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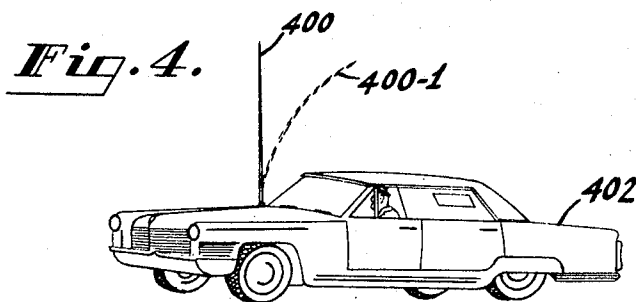
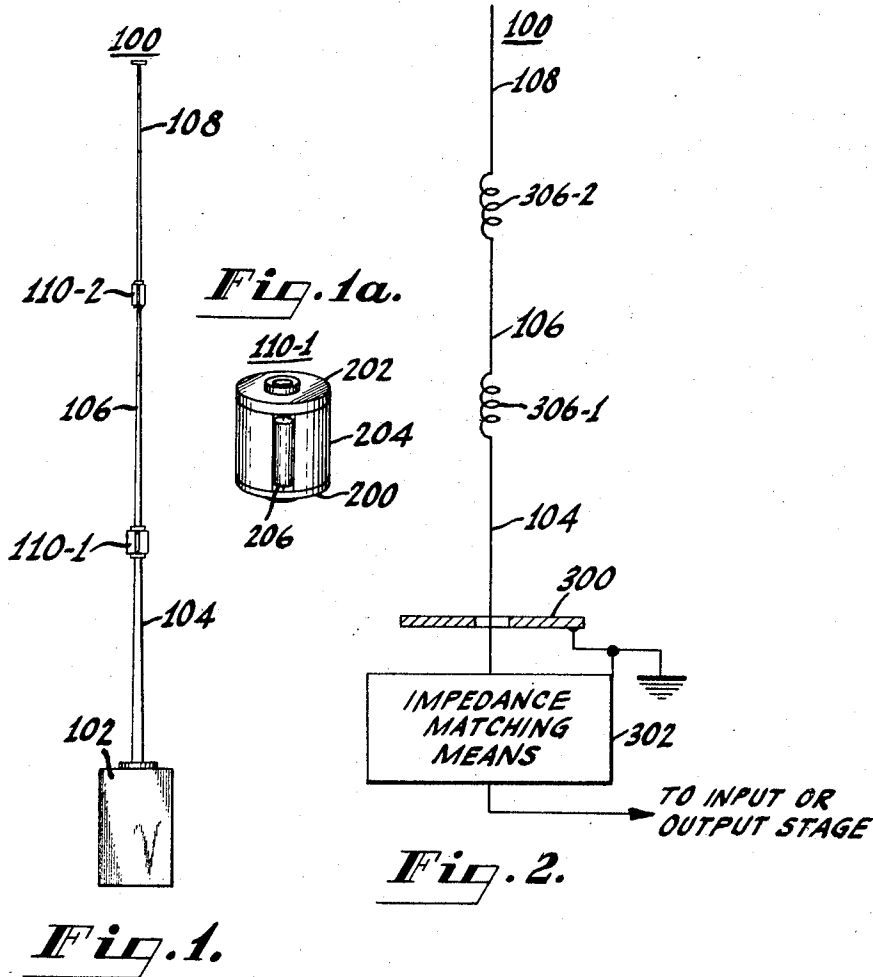
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HALF WAVELENGTH MONOPOLE ANTENNA WITH SPACED LOADING COILS

