Oct. 16, 1945. M. BRUCE 2,387,116

RADIO ANTENNA SYSTEM

Filed April 8, 1944 2 Sheets-Sheet 1

Fig. 1.

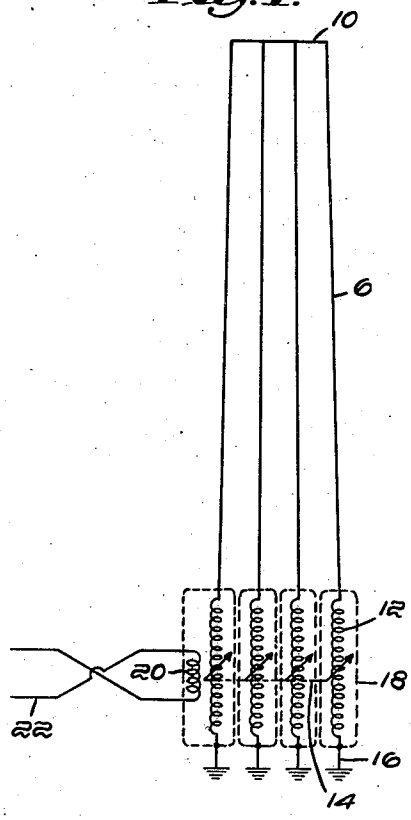
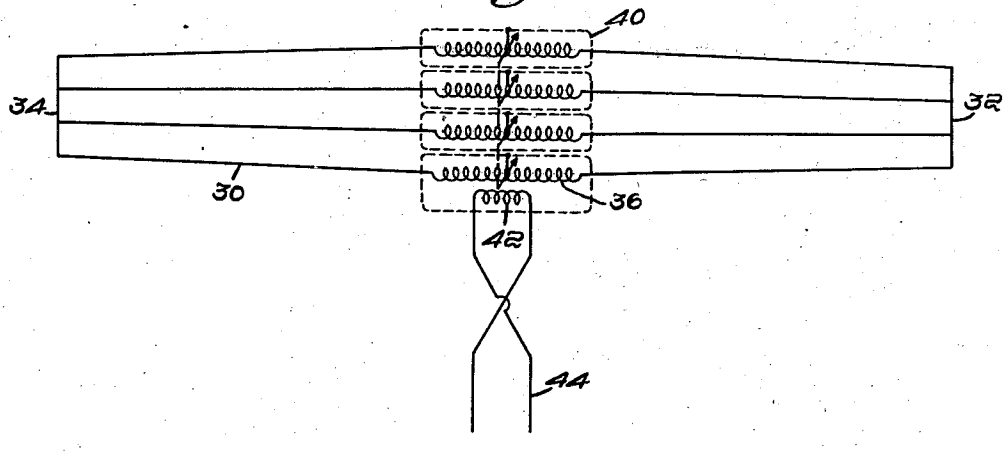



Fig. 2.




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Fig. 3.

