March 9, 1943. M. BRUCE 2,313,046

RADIO ANTENNA SYSTEM

Filed March 26, 1942

Fig. 1

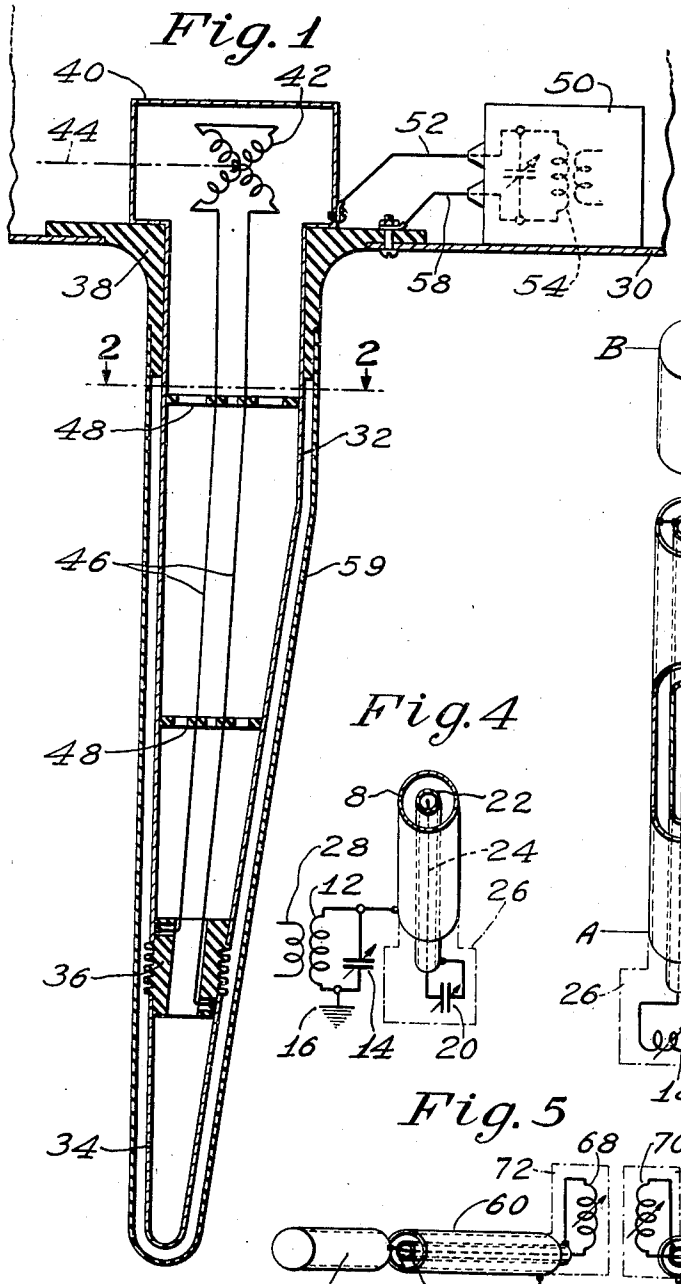


Fig. 2

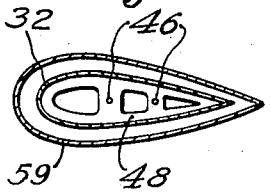


Fig. 3

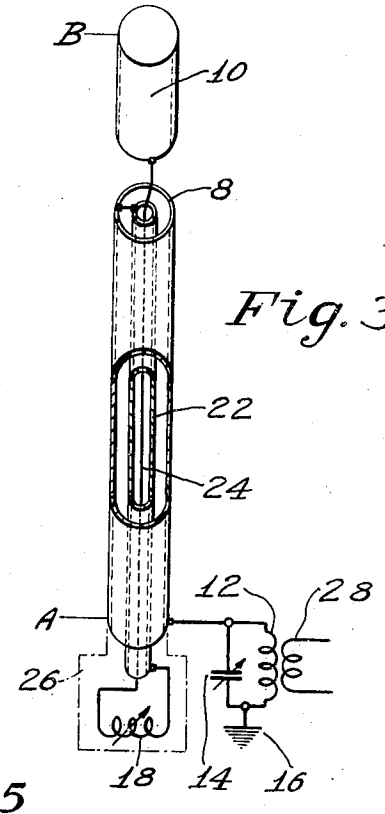
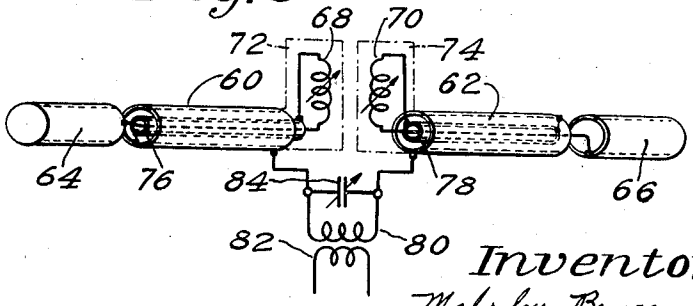