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Sheet 1 of 2



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Sheet 2 of 2

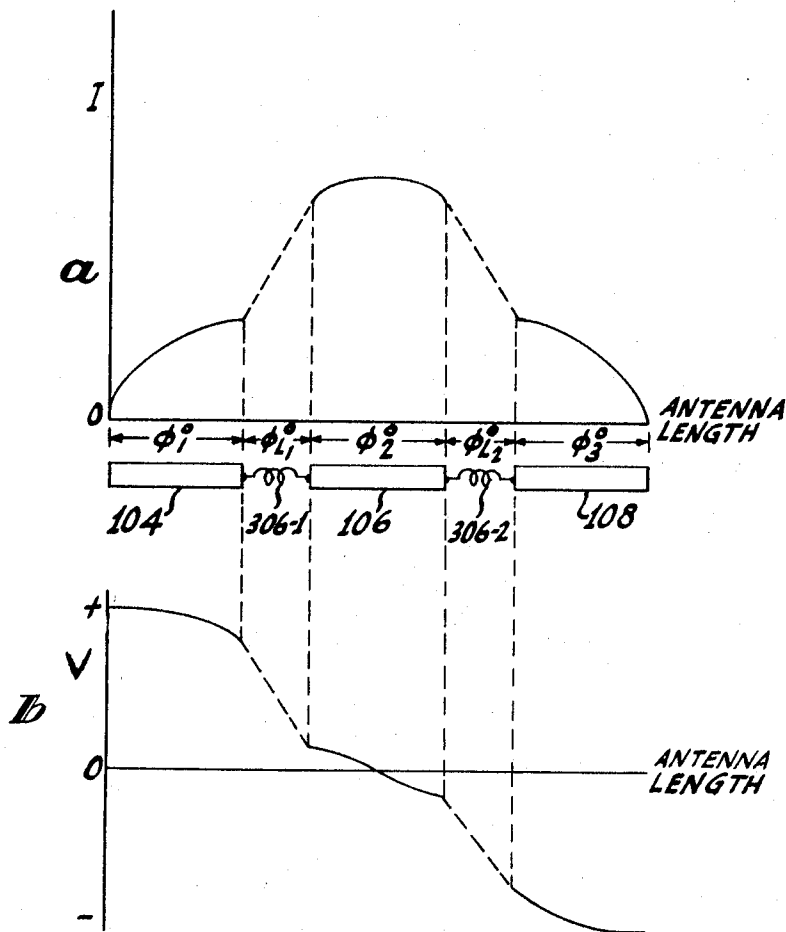


Fig. 3

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1

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HALF WAVELENGTH MONOPOLE ANTENNA WITH SPACED LOADING COILS

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ABSTRACT OF THE DISCLOSURE

An end fed monopole antenna is described having three colinear radiating sections which are approximately equal to each other. A first inductive element is coupled between one end radiating section and the center radiating section and a second inductive element is coupled between the center radiating section and the opposite end section. The total physical length of the three sections is substantially less than one-half wavelength at the operating frequency of the antenna and yet the electrical length of the three sections is arranged so that the electrical length is substantially equal to one-half wavelength at the predetermined frequency.

This invention relates to antennas and, more particularly, to a high efficiency monopole antenna for use with a portable and/or mobile radio set.

The term "monopole antenna" as used herein means a rod-like conductor or plurality of colinear conductors provided with but one (physical) radio frequency feed terminal which is located at an end thereof, further characterized by having an overall linear length which is significantly less than 180° compared to the free space length of the waves being transmitted by or received by the radio set.

The term "radio set," as used herein, means a radio receiver, a radio transmitter, a radio transceiver or any device intended to transmit or receive electromagnetic waves.

It is the practice to use a monopole antenna as the radiating means and/or receiving means for small portable radio sets, such as an FM receiver, or a citizen's band transceiver, for instance. Monopole antennas are also used for mobile radio sets such as are used in vehicles, small boats made of wood or fiber glass, and model airplanes.

Monopole antennas normally used with such radio sets have a length of one-quarter wavelength or less (length equal to or less than 90°) at a frequency within the operating frequency band of the radio set with which it is used. Such an antenna is effective in radiating into space substantially all the energy generated by the transmitter or delivering, in the case of the receiver, substantially all the energy intercepted from space only when the ground plane with which the antenna operates has a radius at least of the order of one-quarter wavelength. The impedance at the feed terminal of such a one-quarter wavelength long antenna having an adequate ground plane is of the order of 30 ohms resistive (plus a small value inductive term) and as the length of the antenna is made (physical) shorter, i.e., less than 90°, the resistive term becomes increasingly smaller and smaller in value and the reactive term becomes an increasingly greater capacitive reactance.

In the case of small portable radio sets, such as a citizen's band transceiver, for instance, the effective ground plane against which the monopole antenna operates is very much smaller than one-quarter wavelength. The impedance at the feed terminal of such a one-quarter

wavelength long antenna having an inadequate ground plane is found to include a resistive term that is significantly larger than 30 ohms, and as the length of such an antenna is made shorter, i.e., less than 90°, the resistive term decreases but at a relatively slower rate.

