenna tends to pick up image, or other undesired signals outside of the desired waveband, the coil 7 may be shunted by a condenser 11 of predetermined capacity such that the combination is parallel resonant in the vicinity of the undesired frequencies, thus enabling the auxiliary inductance 7 to function simultaneously as a wave trap.

With the switches in their third position, the circuit is adapted for tuning over a high frequency range of signals. In the specific embodiment shown, the circuit is arranged to provide "band-spread" tuning over this band by the addition of a small condenser 12 whose function is to "dilute" the effect of the tuning condenser 5 and thereby to limit the frequency range over which the loop circuit can be tuned by the said tuning condenser. For example, the frequency range covered by one model so connected extended from about 9 to 12 megacycles. The high frequency band connections are here effected by the switch S_1 which again short circuits that turn of the loop 1 which is common to the lead wires 8 and 9, by the switches S_2 and S_3 which remove the transformer 3, 4 from circuit, by the switch S_4 which connects the operative turn of the loop directly to the input of the tube V by way of the lead wire 13 and coupling condenser 6, and by the switch S_5 which inserts the condenser 12 in series with the variable tuning condenser 5. A small trimmer condenser 14 may be provided to aid in aligning the circuits when used in the high frequency band.

As previously indicated, the present invention relates in part to the use of a low impedance loop antenna in place of the high impedance loops which were commonly used in self-contained radio receivers prior to this invention. A high impedance loop antenna may be defined as one whose inductance is sufficiently high to permit the loop to be tuned over the desired range by the connection, across its terminals, of a conventional tuning condenser, without the provision of substantial additional series inductance. The usual directly-tuned loops having inductances of the order of 150 microhenries are correctly regarded as high impedance loops and consequently lie outside the range of the present invention. Similarly loop antennas of a type described in my copending application, Serial #279,745, filed June 17, 1939, now U. S. Patent No. 2,249,129, granted July 15, 1941, and having, for example, an inductance of 110 micorhenries supplemented by a lumped inductance of 40 microhenries are regarded as high impedance loops.

A low impedance loop antenna, on the other hand, may be defined as one whose impedance is so low that it must be tuned through the medium of a transformer having a high step-up ratio, or, alternatively, tuned by the series addition of an auxiliary inductance coil or coils whose inductance is large compared to the inductance of the loop itself.

An embodiment of the latter form of the invention is illustrated in Fig. 2 wherein the loop 15 preferably consists of from two to six turns of wire of large diameter, while the additional inductance necessary to enable the loop to be tuned over the desired band is provided by the series lumped inductance 16. In this embodiment, the inductance of the loop 15 may be of the order of 14 microhenries, while the coil 16 may have an inductance of approximately 135 microhenries. The circuit shown in Fig. 2 may be regarded as comprising the usual input tank coil 16, characterized in that one turn of the said coil is greatly enlarged to permit it to function as a loop antenna of low inductance but of large area. This circuit may be regarded as an extension of that shown in the above-mentioned patent, and as in the circuit of that patent it is preferred to design the coil 16 to have as favorable a ratio of reactance to resistance (Q) as possible, the Q of the coil 16 preferably being greater than the Q of the loop 15.

The loop antenna of the present invention may take any suitable mechanical form, such as those illustrated in Figs. 3 and 4, provided that the principles of the invention are followed. No claim is made herein to the specific mechanical construction of the loop per se, as illustrated in Figs. 3 and 4, which forms the subject of a copending application of Palmer M. Craig, Serial No. 389,991 filed April 23, 1941.

In Fig. 3 there is illustrated a physical embodiment of the loop antenna circuit of Fig. 1 in a console radio receiver of known form in which the chassis 2 is mounted on a shelf 17 in the upper portion of the cabinet 18, and the usual loudspeaker 19 is mounted on a baffle board 20. The loop is disposed below the chassis within the cabinet in symmetrical relation thereto and is rotatably mounted on rotary supports 21 and 22. The loop is as large in area as the cabinet and loop rotation will permit.

