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Haruki et al.

[11] **3,918,062**

[45] **Nov. 4, 1975**

[54] **RECEIVING LOOP ANTENNA SYSTEM**

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[73] Assignee: **Matsushita Electric Industrial Co., Ltd.,** Osaka, Japan

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[21] Appl. No.: **491,269**

[30] **Foreign Application Priority Data**

Aug. 1, 1973 Japan 48-87145

[52] **U.S. Cl.** **343/702;** 343/743; 343/862

[51] **Int. Cl.**[2] **H01Q 1/24;** H01Q 7/00

[58] **Field of Search** 343/702, 743, 744, 748, 343/862

[56] **References Cited**

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3,736,591 5/1973 Rennels et al. 343/702

Primary Examiner—Eli Lieberman

Attorney, Agent, or Firm—Burgess, Ryan and Wayne

[57] **ABSTRACT**

In a receiving loop antenna especially adapted for use as a built-in antenna of a portable wireless set and of the type wherein the antenna output terminals are so tapped that power matching impedance of the wireless set may be attained, a circuit having series resonant circuit characteristics and a transmission line connected in series with the circuit and having such a length that impedance matching may be obtained, which may minimize the noise at or in the proximity of the center frequency of the frequency band of the series resonant circuit, are inserted between the antenna output terminals and the input terminals of the wireless set.