The monopole and ground plane may be looked upon as a radiating or intercepting link between space and the transmitter or receiver that includes a first term determined by the radiation resistance of the monopole and a second term determined by the loss resistance, where the term loss resistance includes the loss resistance of the monopole plus the losses resulting from the degree of ineffectiveness of the ground plane, i.e., the efficiency of the ground plane in providing an image antenna. The loss resistance only acts to produce heat. Of course the efficiency of the monopole in radiating or intercepting energy supplied thereto is:

$$\frac{R_R}{R_R + R_L} \times 100$$

which reduces to

$$\frac{1}{1 + \frac{R_L}{R_R}} \times 100$$

where R_R equals radiation resistance and R_L equals loss resistance.

In the case of a relatively short monopole with an inadequate ground plane, R_L can be in the order of ten times R_R which means by way of example, that, if R_L is ten times R_R , more than ninety percent of the energy supplied by the transmitter is lost in heat and not useful to propagate an electromagnetic wave, and in the case of the antenna being used for reception, only some ten percent of the intercepted energy is available at the receiver input.

It is desirable to provide with a radio set or other equipment of the type which has an inherently inadequate ground plane, a monopole antenna which is (a) short in physical length and (b) provides a value of R_R which is very large whereby the loss resistance term R_L will not dissipate an appreciable amount of the energy supplied to or intercepted by the monopole. Likewise, changes in the R_L term will have no significant effect on performance because

$$\frac{R_L}{R_R} \gg 1$$

A monopole antenna having these advantages and features is provided according to the present invention by dividing the antenna into three substantially axially aligned longitudinal rod-like radiating sections (i.e., colinear) wherein each of the rod-like sections has a significant length. An end of a first of the three radiating sections is serially coupled to an end of a second of the three radiating sections by a first inductance, and the other end of the second of the three sections is serially coupled to an end of the third of the sections by a second inductance, the first and second inductances having respective values which render the electrical length of the resulting antenna substantially equal to one-half wavelength (electrical length=180°) at a frequency within the operating frequency band of the radio set with which it is used, although the physical linear length of the resulting antenna is significantly shorter than the free space half wavelength of the radiated and/or received wave.

It is therefore an object of the present invention to provide a high efficiency monopole antenna.

It is a further object of the present invention to provide a high efficiency monopole antenna for use with a radio set presenting a small ground plane.

It is still a further object of the present invention to provide a high efficiency monopole antenna the efficiency of which is not sufficiently affected by variations in the effective size of the ground plane against which the antenna operates or alteration in the relationship between the antenna and this ground plane.

These and further objects, features and advantages of the present invention will become more apparent from the following detailed description taken together with the accompanying drawing, in which:

FIG. 1 shows the physical appearance of the typical small portable radio set together with the monopole antenna of the present invention;

FIG. 1A shows in detail an example of the physical appearance of the inductive coupling means connecting the first and second radiating sections, and the second and third radiating sections, respectively, of the antenna shown in FIG. 1;

FIG. 2 schematically shows the electrical properties of the antenna shown in FIG. 1 together with the ground plane against which the antenna operates and the impedance matching means of the radio set with which the antenna is used;

FIG. 3 shows an approximation of the amplitude of current I and the amplitude of the voltage V as a function of length of the monopole antenna of the present invention; and

FIG. 4 shows the antenna of the present invention mounted on a vehicle for use with a mobile radio set carried by the vehicle.

Referring to FIG. 1, there is shown a monopole antenna 100 of the present invention coupled to a typical small portable radio set 102, such as a citizen's band transceiver. Monopole antenna 100 is assumed to have by way of example a physical length of one-quarter wavelength or less at a frequency within the operating frequency band of radio set 102. Further, monopole antenna 100, which is composed of telescoping segments, comprises first radiating section 104, second radiating section 106 and third radiating section 108. First radiating section 104 is serially and electrically coupled to second radiating section 106 by inductive coupling means 110-1, and second radiating section 106 is serially and electrically coupled to third radiating section 108 by inductive coupling means 110-2.