In a physical emobdiment of the invention shown schematically in Fig. 1 and in perspective in Fig. 3 the following dimensions and values were found satisfactory. The loop antenna 1 consisted of two turns of copper-weld wire approximately 0.10 inch in diameter, and having a copper coating of about 0.003 inch. The steel core of the wire does not effect the electrical characteristics of the loop in any substantial degree, but adds to the mechanical rigidity of the structure, making it substantially self-supporting. The loop measured 16 inches in width and 23 inches in height, with a spacing between turns of 2 inches. The inductance of one such a loop was about 6.2 microhenries. The coils 3 and 4 were of approximately 10 and 100 turns respec-

tively and had inductances of about 3.3 and 225 microhenries respectively. The coils were tightly coupled (about 82%) so that the primary leakage inductance was only 1 microhenry, this being small in comparison to the inductance of the loop, as is desired. The inductance of the single turn loop employed for reception in the intermediate and high frequency bands was somewhat less than half the inductance of the full two turns, and the inductance of the series coil 7 was about 7 microhenries.

Reference is now made to Fig. 4 in which there is illustrated a low impedance loop 23 of four turns mounted in a table model cabinet 24 to the rear of the radio chassis 2. A loop antenna of this type may measure approximately 6 by 11½ inches, may have a spacing between turns of about half an inch, and may have an inductance of the order of 6 microhenries. The loop circuit may be balanced as shown in Fig. 1 if desired. The loop illustrated in Fig. 4, however, is not balanced, one terminal of the loop being connected to the chassis 2 by way of the lead wire 25, while the other terminal may be connected to a suitable tuning system by way of the lead wire 26. The input circuit for this loop may include either a step-up transformer as illustrated in Fig. 1, or a series inductance as illustrated in Fig. 2, the former being preferred however.

Where a single turn loop is employed the inductance is, of course, equal to the self inductance of the turn. However where a multi-turn loop is used the inductance is equal to the sum of the self inductances of the turns, plus the mutual inductances between the several turns, and hence the inductance of the loop tends to increase more rapidly than the turns. Where the turns are closely spaced the inductance increases directly with the square of the number of turns. Consequently where a multi-turn loop is contemplated for use in the present invention it is preferred to reduce the mutual inductance between the turns by spacing the turns as widely as is practical. Thus in the embodiment of Fig. 3 a spacing of two inches has been found satisfactory, while in the embodiment of Fig. 4 a spacing of about half an inch is satisfactory. The specific spacing chosen, and its effect upon the total inductance, will depend to some extent upon the diameter of the conductor employed in the loop. In general it is preferred that the inductance of the loop be kept as low as possible by employing a large conductor size and by designing the loop in such a way that the ratio of pitch (distance between centers of adjacent conductors) to wire diameter is at least 4.

In the specific embodiment already described with reference to Fig. 3 this ratio of pitch to wire diameter was 20. A good practical rule to follow is to design the loop with a pitch/diameter ratio of from 6 to 30, although in table model receivers having only a limited space for the loop winding it may be necessary to employ a ratio of the order of 4. The number of turns chosen in any specific instance may depend at least in part upon the included area of the loop, a small loop preferably having a larger number of turns than a large loop. The choice of the number of turns may conveniently be such that the inductance of the loop is of the order of from 3 to 16 microhenries, although inductances as high at 20 microhenries show substantial improvement over high impedance devices utilized heretofore.

The superiority of a low impedance loop as compared to a high impedance loop from the standpoint of freedom from electrostatic noise signal pickup may be appreciated from the following. If it were possible to balance a loop antenna perfectly there would be no electrostatic pickup. However such perfect balance is not obtainable in practice and hence merely balancing a loop to ground, which is old in the art, is not enough to avoid the electrostatic pickup of noise from nearby spark discharges and the like. Accordingly some unbalance must always be reckoned with. In the general case where the loop is not balanced, or only partly balanced, the desired magnetic pickup will be approximately proportional to the number of turns in the loop, whereas the impedance of the loop will be approximately proportional to the square of the number of turns (or at least to a power greater than 1 and approaching 2). On the other hand the electrostatic pickup of the loop will be proportional to the impedance of the loop. Consequently the ratio of the electrostatic to electromagnetic pickup of a loop is approximately proportional to the square root of the impedance (or inductors), i. e. approximately proportional to the number of turns. Thus a low impedance loop antenna having an inductance of say 6 microhenries will have $\frac{1}{25}$ the impedance of a conventional high impedance loop of 150 microhenries, and will accordingly pick up only ⅕ of the noise picked up by the high impedance loop.