Fig. 4

Fig. 5



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RADIO ANTENNA SYSTEM

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9 Claims. (Cl. 250—33)

The present invention relates to radio antenna systems and more particularly to antenna systems wherein the equivalent electrical length of the antenna element or radiator is less than a quarter wavelength of the operating frequency. In its special aspects, the invention is concerned, though by no means exclusively, with vehicle and particularly aircraft radio antenna systems employing a vertical element or mast insulated from and operating against the metallic structure of the craft as a ground.

For many applications, the simple quarter wavelength vertical antenna operating as a grounded or Marconi type antenna or its equivalent offers distinct advantages, such as a uniform radiation pattern in the horizontal plane, low angle of radiation in the vertical plane together with vertical polarization, and relative ease of insulation in the case of a structure supported at the base only, because of the presence of a voltage node at that point. However, for aircraft radio systems and in other systems, both fixed and mobile, it is not always possible or practical to provide an antenna structure whose equivalent electrical length even approximates a full quarter wavelength of the frequencies at which it may be desired to operate. Thus, the short self-supporting mast type of antenna frequently employed on aircraft is operative as a quarter wave element only at ultra-high frequencies, of the order of 50–60 megacycles in the case of a mast approximately four feet in length. Operation at frequencies whose quarter wavelength is in excess of the mast length may be achieved by employing inductive loading at the base of the antenna, but such a mode of operation is highly inefficient due to unfavorable current distribution on the antenna mast, the more useful portion of the current wave-form appearing on the loading inductance instead of on the mast.

While the art contains examples of antenna systems wherein improved operation, as compared with a base loaded system, may be obtained with antenna heights of less than a quarter wavelength of the operating frequency, these systems are not conveniently adjustable for operation at different frequencies, since such adjustment requires the changing of the value of an inductance mounted at or near the top of the structure. Such systems are particularly unsuited for use in aircraft radio applications for the aditional reason that a coil having adequate insulation to resist voltage breakdown in rarefied atmosphere would contribute appreciable wind resistance to the antenna element.

The present invention, accordingly, has an object the provision of a novel and improved antenna system wherein a mast or other antenna element may be efficiently operated at frequencies whose quarter wavelength is many times greater than the length of the antenna structure, the entire system being adjustable from the base of the structure to permit a high degree of efficiency readily to be obtained at any selected frequency within a wide range of frequencies.

More particularly, the invention is directed to the provision of a compact mast type antenna system of small frontal area for use on aircraft, the system being adjustable from within the craft for highly efficient operation at frequencies ranging from the medium up to and including the ultra-high frequency spectrum, and with a radiation pattern well suited to the requirements of plane-to-plane and plane-to-ground communication, as well as to navigation by radio beams or the like.

With these objects in view, a feature of the invention involves the provision of a mast type antenna of the so-called top loaded type wherein an electrically isolated top section or capacitive member is connected through an adjustable reactance to the upper end of the principal antenna structure, the antenna of the invention being characterized by having this reactance positioned at the base of the structure for ready adjustment, said reactance being connected in the system by a non-radiating transmission line carried within the antenna structure.

As a more specific feature, the invention contemplates the provision of an aircraft radio antenna system employing a mast type antenna which may, if desired, be short enough to permit mounting beneath the plane for improved radiation characteristics and, in the case of military aircraft, minimum interference with visibility and gunfire, the mast comprising an electrically conductive shell having an outer or top section electrically insulated from the main or base section, with an adjustable reactance mounted within the craft and connected between the outer and base sections of the antenna through a transmission line disposed within the base section, said antenna being operated against the aircraft structure as ground and adjustable from within the craft to permit tuning the system for resonant operation at any selected frequency within a range of frequencies whose quarter-wavelength is substantially independent of the

actual height of the mast, while causing a current anti-node to appear on the antenna structure in a position which provides maximum efficiency at the selected operating frequency.