The physical details of inductive coupling means 110-1 are shown in FIG. 1A. As shown in FIG. 1A, inductive coupling means 110-1 comprises a lower metallic member 200, which is adapted to be rigidly connected to the first radiating section 104, and upper metallic member 202, which is adapted to be rigidly connected to the second radiating section 106. An insulating cylindrical member 204 rigidly secures the lower metallic member 200 to the upper metallic member 202. Lower metallic member 200, upper metallic member 202 and insulating cylindrical member 204 together provide means for mechanically attaching second radiating section 106 to first radiating section 104 of monopole antenna 100 to thereby rigidly support the portion of monopole antenna 100 which is above coupling means 110-1. Electrically connecting the lower metallic member 200 to the upper metallic member 202 is an hermetically sealed inductance coil 206. Lower metallic member 200, upper metallic member 202 and inductance coil 206 provide means for electrically connecting second radiating section 106 in series with first radiating section 104. Inductance coupling means 110-2 has the same configuration as inductive coupling means 110-1 shown in FIG. 1A except that the outer diameters of metallic members 200 and 202 and insulating cylindrical member 204 may be somewhat smaller in view of the narrower width of the telescopic segments of antenna 100 at the point where inductive coupling means 110-2 is located.

Referring to FIG. 2, there is shown an equivalent electrical circuit of the pertinent portions of monopole an-

tenna 100 and radio set 102. As shown in FIG. 2, the inductance of coil 306-1, corresponding to the coil 206 of FIG. 1A, serially connects first radiating section 104 to second radiating section 106 of monopole antenna 100. Inductance 306-2, corresponding to the inductive coupling means 110-2 of FIG. 1, serially connects second radiating section 106 to third radiating section 108. The small ground plane provided by radio set 102 against which monopole antenna 100 operates is represented by block 300. Radio set 102 includes impedance matching means 302 for coupling the proximate end of monopole antenna 100 to the input stage of radio set 102 when radio set 102 operates as a receiver or to the output stage of radio set 102 when radio set 102 operates as a transmitter. Impedance matching means 302 provides optimum power transfer between monopole antenna 100 and the input or output stage, as the case may be, of radio set 102.

As stated above, the physical length of monopole antenna 100 is assumed to be one-quarter wavelength or less at a frequency within the operating frequency band of radio set 102. The values of inductances 306-1 and 306-2 are chosen to render the electrical length of monopole antenna 100, with respect to ground plane 300, substantially one-half wavelength (electrically 180° long) at a frequency within the operating frequency band of radio set 102. Since monopole antenna 100 has an electrical length of one-half wavelength (electrically 180° long), the terminating impedance it presents to impedance matching means 302 is quite high, being of the order of 10,000 ohms or more. Since the terminating impedance presented by the antenna is high, the ground plane can be small and effectively change in size without affecting the antenna impedance. Because this is true, objects close to ground plane 300 do not affect the efficiency of monopole antenna 100.

It is known to cause a monopole antenna having a physical length of one-quarter wavelength or less to have an effective electrical length of one-half wavelength 180° by adding a lumped inductance. However, in the past it has been the practice to add only a single lumped inductance which is located either at the center of the monopole antenna, dividing it into two rather than three radiating sections, or at the end of the monopole antenna proximate to the input stage of the radio set. In the case where the inductance coil is positioned at the center of a monopole antenna having a physical length of one-quarter wavelength or less to provide an effective electrical length of one-half wavelength, the current maximum occurs in the coil with low current in the radiating section or rod element of the antenna. A poor coupling of energy between the radiating section and free space results. Likewise, in the case where the inductance coil is positioned at the proximate end of the antenna to provide an effective electrical length of one-half wavelength for an antenna one-quarter wavelength or less in physical length, maximum current occurs in the coil with low current in the radiating section or portion of the antenna which actually couples energy to or from free space. Again, the coupling of energy to or from the antenna is poor since the current maximum is in the coil.

The use of the so called capacitive hat positioned at the distal end of a one-quarter wavelength or less antenna has also been suggested. Such structures are mechanically awkward and cumbersome. Further, use of such a device results in current maximum at the feed point of the antenna so that there is an unbalanced condition with respect to the ground plane. Loss of power results.

In the present invention, two separate inductances are used to divide the antenna into three radiating sections, as disclosed herein. In particular, an antenna has both a current portion radiation aperture, i.e., the integral of the current amplitude at each point along the antenna over the entire radiating length of the antenna, and a voltage portion radiation aperture, i.e., the integral of the voltage amplitude at each point along the antenna over the

entire radiating length of the antenna. Although the radiation is affected by the values of both the current portion radiation aperture and the voltage portion radiation aperture, in a monopole antenna the value of the current portion radiation aperture is by far the more significant of the two.