In practice it has been found that the superiority of the low impedance loop antenna circuit of the invention over the conventional high impedance antenna, even when the latter is electrostatically shielded and the former is not, may be even greater at some frequencies than is indicated by the figures given above. The following figures obtained in comparative noise measurements are illustrative of the superiority of the novel low impedance balanced loop antenna circuit as compared with the conventional shielded hight impedance loop antenna. Readings were made as a convenient point in the receiver at three frequencies in the broadcast band with the aid of a peak voltmeter.

Frequency	High imp. loop peak noise	Low imp. loop peak noise	Superiority
1500	45	13	3½ to 1
1000	45	10	4½ to 1
540	55	3.5	16 to 1

The above figures and comparisons are based on voltage readings, while most loudspeaker measurements are based on watts. If these peak voltage measurements are equated in terms of peak watts it is found that receivers employing the novel low impedance loop antenna are, on a wattage basis, from 12 to 236 times more free from impulse noise than are receivers employing conventional shielded high impedance loops.

In order to keep the impedance of all exposed antenna elements to a minimum, and thereby to reduce the pickup of noise, it is preferred to construct the loop itself in such a manner that its ends are disposed near the receiver chassis, so that short low impedance leads may be employed to connect the loop to the receiver.

In order to keep the inductance of the loop low, it is preferred to use as few turns as possible, and in practice two to four turns have been found especially satisfactory. However since the output voltage of a given loop is proportional to

the number of turns, it is desirable to compensate for the loss of turns by increasing the area of the loop as much as possible, the output voltage being also proportional to the area of the loop. On the other hand an increase in loop area tends to increase loop inductance, but this effect can be as least partially countered by increasing the diameter of the wire used in the loop. An increase in wire diameter results, of course, in a decrease in inductance. Wire diameters of the order of one-tenth of an inch, or larger, have been found satisfactory for this purpose.

The use of large wire sizes, and particularly of a wire having a steel core, has the added advantage that a loop so constructed becomes substantially self supporting, and may require only a few wooden spacing members as shown in Fig. 3 to make the loop mechanically stable and rigid. Alternatively the turns of the loop may be held in alignment by suitably formed and riveted sheets of fiber board as shown in Fig. 4. The use of a conductor having a steel core with a thin copper coating is advantageous further in that the cost of such wire is substantially less than that for a solid copper conductor. In place of solid conductors it is also contemplated to employ tubular conductors of large diameter, as well as conductors of square or rectangular cross section.

While the electrical and mechanical features of the invention have been described with respect to certain specific embodiments it should be understood that this has been for the purpose of disclosure, and should not be taken as a limitation of the invention to these specific constructions.

I claim:

1. In a low impedance loop antenna circuit, a loop winding of relatively large included area, said winding being constructed of a relatively large conductor and having a small number of turns, said loop winding having a low impedance to frequencies in at least one of the wave-bands to be received, a low impedance connection between said loop winding and a point of substantially fixed potential, inductive means having a greater impedance than said loop coupled to said loop winding for supplementing the inductance of said loop, said inductive means also having a higher Q (ratio of reactance to resistance) than said loop winding, adjustable means connected to said inductive means for tuning said loop circuit over a desired band of frequencies, and means for coupling said loop circuit to the input element of a radio receiver.

2. In a low impedance loop antenna circuit, a loop winding of relatively large included area, said winding consisting of from 2 to 6 turns of a relatively large conductor, and having a ratio of winding pitch to wire diameter of from 4 to 30, said loop winding having a low impedance to frequencies in the range 540 to 1600 kilocycles, a low impedance connection between said loop winding and a point of substantially fixed potential, inductive means having a greater impedance than said loop coupled to said loop winding for supplementing the inductance of said loop, said inductive means also having a higher Q (ratio of reactance to resistance) than said loop winding, adjustable means connected to said inductive means for tuning said loop circuit over a desired band of frequencies, and means for coupling said loop circuit to the input element of a radio receiver.