5 Claims, 11 Drawing Figures

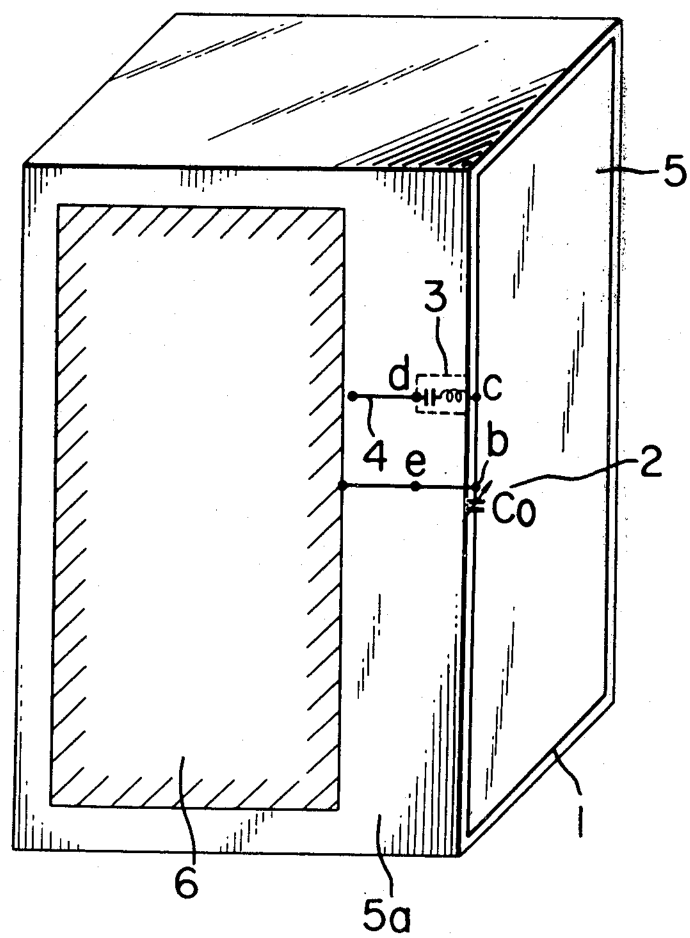

FIG. 1
PRIOR ART

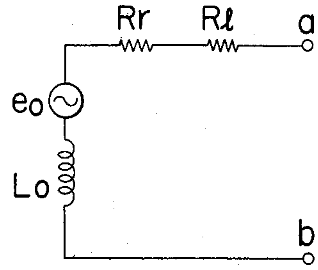

FIG. 2A
PRIOR ART

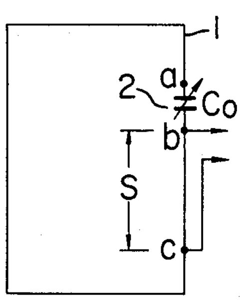

FIG. 2B
PRIOR ART

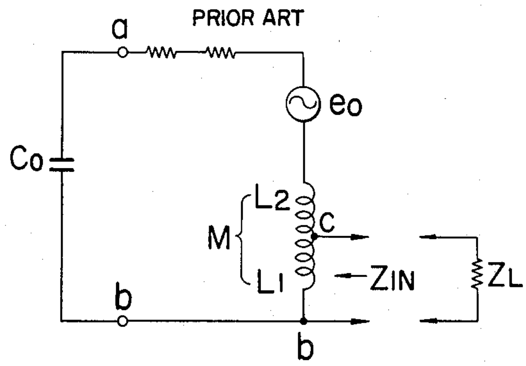

FIG. 3A
PRIOR ART

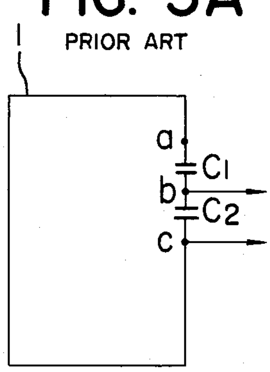

FIG. 3B
PRIOR ART

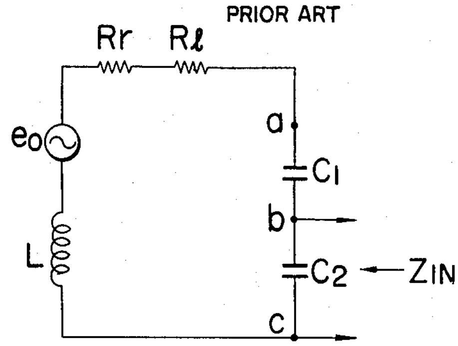

FIG. 4

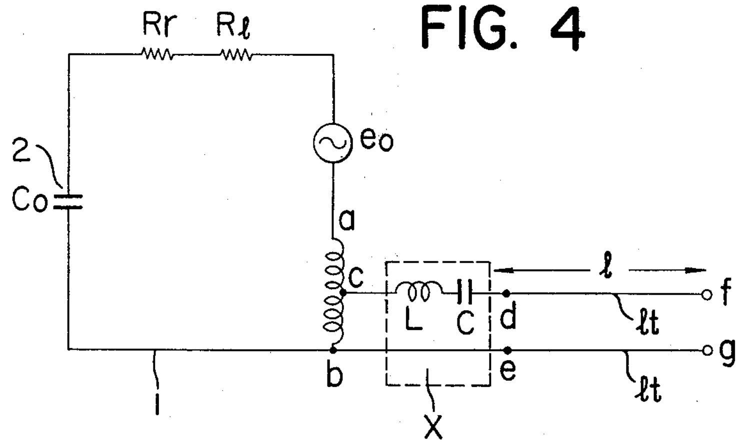
Rr
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FIG. 6