By the arrangement of the present invention, the positioning of the two inductances results in the current maximum occurring at the center section 106 of the antenna. Optimum coupling of energy results between the radiating element of the antenna and free space. The construction results in increased resistance at the feed point of the antenna whereby ohmic power loss is minimized. Further, a reasonably long rod-like radiator of reasonable effective length in the form of the center section rod of the antenna is provided having significant radio frequency current flowing therethrough so that there is a good coupling from the antenna to free space.

Referring to curve (a) of FIG. 3, there is shown a representative curve showing the current amplitude I at each point along the length of a three radiating section monopole antenna such as antenna 100, where the value of the current portion radiation aperture is manifested by the area under the curve. The three antenna sections 104, 106, 108 are assumed to be of equal length and are represented by equal angles ϕ_1° , ϕ_2° , and ϕ_3° . The inductances 306-1 and 306-2 are of equal value and are represented by angles ϕ_{L1}° and ϕ_{L2}° . It is understood that the angles representing the antenna sections 104, 106, 108 and inductances 306-1, 306-2 total one hundred eighty degrees for the overall electrical length of the antenna. It is seen that the maximum current amplitude occurs at the center section or rod 106 of the antenna. A representative curve showing the voltage distribution E for the same antenna is shown in curve (b) of FIG. 3. By way of example only, let it be assumed that an antenna of a physical length of approximately five feet is provided for operation at 27 megacycles. Inductances 306-1 and 306-2 are 4.7 microhenries in value. The three antenna sections 104, 106, 108 will each have an angle of approximately 22 degrees and the two inductances 306-1, 306-2 will each have an angle of approximately 57 degrees, making a total of one hundred eighty degrees for the antenna. In the case where the antenna is telescoping as shown in the drawing, the angle for the three sections will not be precisely equal even though the sections may be of equal length. This is so since the diameter of the sections changes along the length of the antenna and the angle represented by each section is determined accordingly.

While the three sections can be of substantially equal length, the value of the current portion radiation aperture remains quite high even when the relative lengths of the three radiating sections of monopole antenna 100 are very different from each other so long as each of the three radiating sections is of significant length, i.e., the shortest of the three radiating sections is not so short as to be of negligible effect as a radiating section. The dimensions of the respective sections should be chosen so that there is sufficient current flow through the inductors, whereby the end sections must be of a finite length. At the same time, the current flow through the inductors should be such as to provide maximum current flow through the center section so that the coupling of energy between the antenna and free space is optimized. It has been found that the performance of a three section monopole antenna of the type disclosed herein wherein the relative lengths of the three sections were approximately equal is several hundred percent higher than a conventional short, non-loaded monopole antenna.

A three section monopole antenna of the type described herein is particularly suited for use wherever the radio set provides a small ground plane. One such case is the citizen's band transceiver described above. Another case is a small portable FM receiver. A still other case is in conjunction with a radio set aboard a wooden or fiber

glass boat, wherein the normally heavy copper plate attached to the boat to provide a ground plane may be replaced with a small area of aluminum foil.

When a mobile radio is carried by a vehicle, such as a car for instance, and a monopole antenna therefore is mounted on the exterior of the vehicle, a large ground plane for the antenna is provided by the metallic body of the vehicle. However, as shown in FIG. 4, such a monopole antenna 400, which is normally straight when the vehicle is at rest, tends to bow, as shown by reference 400-1 when the vehicle moves at high speeds. This changes the spatial relationship of antenna 400 with respect to the ground plane provided by vehicle 402 which normally adversely affects the efficiency of the antenna. It has been found that a three section monopole antenna of the type described herein when mounted on a vehicle maintains a substantially uniform high efficiency despite bowing of the antenna when the vehicle moves at high speeds.

Reference has been made to a one-quarter wavelength antenna in connection with the description of one embodiment of the invention. In practice, the antenna may be longer in physical length, for example, three-eighths of a wavelength at the operating frequency with a pair of inductances positioned and operated in the manner described. Further, reference has been made to a telescoping antenna. In practice, the antenna may be a rigid structure electrically divided in the manner shown herein by a pair of inductor elements.

Although only certain embodiments of the invention have been described herein, it is not intended that the invention be restricted hereto, but that it be limited by the true spirit and scope of the appended claims.