In the drawing illustrating the several features of the invention as embodied in various systems and arrangements, Fig. 1 is a sectional view of an antenna constructed in accordance with the invention and adapted for use on vehicles, the particular embodiment illustrated being shown as installed in an airplane with the antenna projecting downwardly from the underside of the fuselage of the craft; Fig. 2 is a transverse sectional view taken along the line 2—2 of Fig. 1; Fig. 3 is a schematic view of the antenna system of the invention and illustrating, in respect to certain features, an alternative arrangement as compared with the construction of Fig. 1; Fig. 4 is a broken schematic view of the lower portion of an antenna system similar to that shown in Fig. 3, but with capacitive reactance substituted for inductive reactance; and Fig. 5 is a schematic view of another embodiment, wherein the invention is applied to an ungrounded or dipole antenna system.

Considering first the simplified schematic showing of the invention in Fig. 3, the cylindrical portions 8 and 10 may be taken to represent the base and outer sections respectively of the antenna elements or mast structure of an antenna whose height is represented by the distance from A to B, the lower end A being adjacent but insulated from ground. It may likewise be assumed that the distance AB is substantially less than a quarter-wavelength of the operating frequency according to the formula:

Antenna length (in feet) =

$$\frac{234}{\text{frequency}}$$

(in megacycles).

In the case of electrically continuous antenna structure of height AB, the antenna coupling circuit represented by inductance 12 and shunt capacity 14 would, according to conventional practice, be adjusted to values large enough to load the antenna system to resonance. However, in the case of a grounded or Marconi type antenna system which has been so tuned, the current distribution is such that the maximum current occurs at or near the ground connection 16, with the current gradually decreasing to substantially zero near the top or radiating portion of the antenna system. It is therefore evident that with a system employing substantial loading at the base, the current will largely appear on the loading inductance, with very little appearing on the actual antenna structure from which radiation takes place.

To provide greatly increased efficiency while requiring no additional mast height, the antenna system of the invention employs a separate element 10 which may conveniently be the top or outer end portion of the mast structure, electrically isolated from the main or base portion 8 of the antenna structure. This top or outer element serves as a capacitive member which, when connected to the adjacent portion of the base member 8 through an inductive reactance, serves to alter the current distribution on the antenna so that a current maximum may be caused to appear at an elevated position on the main antenna portion 8. This raising of the current maximum on the antenna structure may be readily achieved by providing suitable values of net reactance, which may be inductive or capacitive, depending on antenna length and frequency, even for antennas whose total height is far less than a quarter-wavelength of the operating frequency, with the result that a marked increase in efficiency is attained as compared with a base loaded system.

To make possible convenient adjustment of the system from the base instead of at the top of the antenna as is necessary where the series inductance is disposed at the top of the main antenna section 8, the present antenna provides an arrangement which permits this inductance to be located at the base of the antenna, thus rendering the system practical for use at various operating frequencies with maximum flexibility of operation. In Fig. 3, the adjustable reactance is shown as a variable inductance 18, while Fig. 4 shows as the reactance a variable capacitance or condenser 20. In practice, the provision of suitable switching would permit the insertion of either condenser or inductance as circumstances required.

This adjustable reactance is connected in series through a transmission line between the base member 8 and the outer or capacitive member 10, the connections being made to the outer end of the base member and the inner end of the top member, respectively. A transmission line of the concentric type is illustrated, comprising an outer shielding member 22 and an inner conductor 24. Since this transmission line is less than a quarter-wavelength in length, the mast height having been assumed to be less than a quarter-wavelength of the operating frequency, the transmission line is itself inductively reactive, and in certain cases may supply a large portion of the inductive reactance generally needed to attain the desired current distribution on the antenna system. Such transmission line provides an inductive reactance of relatively low loss characteristics, as compared with the conventional inductance coil. Due to the high voltage which may appear across a series inductance in the case of a top-loaded antenna system, the use of the transmission line for reducing the value of lumped inductance necessary likewise reduces the voltage appearing across the adjusting reactance at the base, thus reducing the possibility of voltage breakdown at high altitudes. Since, in most cases, the transmission line does not have equal and opposite voltages thereon, as is the case with the usual feeder system, the placing of the line within the main structure 8 of the antenna effectively prevents radiation from the line. Complete shielding is provided by enclosing the adjusting reactance represented by coil 18 or condenser 20 in shielding 26 which is electrically continuous with the base portion 8 of the antenna structure.