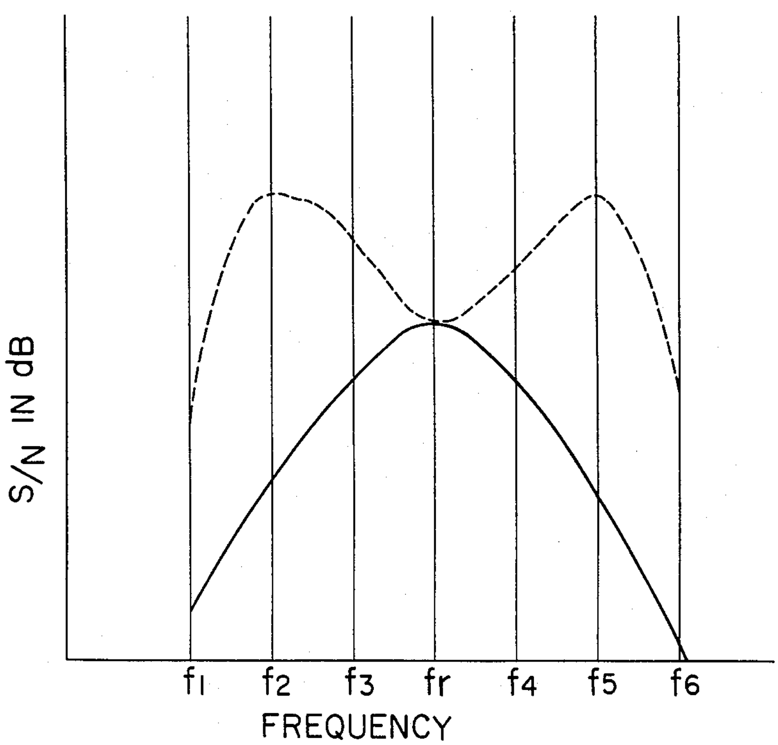
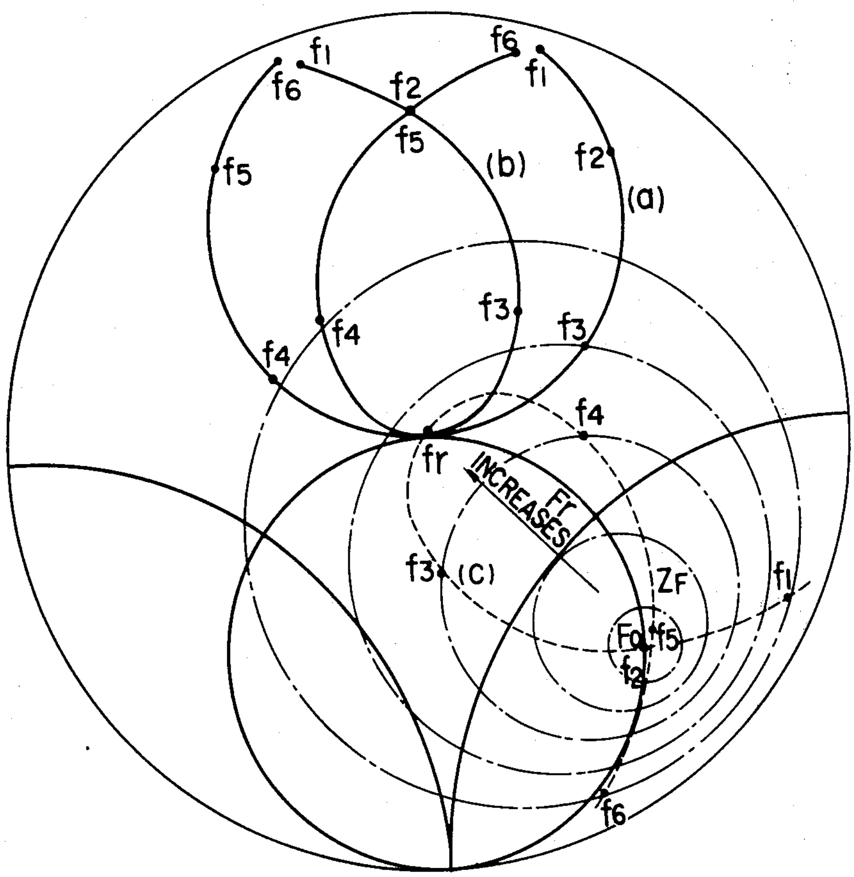

S/N IN dB
f1
f2
f3
fr
f4
f5
f6
FREQUENCY

FIG. 5


f1
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f6
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(b)
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(a)
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INCREASES
f3
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FIG. 7