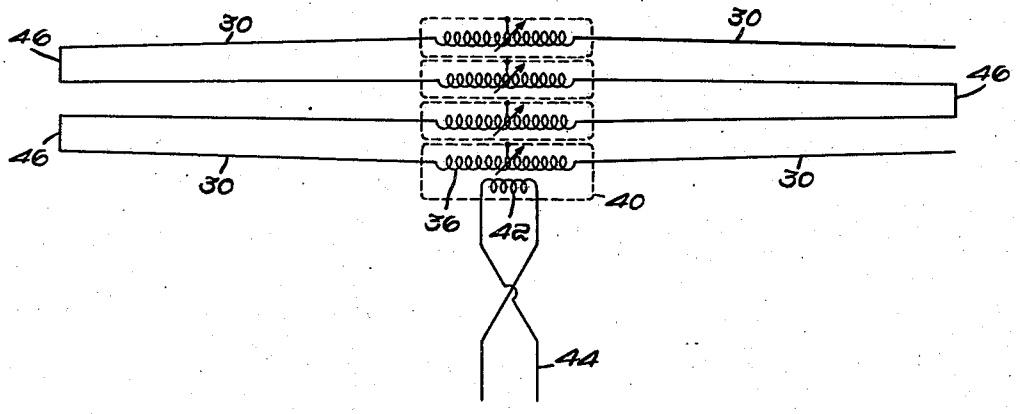
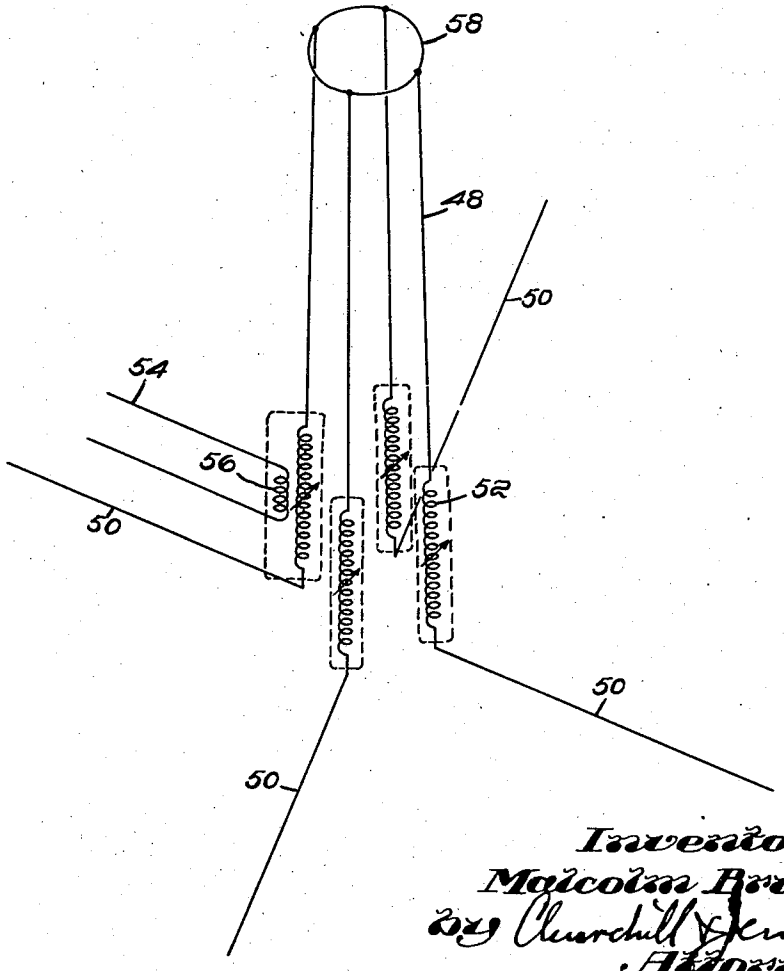



Fig. 4.




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Patented Oct. 16, 1945 2,387,116

# UNITED STATES PATENT OFFICE

2,387,116

## RADIO ANTENNA SYSTEM

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Application April 8, 1944, Serial No. 530,103

10 Claims. (Cl. 250—33)

The present invention relates to antenna systems and more particularly to systems wherein the physical dimensions of the antenna are small relative to the operating frequency. The invention is principally concerned with improvements in antenna systems for use on aircraft and other vehicles, though it possesses a wide field of application where antenna systems of small dimensions are required.

For a number of purposes, a vertical quarter-wave element operating against ground possesses certain desirable operating characteristics. Such an antenna is non-directional in the horizontal plane, provides radiation with vertical polarization, and is an efficient radiator. Thus for general communication purposes it is frequently desirable to attempt to realize the characteristics of a vertical quarter-wave grounded system.

In many instances, however, the operation frequency is such that it is impossible to employ an antenna structure that even remotely approaches the dimensions of a quarter-wave element. Particularly is this the case where the antenna element is to be mounted on vehicles, especially aircraft, where the size of the element is strictly limited to dimensions which are normally resonant only at the higher frequencies. For operation at lower frequencies, the equivalent electrical length of such an element may be but a small fraction of a quarter wavelength, possibly $1/30$ wavelength, for example.

Resonant operation of a short antenna element is possible by inserting at the base a loading circuit having a relatively large value of inductive reactance, but such an arrangement is exceedingly inefficient. The reason for this is readily apparent when the factors influencing the radiation efficiency of such a system are considered. In general, the radiation efficiency varies directly as the radiation resistance and inversely as the sum of the radiation and loss resistances. The radiation resistance of a grounded quarter-wave vertical antenna referred to the base is approximately 36 ohms. With shorter antennas the radiation resistance is proportionately less, and may be only a fraction of an ohm in the case of an antenna that is very short relative to its operating frequency.