In tuning the system for operation at a particular frequency, the inductance 12 of the antenna coupling circuit may be coupled to a link coupling coil 28 which is in turn, connected to the radio apparatus, or alternatively, the coil may be taken to represent the tuned circuit itself of a transmitter or receiver or other apparatus without altering the actual adjustment and mode of operation of the system. For any given frequency, resonance may be obtained with various values of the adjustable reactance, represented by inductance 18 or capacitance 20, since the loading effect of the tuning and coupling circuit may be varied over wide values by condenser 14 and inductance 12 in each case. For antenna lengths less than a quarter-wavelength of the operating frequency, the adjustable reactance will generally be inductive. For each value, then, of inductance

18, with the system adjusted to resonance by means of the tuning and coupling circuit, a different current distribution is obtained. While the most satisfactory method to obtain the optimum current distribution on the antenna is by field strength measurements, in general highly satisfactory results are obtained when the current maximum is caused to appear approximately at the mid-point of the main section of the antenna. It is evident that by enabling the adjusting reactance in control of current distribution to be mounted at the base of the antenna, this adjusting for optimum current distribution is greatly simplified, permitting maximum efficiency readily to be attained. In view of the simplicity of adjustment, operation over a wide range of frequencies is made entirely practical, without loss of efficiency even in cases where the antenna length is far short of a quarter-wavelength of the operating frequency.

By way of illustrating a practical application of the system to a specific embodiment wherein its advantages may be fully utilized, Fig. 1 shows an antenna system for vehicles, and more particularly aircraft, where the requirements of limited physical dimensions together with high efficiency have heretofore been met with but little success. The metallic surface of the fuselage of the craft is indicated at 30, with the base and outer portions of the antenna mast represented at 32 and 34, respectively. In view of the reduced antenna length made possible by the invention without loss of efficiency, the mast is shown as projecting downwardly from the underside of the craft, since this affords a somewhat improved radiation pattern with a lower angle of radiation in the vertical plane. Likewise, under-the-plane mounting of the antenna is highly desirable in radio beam navigation in detecting accurately the "cone of silence" when passing directly over the beam transmitter. The mast, of course, may be likewise mounted in conventional fashion so as to project upwardly from the top of the fuselage, or in any other manner, as desired.

The mast structure may be in the form of a streamlined shell (see section, Fig. 2), the outer end section 34, (in this case the lower section) which serves as the capacitive member, being carried by the main section 32 on an insulating sleeve 36. The main or base section is in turn insulated from the fuselage by a flanged insulating bushing 38. The adjusting reactance in control of current distribution is shown as being inductive and therefore equivalent to the inductance 18 of Fig. 3. For convenient adjustment, the reactance in this embodiment is mounted within the fuselage of the craft and contained within shielding 40 formed by an extension of the base section 32. The inductance is represented schematically as a variometer 42, this type permitting convenient adjustment from without the shield by means of a rotatable shaft, the axis of which is indicated by dot and dash line 44. Other forms of variable inductance may be employed as circumstances permit or require, while a variable capacitance similar to the showing of Fig. 4 may be employed when operation is contemplated in a different frequency range relative to antenna length, as hereinafter described.

The inductance 42 is connected between the base and outer sections 32 and 34 of the antenna mast through a transmission line 46 of the open or two-wire type. Insulating spacers 48 are disposed at intervals within the antenna structure to maintain the line rigid and uniformly spaced. Like the line of Fig. 3, the line 46 will, under most conditions of operation, be inductively reactive, being less than a quarter-wavelength in length for all frequencies up to 60 mc., assuming the mast length to be not appreciably greater than three feet as will generally be the case, at least with the downwardly extending mast.

The antenna is connected to the radio equipment 50 by a lead 52 from the base section 32 to one side of the antenna tuning and coupling coil 54, while the other side of the coupling coil is grounded by lead 58 to the fuselage structure 30 of the aircraft close to the base of the mast. To avoid loss of efficiency and detuning effects due to ice formation across the insulators 36 and 38, the whole mast may be enclosed in a thin shell 59 of insulating material which likewise provides an unbroken, smoothly streamlined housing, the housing fitting over the reduced outer portion of the base insulator 38.