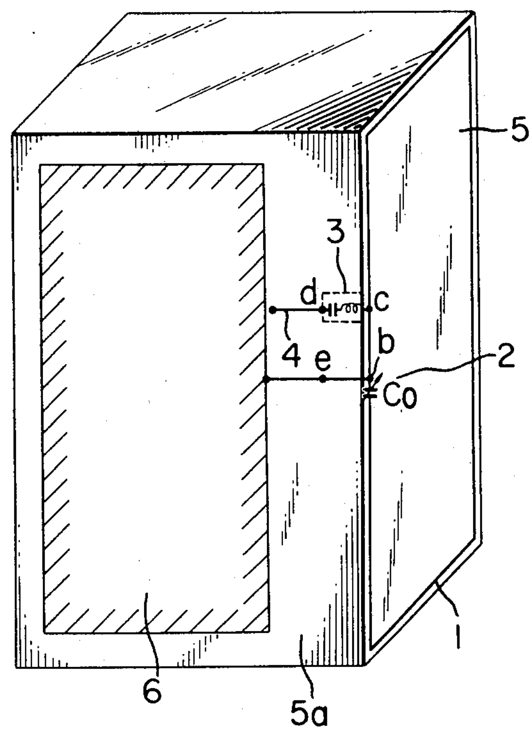


FIG. 8

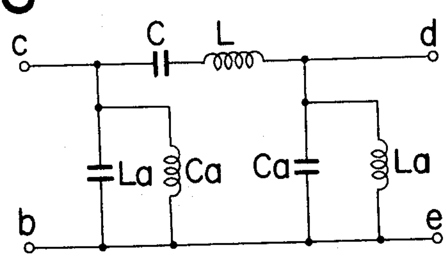
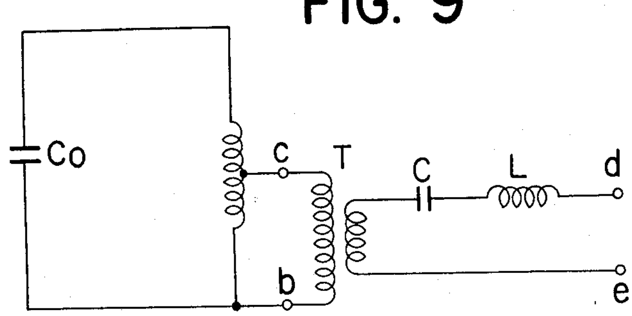


FIG. 9



RECEIVING LOOP ANTENNA SYSTEM

BACKGROUND OF THE INVENTION:

The present invention relates to generally a receiving loop antenna, and more particularly a receiving loop antenna especially adapted for use as a built-in antenna of a portable or small-sized wireless set.

In general, the small-sized portable wireless sets of the hand carried type, the pocket size type, or those generally carried on backs of the operators, have a built-in antenna such as a quarter-wavelength whip antenna, a dipole antenna or ferrite antenna. However, when the whip or dipole antenna, which is of the electric field type, is brought to close to or into contact with the body of the user, the antenna efficiency suddenly drops because of the considerable decrease in the intensity of the electric field around the human body. The ferrite antenna which is of the magnetic field type has an advantage over the whip or dipole antenna in that the magnetic field is intensified around the human body, but it still has a defect that the loss within a ferrite core is so increased as the operating frequency is increased.

In order to overcome the above inherent defects, the inventors made extensive studies and experiments and succeeded in providing an improved built-in loop antenna of the type in which a small loop antenna is attached to one side wall of the casing of the portable wireless set in parpendicular relation with the grounding plate or printed circuit board of the wireless set, and the antenna output terminals are so tapped that the impedance of the loop antenna may be matched to the input impedance of the wireless set. However, in addition to the impedance matching, it is important that the maximum signal-to-noise ratio, S/N, be attained.

SUMMARY OF THE INVENTION

The primary object of the present invention is therefore to provide an improved receiving loop antenna especially adapted for use as a built-in antenna of a portable wireless set and capable of considerably improving the signal-to-noise ratio, S/N, of the wireless set.

In this invention a loop antenna is provided in one wall of the wireless set, which wall is to be in a position perpendicular to human body when put in the pocket of the operator where it is influenced by the high intensity of magnetic field component provided by the human body. The other wall perpendicular to the wall having the loop antenna of the wireless set case is provided with a grounding plate, and the grounding plate and the loop antenna form an asymmetrical dipole antenna, which antenna has a reasonable sensitivity to the electric field component. A circuit having series resonant circuit characteristics and a transmission line are coupled with the loop antenna, and the small loop antenna characteristics and the input impedance-noise figure characteristics are combined, and the decrease of receiving range by the reduction of antenna size is complemented. Thus, the optimum noise matching is obtained.

Briefly stated, in accordance with the present invention, the antenna output terminals are tapped on the loop antenna at the points that the impedance thereof may enable the wireless set connected thereto to give the maximum output power (the above impedance being defined as "the power matching impedance" hereinafter in this specificiation). Between the antenna

output terminals and the input terminals of the wireless set is inserted a circuit having a series resonant circuit characteristic and transmission lines connected in series with the circuit and having lengths such that the impedance matching (to be referred to as "the noise matching" hereinafter in this specification) at which the noise at or in the proximity of the center frequency of the frequency band of the series resonant circuit may be minimized, may be attained.

Therefore, the receiving loop antenna in accordance with the present invention may receive the high-intensity magnetic field around the human body as well as the electric field with the omnidirectional property of the loop antenna; and further it may be used as an antenna system of high S/N ratio because noise matching and power matching are combined.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is an equivalent circuit of a prior art loop antenna;

FIGS. **2A** and **3A** are circuit diagrams of prior art loop antennas, respectively;

FIGS. **2B** and **3B** are equivalent circuits of the loop antennas shown in FIGS. **2A** and **3A**, respectively;

FIG. **4** is a circuit diagram of a loop antenna in accordance with an embodiment of the present invention;

FIG. **5** is a Smith chart used for the explanation thereof;

FIG. **6** is a graph illustrating the improvement of the signal-to-noise ratio, S/N, attained by the present invention over the prior art antenna;

FIG. **7** is a schematic perspective view illustrating the antenna system of the present invention mounted on a portable wireless set; and

FIGS. **8** and **9** are circuit diagrams of other embodiments of the present invention respectively.