The loss resistance consists of ground losses and losses in the base loading circuit. In so far as vehicle antennas are concerned, the ground losses are generally low because in most instances the ground comprises a considerable amount of highly conductive metallic structure. The most important source of loss is therefore to be found in the base loading circuit. When the radiation resistance is of the same order as the loss ressitance of the antenna system, the efficiency of the system is unreasonably low, as the power radiated and the power loss are of the same order of magnitude. In extreme cases the power radiated may be but a small fraction of the power supplied to the antenna system.

If, however, the radiation resistance of the antenna can be increased appreciably, a substantial improvement may be realized. Where, as in the case under discussion, the loss resistance is excessive due to the insertion at the base of a loading circuit having a relatively large value of inductive reactance in order to attain resonant operation, the possible improvement in efficiency which results upon even a moderate increase in radiation resistance is considerable.

It is therefore an object of the invention to provide an intenna system of small physical dimensions relative to the frequency of operation but having relatively high radiation resistance.

Another object of the invention is to provide a compact and efficient antenna system which may be readily adjusted for resonant operation over a relatively wide range of frequencies.

Still another object of the invention is to provide an antenna system of small physical dimensions relative to its operating frequency, and having a favorable current distribution along its length.

For certain purposes an antenna system having somewhat different characteristics than those of a quarter-wave antenna may be desired, for example those of an ungrounded or dipole type of antenna. The invention therefore contemplates as still another object the provision of a dipole type antenna which may be small in size relative to its operating frequency but nevertheless capable of operating at high efficiency.

Figure 1 illustrates in schematic fashion one form of the antenna system of the invention, while Figure 2 illustrates in similar fashion a dipole antenna system embodying the invention. Figures 3 and 4 illustrate modified forms of the antenna system of the invention. The realization of specific embodiments of these systems for particular applications may be readily accomplished by those skilled in the art.

The antenna system of the invention employs a plurality of closely spaced substantially parallel linear elements 6, such as wires, rods, tubes or the like. In the case of the grounded type antenna as shown in Figure 1, these elements will be perpendicular to the surface of the ground

or structure equivalent to ground. While the spacing between elements is preferably a very small fraction of a quarter wavelength, the spacing of these elements is not at all critical and need not be exactly uniform provided that the system is symmetrical. For vehicle use, the elements may be contained in a simple hollow shell of insulating material, the shell having appropriate contour for the specific application.

Since the invention is concerned with antennas which are very much shorter, relative to the operating frequency, than antennas of conventional design, it will be assumed for purposes of illustration that the length of each element **6** may be only 1/30 of a wavelength or less of the desired operating frequency. Normally an antenna of this length would have such a low value of radiation resistance that if base loading were attempted in order to attain resonant operation, very little radiation would take place, and substantially all the power supplied to the antenna would be dissipated by losses in the loading reactance and ground.

As will hereinafter appear, the radiation efficiency may be substantially increased by the provision of a plurality of antenna elements which are arranged in substantially parallel closely spaced relation and operated in phase. In-phase operation is attained by interconnecting the elements at a point remote from the base or tuning means and adjacent the top or outer ends, as by the jumper **10** or other low impedance means. In order that each element may be adjusted to resonance, separate base-loading reactances **12** are provided between the lower ends of the elements and ground. These reactances are inductive, comprising variable inductances or inductively reactive circuits.

For tuning the system, the variable elements of the inductive reactances **12** may be ganged in conventional manner for simple control tuning, as indicated by the dot-and-dash line **14**. Short direct leads **16**, preferably separate, connect the reactances to ground or to the equivalent ground supplied by the metallic structure of the vehicle in case of a mobile installation. Shielding between the separate reactances is desirable, such as indicated at **18**.

In coupling the system to the radio equipment, coupling need be made to one of the elements only, since all elements are maintained in phase through having their top or free ends coupled or connected together. As a result, the excitation of one antenna element excites the other elements in phase. The coupling system may comprise an inductance **20** coupled to one of the antenna inductances **12** and connected by a transmission line **22** of appropriate impedance to the radio equipment, not illustrated.

The improved performance of the above-described system arises from the fact that when several antenna elements are arranged in close proximity, a current in each element induces a voltage in every other element, giving rise to mutual impedances such as exist in any other coupled circuit arrangement. The resistance componant of this antenna impedance is the radiation resistance, while the reactive component depends upon the tuning of the system and becomes zero at resonance. The multi-tuned in-phase antenna system can, therefore, be considered as a plurality of circuits each having a self-impedance, together with a mutual or transfer impedance relative to every other antenna element of the system.