What is claimed is:

1. An antenna adapted to be end fed and designed for operating at a predetermined frequency band including in combination:

a radiation portion comprised of a center section and a pair of end sections, said sections positioned end to end in a colinear manner, the total physical and the total electrical length of the three sections being substantially less than $\frac{1}{2}$ wavelength at said predetermined frequency band,

a pair of inductive elements,

means electrically coupling one of the elements between an end of the center section and one of the end sections,

means electrically coupling the other element between the other end of the center section and the other of the end sections, the lengths of the sections and the inductive values of said elements being proportioned so that the combination is physically significantly shorter than $\frac{1}{2}$ wavelength but is electrically substantially equal to $\frac{1}{2}$ wavelength at the predetermined frequency whereby the impedance of said antenna at the end fed point is high and the efficiency of the antenna is substantially independent of the size of the ground plane.

2. The antenna defined in claim 1, wherein the respective lengths of said center and pair of end sections are approximately equal to each other.

3. The antenna defined in claim 1, wherein the entire physical length of said antenna in said combination is substantially shorter than one-quarter wavelength at said predetermined frequency band.

4. Radio apparatus including a radio set operating in a predetermined frequency band, an end fed monopole antenna for said radio set, and coupling means including a high impedance matching network coupling said radio set and said end fed antenna for providing transfer of power in said predetermined frequency band therebetween, said antenna comprising:

a radiation portion comprised of a center section and a pair of end sections said sections positioned end to end in a colinear manner, the total physical and the total electrical length of the three sections being sub-

7

stantially less than $\frac{1}{2}$ wavelength at a predetermined frequency,

a pair of inductive elements,

means electrically coupling one of the elements between and end of the center section and one of the end sections,

means electrically coupling the other element between the other end of the center section and the other of the end sections, the lengths of the sections and the inductive values of the elements being proportioned so that the combination is physically significantly shorter than $\frac{1}{2}$ wavelength but is electrically substantially equal to $\frac{1}{2}$ wavelength at the predetermined frequency whereby the impedance of said antenna at the end fed point is high and the efficiency of the antenna is substantially independent of the size of the ground plane.

5. An end fed monopole antenna designed for operation in a predetermined frequency band, said antenna comprising three substantially axially aligned longitudinal radiating sections, a first inductive means coupling a first of said sections to a second of said sections, and a second inductive means coupling said second of said sections to the third of said sections, the entire physical length of said antenna being less than one-half wavelength at a given frequency within said predetermined frequency band, said first and second means having respective values which taken with the lengths of said sections render the electrical length of said antenna substantially equal to one-half wavelength at said given frequency and cause said antenna to have one current maximum which occurs in the center section of said radiating section whereby the impedance of said antenna at the end fed point is high and the efficiency of the antenna is substantially independent of the size of the ground plane.

6. Radio apparatus comprising a radio set operating in a predetermined frequency band, an end fed monopole antenna from said radio set, and coupling means including a high impedance matching network coupling said radio set and said end fed antenna for providing transfer of power in said predetermined frequency band therebetween, wherein said antenna comprises three substantially axially aligned longitudinal radiating sections, a first inductance serially coupling a first of said sections to a second of said sections, and a second inductance serially coupling said second of said sections to the third of said sections, the entire physical length of said antenna being

8

less than one-half wavelength at a given frequency within said predetermined frequency band, said first and second inductances having respective values which taken with the length of said sections render the electrical length of said antenna substantially equal to one-half wavelength at said given frequency and cause said antenna to have a single maximum current point in the center section of said radiating sections whereby the impedance of said antenna at the end fed point is high and therefore the efficiency of the antenna is substantially independent of the size of the ground plane.

7. Radio apparatus as defined in claim 6, wherein the respective lengths of said first, second and third sections are approximately equal to each other.

8. Radio apparatus as defined in claim 6, wherein the physical length of said antenna is substantially shorter than one-quarter wavelength at said given frequency.

9. Radio apparatus as defined in claim 6, wherein said coupling means are matched impedance means to provide substantially maximum power transfer between said radio set and said antenna at said given frequency.

10. Radio apparatus as defined in claim 6, wherein said radio set provides a ground plane with respect to said monopole antenna which ground plane has dimensions which are small relative to one-quarter wavelength at said given frequency.

11. Radio apparatus as defined in claim 6, wherein said radio set is a portable transceiver.

12. Radio apparatus as defined in claim 6, wherein said radio set is a portable frequency modulation receiver.

13. Radio apparatus as defined in claim 6, wherein said radio set is a mobile radio set for use within a vehicle and said antenna is mounted on the outside of said vehicle and is subject to being temporarily bowed by air currents while said vehicle is in motion.

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U.S. Cl. X.R.

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