The same reference numerals are used to designate similar parts throughout the figures.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

PRIOR ART, FIGS. 1, 2 and 3

Prior to the description of the preferred embodiment of the present invention, some prior art antennas will be briefly described in order to more specifically point out the defects and problems thereof which the present invention may substantially eliminate.

In general, the peripheral length of a built-in loop antenna of a compact wireless set is considerably smaller than the wavelength used so that it may be treated as a small loop antenna in analyses. The radiation resistance R_r of a small loop antenna with a cross sectional area A is in inverse proportion to the fourth power of the wavelength λ_0, as shown in the following relation:

$$R_r = \frac{320 \cdot \pi^4 \cdot A^2}{\lambda_0^4} \quad (1)$$

The equivalent circuit of the small antenna is shown in FIG. **1**, in which

e_0 = voltage induced across the loop antenna;

R_l = loss resistance; and

L_0 = inductance of the loop antenna.

For instance, when the wavelength $\lambda_0 = v/f$, where v is equal to the velocity of light, f is equal to 150 MHz and the dimension of the loop antenna is 77×12.5 mm^2, the radiation resistance R_r is 0.002 ohms.

Therefore, the loop antenna having such a low radiation resistance cannot be used with the wireless set because the mismatching loss becomes intolerably high.

In order to overcome this inherent defect, there have been devised and demonstrated various loop antennas such as those shown in **FIGS. 2** and **3.**

In a loop antenna **1** of the type shown in FIG. **2A**, a variable capacitor **2** with a capacitance C_0 is inserted for tuning, and output terminals *b* and *c* are spaced apart from each other by a distance S so as to match the impedance of the loop antenna **1** with the input impedance of the wireless set. The equivalent circuit of the loop antenna **1** is shown in FIG. **2B,** wherein

L_1 and L_2 = self-inductances of the sections between *b* and *c* and between *a* and *c*, respectively;

M = mutual inductance between the above two sections; and

C_0 = tuning capacitance.

The impedance Z_{in} of the loop antenna **1** looking back from the terminals *b* and *c* into it is given by

$$Z_{in}\Big|_{\text{resonance}} = [L/(C_0R)]\,[(L_1+M)/L]^2 \qquad (2)$$

where $R = R_r + R_l$; and

$L = L_1 + L_2 + 2M$

The voltage V induced across the terminals *b* and *c* is given by

$$V = (\sqrt{L/C_0})\,(1/R)\,[(L_1 - M)/L]\,e_0 \qquad (3)$$

Therefore, the maximum available power P_{max} of a load with impedance Z_L connected between the terminals b and c is given by

$$P_{max} = \frac{V^2}{4Z_{in}}\Big|_{\text{resonance}} = e_0^2/\,[4(R_r + R_l)] \qquad (4)$$

In summary, as is clear from Eq. (2), the inductances L_1 and L_2 and the mutual inductance M may be varied by changing the tapping position of the terminal *c* so that the input impedance Z_{in} may be so varied as to match with the load impedance Z_L in a relatively simple manner. That is, the inductance of the loop antenna itself is utilized to match the input impedance thereof.

In a loop antenna of the type shown in FIG. **3A**, two capacitors C_1 and C_2 are inserted in order to attain the impedance matching. The equivalent circuit is shown in FIG. **3B.** The capacitors C_1 and C_2 are connected in sereis for tuning, and one output terminal *b* is the junction between the capacitors C_1 and C_2 while the other output terminal *c*, the other terminal of the capacitor C_2. The input impedance Z_{in} at a resonant frequency is given by

$$Z_{in}\Big|_{\text{resonance}} = [L/(C_0R)]\,[C_1/(C_1 + C_2)]^2 \qquad (5)$$

where C_1 and C_2 are capacitances of the capacitors C_1 and C_2, respectively.

Therefore, it is seen that the input impedance Z_{in} may be changed by changing the capacitances C_1 and C_2.

The impedance matching between the loop antenna and the wireless set may be attained in the manners described above, but when the antenna loss is considerably greater, the signal-to-noise ratio, S/N, of the wireless set must be taken into consideration. That is, the antenna for the wireless set must be so designed that not only the impedance matching may be attained but also S/N in the wireless set may become maximum.