When several antenna elements, operating substantially in phase by reason of having their free or outer ends coupled or connected together by a jumper or other low impedance, are arranged in closely spaced relation, the resistive component of the transfer impedance of each element to every other antenna element is found to be approximately equal to the radiation resistance of a single antenna element. Thus, when the multi-tuned in-phase antenna system comprises two elements, the current in each element is half of the total current and the radiation resistance of each element becomes approximately twice that of a single element antenna. When the antenna system comprises four elements the current in each element is one-fourth of the total current and the radiation resistance of each element is therefore approximately four times that of a single element antenna.

Where the antenna dimensions are such that normally the radiation resistance would reach low values with a corresponding reduction in radiation efficiency, as in the case of an antenna whose length is a small fraction of a quarter wavelength of the desired operating frequency, the use of a multi-element system having independent base loading means for the individual closely spaced elements permits a substantial increase in radiation efficiency, depending on the number of elements employed. Since no increase in height is required, and as the elements may be very closely spaced, the physical dimensions of the system as a whole are not appreciably larger than a single element base-loaded system. Since there is no appreciable potential difference between corresponding points of the various antenna elements, only a minimum amount of insulation need be employed between the several elements. For aircraft use, the entire system might well be enclosed in a single protective insulating enclosure of relatively small frontal area.

A further advantage results from the fact that for a certain power supplied to the antenna, the voltage at the free end will be practically the same regardless of whether the antenna is a multi-tuned in-phase system or a single element system. The input voltage will however be higher in the case of the multi-tuned system, due to the increased radiation resistance at the base, and accordingly there will be less variation in the voltage standing wave between the base and the free end of the antenna. Correspondingly, there will be less variation in the current distribution between these points. The more uniform current distribution on the antenna element substantially increases the radiation efficiency because the available length of the antenna is more effectively utilized, since the radiation from any point on an antenna is proportional to the square of the current at that point.

As the radiation resistance of each antenna element is increased, the tuning of the system becomes correspondingly more broad, and ganged tuning becomes practical. By the substantial increase in radiation resistance achieved through multi-tuned in-phase operation the use of a base loading reactance of considerable magnitude is made possible while retaining satisfactory radiation efficiencies. As a result, the antenna elements may be much shorter than conventional practice dictates, without sacrifice in performance.

The same principles and advantages apply in the case of a dipole or ungrounded system, which may be employed where no ground or structure

equivalent to ground is available, or where the radiation pattern of a dipole is desired. As illustrated in Figure 2, the system is composed of a plurality of substantially colinear elements **30** arranged in pairs to form dipoles which are disposed in substantially parallel closely spaced relation with their outer ends coupled or joined by jumpers **32** and **34** respectively to provide in-phase operation. As in the first described arrangement, the length of each element may be substantially less than a quarter-wavelength of the operating frequency, so that the overall length of each dipole is substantially less than the approximately half-wavelength dimensions of a conventional dipole. To attain resonant operation under these conditions, inductive reactances **36** are connected between the inner ends of each pair of elements. The reactances are adjustable, and single control tuning means is preferably provided, as in the previously described embodiment. Individual shields **40** are likewise provided, the shields being connected to the mid point of the reactances enclosed therein. Coupling to one of the reactances **36** is made by a coupling coil **42** fed by transmission line **44** from the radio equipment, not shown.

This system is particularly effective in applications where a dipole type antenna is required and where the limitation on physical dimensions of the antenna is such that the radiation resistance of a conventional system would be very much less than a conventional half-wave antenna of approximately 72 ohms resistance at the center. By making possible a substantial increase in radiation resistance, an efficient system may be provided even though the overall dimensions are so small that substantial values of loading reactance are necessary at the center of each pair of colinear elements in order to attain resonance at the operating frequency.

While preferably the several dipoles are coupled or connected together at each end thereof, as illustrated in Figure 2, it is sufficient if but one end of each pair of colinear elements or dipole is connected to the corresponding end of another pair of elements or dipole. Such interconnection of one or both ends insures that the dipoles operate in phase, with consequent increase in radiation resistance as compared with a single dipole of similar dimensions. Figure 3 illustrates an arrangement involving bonds **46** at one end only of each dipole.