3. In a low impedance loop antenna circuit, a loop winding of relatively large included area, said winding being wound from a conductor having a diameter of the order of at least one tenth inch and having an inductance of the order of from 3 to 20 microhenries, a low impedance connection between said loop winding and a point of substantially fixed potential, inductive means having a greater impedance than said loop coupled to said loop winding for supplementing the inductance of said loop, said inductive means also having a higher Q (ratio of reactance to resistance) than said loop winding, adjustable means connected to said inductive means for tuning said loop circuit over a desired band of frequencies, and means for coupling said loop circuit to the input element of a radio receiver.

4. In a self-contained radio receiver, a cabinet for housing all the component parts of said receiver, including a metal chassis, loudspeaker and loop antenna, a supporting means in said cabinet for supporting said chassis near the top of said cabinet, a rotatable loop antenna supported in said cabinet below said chassis and said supporting means, said loop antenna being substantially as large as the dimensions of the cabinet space below said supporting means permit, but having regard to the degree of rotation required of said loop antenna, said loop winding being wound from a relatively large conductor and having a small number of turns, said loop winding having a low impedance to frequencies in the range 540 to 1600 kilocycles, a low impedance connection between the electrical center of said loop winding and said chassis, inductive means having a greater impedance than said loop coupled to said loop winding for supplementing the inductance of said loop, said inductive means also having a higher Q (ratio of reactance to resistance) than said loop winding, adjustable means connected to said inductive means for tuning said loop circuit over said range of frequencies, and means for coupling said inductive means to the input elements of said radio receiver.

5. In a self-contained radio receiver, a cabinet for housing all the component parts of said receiver, including a metal chassis, loudspeaker and loop antenna, a supporting means in said cabinet for supporting said chassis near the top of said cabinet, a rotatable loop antenna supported in said cabinet below said chassis and said supporting means, said loop antenna being substantially as large as the dimensions of the space below said supporting means allow, but having regard to the degree of rotation required of said loop antenna, said loop winding comprising a relatively large conductor having a small number of turns, said loop winding having a low impedance to frequencies in the range of 540 to 1600 kilocycles, a tightly coupled step-up transformer having a low impedance primary and a high impedance secondary connected between the terminals of said loop antenna and the input terminals of a space discharge device in said receiver, said secondary winding having a higher Q (ratio of reactance to resistance) than said loop winding, adjustable tuning means connected in shunt with said secondary winding for tuning the loop antenna circuit over said frequency range, and a low impedance connection between the electrical center of the primary circuit and said chassis.

6. In a multi-band radio receiver, a low impedance loop antenna winding of large included

area and few turns, a step-up transformer having low and high impedance windings, a vacuum tube having input and output circuits, and a tuning condenser connected in shunt with said input circuit, switching means operative in a lower frequency band for connecting the low impedance winding of said step-up transformer to said loop winding and for connecting the high impedance winding of said transformer to said input circuit, additional switching means operative in a higher frequency band for taking said transformer out of circuit and for connecting only some of the turns of said loop winding to said input circuit directly, and means for short circuiting the unused turn or turns of said loop winding.

7. A multi-band radio receiver as claimed in claim 6 characterized in that when said switching means are adjusted for reception in said higher frequency band the said direct connection between said loop winding and said input circuit includes, in series, a winding adapted to increase the overall inductance of the tuned circuit to enable it to be tuned over a desired frequency band.

8. In a low impedance loop antenna circuit, a loop winding of large included area, said winding consisting of 2 to 6 turns of a conductor having a diameter of the order of at least one-tenth inch, said winding having a ratio of winding pitch to wire diameter of 4 to 30, and having an inductance of the order of 3 to 20 microhenries, a low impedance connection between said loop antenna circuit and a point of substantially fixed potential, inductive means having a greater impedance than said loop winding coupled to said winding for supplementing the inductance thereof, and adjustable means connected to said inductive means for tuning said loop circuit to frequencies in the range 540 to 1600 kilocycles.

WILLIAM H. GRIMDITCH.