In operation, the antenna system will not only be adjusted to resonance, but in addition, by suitable choice of values of inductance 42, a current maximum may be caused to appear at any position on the base section 32 of the mast. There thus results a system possessing the advantages of a full quarter-wave vertical radiator, such as vertical polarization, a low-angle radiation pattern in the vertical plane, and a uniform radiation pattern in the horizontal plane, all of which are of distinct importance in the case of aircraft radio operation. Any improvement in the antenna, such as is made possible by the present system, thus permits a substantial extension in range of communication without adding appreciably to weight or bulk of the equipment as a whole.

For operation at frequencies whose quarter-wavelength may be approximately equal to or even exceed the length of the antenna, as, for example, if the aircraft antenna system hereinbefore described were to be employed for operation in the ultra-high frequency spectrum, the antenna system of the present invention likewise offers distinct advantages over the conventional quarter-wave system. Depending, of course, on the particular operating frequency and the actual antenna length, the reactance in control of the current distribution on the antenna may, to provide the most favorable distribution, be either inductive or capacitive. If the former, then there would be employed the variometer 42 or other form of variable inductance, while capacitive reactance would be provided by the substitution of a variable condenser 20 according to the schematic diagram of Fig. 4. In determining the reactance needed it should be remembered that if the transmission line is greater than a quarter-wavelength but less than a half-wavelength, then capacitive reactance is contributed by the line, while if the line length exceeds a half-wave but is less than three-quarter-wavelengths long, the line again becomes inductively reactive.

Since it is possible, by altering the current distribution, to cause a current anti-node or maximum to appear at a relatively elevated position on the antenna, in the case of a vertical system, or at a point well removed from the base or connection to ground in the case of non-vertical systems, the present system frequently provides operating characteristics superior even to the full quarter-wave antenna, especially where the antenna length is somewhat greater than a quarter-wavelength of the particular operating

frequency. It is thus apparent that the antenna system may be employed for effective communication, both transmission and reception, at frequencies ranging from those where the mast length is but a small fraction of a quarter-wavelength, up to and including frequencies where the mast length is greater than a quarter-wavelength, in each case with a marked increase in efficiency as compared with systems heretofore employed and available.

In certain applications it is not possible or desirable to employ a grounded or Marconi type antenna system. Such a situation occurs where an antenna having well-defined directional characteristics is required, as for example, in the case of instrument of "blind" landing of aircraft, where an ultra-high frequency beam must be accurately followed to obtain the proper glide path. For this purpose a dipole system is frequently employed, the dipole being mounted on the aircraft transversely of the axis of the fuselage.

To provide a dipole type antenna of reduced over-all length, well adapted for aircraft use where minimum wind resistance is essential, the embodiment illustrated in Fig. 5 may be employed. The system is substantially similar to that shown in Fig. 3, with ground omitted and a duplicate of the system of Fig. 3 connected in its place. The system thus comprises left and right base or main sections 60 and 62, associated outer end sections 64 and 66, and separate adjustable reactances, shown as inductances 68 and 70. These reactances are disposed adjacent the center of the system for convenient adjustment, and are mounted in separate shield cans 72 and 74 continuously with their associated main antenna sections 60 and 62. These inductances are connected between their associated outer elements and base sections by transmission lines shown as 76 and 78, though the two-wire or other types of lines may be employed. A coupling coil 80 provides transfer of radio frequency energy to or from link coupling coil 82 of the radio equipment in accordance with conventional practice. As in the previously described embodiments, adjustment of the variable reactances 68 and 70 and the coupling inductance 80 with its associated variable capacitance 84 permits the system to be tuned to resonance, and in addition, permits increased current to appear along the dipole element by reducing the value of the tuning and coupling reactance necessary to tune the system to resonance.

In connection with the coupling units illustrated in the drawing, it is to be understood that while parallel tuned circuits have been illustrated, the invention is not limited thereto but contemplates the use of series tuned circuits where circumstances result in such circuits being preferable. For antenna coupling purposes, the use of either series or parallel tuned circuits, as the case may require, is well recognized in the art. Likewise, where "ground" has been referred to, it is to be understood that this may refer either to the conventional connection to earth, or to conductive structure of such dimensions as to be substantially non-resonant, as for example, the metallic structure of a vehicle, the fuselage of aircraft, or the like.