THE INVENTION

The antenna impedance must be so selected that the noise figure in the input circuit of the wireless set may be minimized over a wide range of frequencies. For this purpose, it is imperative that the prior art antenna whose impedance may be adjusted in the manner described above be so improved as to be connected to the input terminals of the wireless set through circuit having L-C series resonant circuit characteristics and through a transmission lines having lengths *l*.

Now referring to FIG. **4** illustrating a preferred embodiment of the present invention, a series resonant circuit X consisting of a capacitor C and an inductor L has its one end connected to one antenna output terminal *c* and the other end *d* connected to one input terminal *f* of the wireless set through a transmission l_t line having a length *l*.

The impedances of the antenna system of the present invention are shown in the Smith chart in FIG. **5.** In general, the "power matching impedance" for maximum power transfer is different from an impedance capable of attaining the "noise matching". In general, the input impedance of the wireless set is **50** or **75** ohms.

It is assumed that the noise figure or factor becomes minimum F_0 when Z_F is equal to ($R_F = jX_F$). Then, it becomes higher as the impedance deviates from Z_F as indicated by the chain circles in the Smith chart in FIG. **5,** wherein the impedance Z_r is the normalized impedance of the Smith chart and is the input impedance the wireless set.

When Z_R is a pure resistance which gives the miximum power transfer, the capacitance of the capacitor **2** (see FIG. **4**) is so selected that the antenna may be tuned to a frequency f_r. The output terminal *c* is so tapped that the impedance $Z_{b\text{-}c}$ of the loop antenna looking back from the terminals *b* and *c* into the loop antenna may satisfy the following relation:

$$Z_{b\text{-}c} = [L/(C_0R)]\,[(l_1 + M)/L]^2 \qquad (6)$$

The frequency characteristic curve at $Z_{b\text{-}c}$ over a frequency range from f_1 to f_6 is indicated by the curve (*a*) in the Simth chart in FIG. **5.**

Standing wave ratio S which defines the relation between the pure resistance Z_R and the impedance Z_F which gives the noise matching in the wireless set is:

$$S = [l + |r|]/[1 - |r|] = [1 + |(Z_F - Z_R)/(Z_F + Z_R)|] * */[1 - |(Z_F - Z_R)/(Z_F + Z_R)|] \qquad (7)$$

Therefore, the resistance component R, that is a point at which one standing-wave -ratio circle intersects the real axis of the Smith chart, is given by

$$R = \frac{Z_R}{S} \qquad Z_{F2} = (Z_R/S) + JX_2 \qquad (8)$$

The resistance component of the input impedance of the loop antenna becomes Z_R/S at the frequencies f_2 and f_5 on the curve (*a*) in FIG. **5.** At f_2 and f_5, the impedances are

$$Z_{f5} = (Z_R/S) - jX_5 \qquad (9)$$

At f_2 which is lower than the resonant frequency f_r, the reactance component is an inductance component but at $f_5$which is higher than the resonant frequency f_r, it is a capacitance component.

The series resonant circuit X inserted between the terminals *c* and *d* (or between the terminals *b* and *c* and the terminals *d* and *e*) is tuned to the resonant frequency f_r. At the resonant frequency the impedance of the tuning circuit X is zero. At a frequency lower than the resonant frequency the tuning circuit X exhibits capacitance while at a frequency higher than the resonant frequency, it exhibits inductance. The impedance is so selected as to satisfy the following relations at the resonant frequency f_r, at a frequency f_2 lower than the resonant frequency and at the frequency f_5 higher than the resonant frequency.

$$Z = 0 \text{ at } f_r$$
$$Z = -jX_2 \text{ at } f_2$$
$$Z = +jX_5 \text{ at } f_5 \qquad (10)$$

Therefore, the frequency characteristics at $Z_{d\text{-}e}$, the impedance looking back from the terminals d and e are shown by the curve (b) in FIG. **5**, which intersects at f_2 and f_5.

The length l of the transmission line l_t having the characteristic impedance equal to the reference impedance Z_R is so selected as to satisfy the following relation:

$$Z_F = \{ [(Z_R/S) + jZ_R \tan\beta l] / [Z_R + (jZ_R/S) \tan\beta l)] \}$$
$$= Z_R [(1 + jS \tan\beta l) / (S + j \tan\beta l)] \qquad (11)$$

where β is a constant.