The nature and scope of the invention having been indicated, and various embodiments thereof including a specific application illustrated and described, what I claim is:

1. An antenna system comprising a main section, a capacitive member at one end thereof and insulated therefrom, a reactance adjacent the other end of the main section, and a transmission line connecting the reactance between the capacitive member and the end of the main section adjacent said member, said transmission line being shielded at least in part by the main section of the antenna.

2. An antenna system comprising a main antenna element, a capacitive member at the top thereof and insulated therefrom, a reactance adjacent the base of the main element, and means including a connection from the capacitive member to the reactance for connecting the reactance between said capacitive member and main antenna element, said connection running within and being shielded by said main antenna element.

3. In an antenna system of the grounded type, a main antenna section, a capacitive member at the top thereof and insulated therefrom, an adjustable reactance adjacent the base of the main section, and a transmission line connecting the adjustable reactance between the capacitive member and the main section, said transmission line running within and being shielded by said main section of the antenna.

4. An antenna system comprising an electrically-conductive antenna member having a physical length substantially less than a quarter-wavelength of the operating frequency, a capacitive element at the top of the member and insulated therefrom, an adjustable reactance adjacent the base of the antenna member, and a transmission line running from said reactance to the top of the antenna member and to the capacitive element to connect the reactance therebetween, whereby the current distribution on the antenna member may be controlled by adjusting the reactance at the base thereof.

5. An antenna system comprising an electrically-conductive shell having a length less than a quarter-wavelength of the operating frequency, a capacitive element at the top of the shell and insulated therefrom, a variable inductance adjacent the base of the shell, a transmission line disposed within the shell and connecting the variable inductance across the capacitive element and top of the shell, said line being less than a quarter-wavelength long and inductively reactive, whereby an inductive reactance is provided between capacity element and top end of the shell, the value of said reactance being adjustable at the base of the structure to provide control of the current distribution on the shell at the selected operating frequency.

6. A radio antenna system for aircraft comprising a conductive mast insulated from and projecting outwardly from the structure of the craft so as to be electrically exposed to space, said mast having a length less than a quarter-wavelength of an operating frequency to be employed, the mast comprising a base section and a relatively shorter outer section insulated therefrom, a variable reactance enclosed within the portion of the base section adjacent the structure of the craft, and a transmission line disposed within the base section and shielded thereby, said transmission line extending from the variable reactance to the outer section and adjacent portion of the base section, respectively, to connect said reactance across said mast section and thereby provide a reactance therebetween adjustable at the base of the mast to cause a current anti-node to appear at a position on the mast outwardly of

the base thereof at the selected operating frequency.

7. A radio antenna system for aircraft comprising a conductive mast insulated from the structure of the craft and electrically exposed to space, said mast comprising base and outer sections with electrical insulation therebetween, a variable inductance disposed adjacent the base section, a transmission line enclosed within said base section and extending from the inductance to the outer section and adjacent portion of the base section, to connect said inductance across said mast sections, and adjustable tuning and coupling means disposed adjacent and connected between the base of the mast and the adjacent structure of the aircraft for coupling the antenna to radio equipment, said variable inductance and adjustable coupling means enabling the system to be adjusted to resonance while causing a current anti-node to appear at an elevated position on said mast at frequencies whose quarter-wavelength is substantially in excess of the length of the mast.

8. A radio antenna for aircraft comprising an electrically conductive mast, insulating means at the base thereof for mounting the mast on aircraft with the mast projecting outwardly from the structure of the craft, said mast comprising a main element and an outer end member insulated therefrom, reactive means mounted adjacent the base of the mast and connected to the outer end member and main element by connecting means within the mast, and a cover of insulating material forming a substantially complete enclosure for the mast.

9. A dipole antenna system having a total physical length substantially less than a half-wavelength of the operating frequency, said antenna comprising main antenna elements and outer end portions insulated therefrom, tuning and coupling means connected between the inner ends of the main antenna elements, reactive means disposed adjacent the inner ends of said antenna elements, and means carried within the main antenna elements for connecting the reactive means between the outer end portions and the adjacent antenna elements.

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