Therefore the impedance $Z_{f\text{-}g}$ looking back from the terminals f and g into the network is given by

$$Z_{f\text{-}g} = Z_R [(Z_{d\text{-}e} + jZ_R \tan\beta l) / (Z_R + jZ_{d\text{-}e} \tan\beta l)] \qquad (12)$$

The curve (c) in FIG. **5** shows the frequency characteristic curve at $Z_{g\text{-}f}$.

Thus, the satisfactory "noise matching" may be attained at f_2 and f_5 with the result of the optimum S/N, and the "power matching" may be attained at f_r, resonant frequency.

In FIG. **6**, the solid curve shows the signal-to-noise ratio at the output terminals of the wireless set connected to the prior art antenna which was designed only to attain the impedance matching as described above and whose frequency characteristic curve is shown at (a) in the Smith chart in FIG. **5**. The broken curve line shows the S/N of the wireless set connected to the loop antenna in accordance with the present invention whose impedance characteristic is indicated by the curve (c) in the Smith chart in FIG. **5**. It is apparent that the signal-to-noise ratio, S/N, is considerably improved over the wide frequency range by the antenna system in accordance with the present invention.

FIG. **7** shows the antenna system in accordance with the present invention attached to a portable wireless set. The loop antenna **1** is attached to one side wall **5** of the wireless set which is substantially perpendicular to the body of an operator, and a grounding plate **6** is attached to another side wall **5**a perpendicular to the antenna mounting side wall **5**. The antenna system in accordance with the present invention includes the capacitor **2**, the series tuning circuit **3**, and the transmission line **4**, as described hereinbefore.

The simplest series resonant circuit may be constructed, as shown in FIGS. **4** and **7**, by an impedance element and a capacitive element connected in series; however another circuit having a similar frequency characteristics as this circuit can also show similar features.

FIG. **8** shows the second embodiment of this invention. In this embodiment two parallel resonant circuits which resonate at desired frequency ranges are connected between the grounding plate and the both ends of the series resonant circuit. The parallel resonant cir-

cuits consist of an inductor L_a and a capacitor C_a respectively. This parallel resonant circuit has a high resonant impedance in receiving frequency range; this is the reason the circuit has the same characteristics as that of L-C series resonant circuit. Outside of the receiving frequency range the impedance becomes low. This characteristic is useful for the attenuation of frequency components outside of the receiving frequency range. This is also useful for the improvement of spurious characteristics.

In the third embodiment of this invention shown in FIG. **9**, the loop antenna and the series resonant circuit are coupled through an impedance conversion transformer T. This will broaden the variable range in impedance range of series resonant circuit.

What is claimed is:

1. In a receiving loop antenna system especially adapted for use as a built-in antenna which consists of a loop antenna and a grounding plate perpendicular to the loop antenna for a portable wireless set, the antenna output terminals being tapped at such points that said antenna may be matched with the input impedance of said wireless set, the improvement comprising

a series-connected circuit comprising

a. a circuit having series resonant circuit characteristics and tuned to the center frequency of the operating frequency range of said wireless set, and

b. a transmission line having such a length as to attain the impedance matching which minimizes the noise in the proximity of said center frequency,

said series-connected circuit being inserted between the output terminals of said antenna and the input terminals of said wireless set.

2. A receiving loop antenna system as defined in claim **1** wherein

ther length l of said transmission line is determined to satisfy the following relation

$$Z_F = Z_R [(1 + j\tan\beta l) / (S + j \tan\beta l)]$$

where Z_F = impedance at which the noise matching of said wireless set may be attained;

Z_R = impedance at which the power matching of said wireless set may be attained;

$$S = [1 + | (Z_F - Z_R) |] / [1 - (Z_F - Z_R)/* *(Z_F + Z_R) |]; \text{ and}$$

β = coefficient.

3. A receiving loop antenna system as defined in claim **1** wherein

said series tuning circuit comprises

an inductor, and

a capacitor.

4. A receiving loop antenna as defined in claim **1** wherein

said circuit having series resonant circuit characteristics; a series circuit consisting of a capacitor and an inductor; and parallel resonant circuits each consisting of an inductor and a capacitor, being connected with both ends of said series circuit respectively.

5. A receiving loop antenna as defined in claim **1** wherein

said loop antenna and said circuit having series resonant characteristic are coupled through impedance conversion transformer.

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