In certain applications, considerations of space and structure may preclude the use of either the grounded or the dipole type system. In such cases, the modification illustrated in Figure 4 may be advantageously employed. The system resembles the multiple dipole arrangement of Figure 2 in that the antenna is made up of relatively short elements **48** and **50** (in terms of operating frequency) which are arranged in pairs with center-connected loading reactances **52** for adjusting the system to resonance. Each pair of elements constitutes in effect a bent dipole, with the elements **50** forming an angle with the closely spaced elements **48**. Coupling to the radio equipment (not shown) is by transmission line **54** and coil **56**, coupled to one of the loading reactances. The closely spaced elements **48** have their free ends connected together by a jumper **58** to insure in-phase operation, with consequent beneficial increase in the radiation resistance of the system.

Having thus described the invention as embodied for purposes of illustration in systems operating in the manner of grounded quarter-wave and ungrounded half-wave systems, I claim as my invention:

1. A radio antenna system comprising a plurality of closely spaced antenna elements substantially less than a quarter-wavelength of the operating frequency in length, a plurality of inductively reactive tuning means connected in the antenna elements in the vicinity of a current loop, means for coupling radio equipment to at least one of the antenna elements, said elements being spaced less than a quarter-wavelength apart, and low impedance means connecting said elements at a point remote from the tuning means to provide substantially in-phase operation of the elements at the operating frequency.

2. A radio antenna system comprising a plurality of closely spaced antenna elements substantially less than a quarter-wavelength of the operating frequency in length, individual inductively reactive tuning means connected between each antenna element and ground, and means for coupling radio equipment to at least one of said antenna elements, the elements being spaced less than a quarter-wavelength apart and connected by low impedance means adjacent their free ends to provide substantially in-phase operation of said elements at the operating frequency.

3. A radio antenna system comprising a plurality of closely spaced antenna elements substantially less than a quarter-wavelength of the operating frequency in length, individual inductively reactive tunable devices connected between each antenna element and ground, common actuating means for tuning said devices simultaneously, means for coupling radio equipment to at least one of said antenna elements, said elements being spaced less than a quarter-wavelength apart, and low impedance means connecting the free ends of said elements to provide substantially in-phase operation of said elements at the operating frequency, whereby the radiation resistance of the system is caused to be substantially higher than the radiation resistance of a single element system of similar dimensions.

4. A radio antenna comprising a plurality of pairs of closely spaced antenna elements, the elements of each pair being substantially colinear, at least one element of each pair having a length substantially less than a quarter-wavelength of the operating frequency, individual inductively reactive tuning means connected between the inner ends of each pair of elements, means for coupling radio equipment to at least one of said pairs of elements, said pairs of elements being spaced less than a quarter-wavelength apart, and low impedance means connecting said elements at a point remote from the tuning means to provide substantially in-phase operation of the elements at the operating frequency.

5. A radio antenna system comprising a plurality of closely spaced antenna elements substantially less than a quarter-wavelength of the operating frequency in length, individual inductively reactive tuning means connected between each antenna element and ground or equivalent, common actuating means for tuning said means, individual shielding means for each of said tuning means, means for coupling radio equipment to at least one of said antenna elements, said elements being spaced less than a quarter-wavelength apart, and low impedance means connecting the free ends of said elements to provide substantially in-phase operation of said elements at the operating frequency, whereby the radiation resistance of the system is caused to

be substantially higher than a single element system of similar dimensions.

6. A radio antenna system comprising a plurality of pairs of closely spaced antenna elements, the elements of each pair being substantially colinear, each element having a length substantially less than a quarter-wavelength of the operating frequency, individual inductively reactive tuning means connected between the inner ends of each pair of elements, and means for coupling radio equipment to at least one of said pairs of elements, said pairs of elements being spaced less than a quarter-wavelength apart the outer ends of the elements being connected together to provide substantially in-phase operation of the system at the operating frequency and thereby afford substantially greater radiation resistance than that of a single dipole of similar dimensions.

7. A radio antenna system of the dipole type comprising a plurality of pairs of antenna elements spaced less than a quarter-wavelength apart, each element having a length substantially less than a quarter-wavelength of the operating frequency, individual inductively reactive tuning means connected in each pair of elements in the vicinity of a current loop, common actuating means for tuning said means, individual shielding means for each of said tuning means, means for coupling radio equipment to at least one of said pairs of elements, and means connecting the free ends of said elements to provide substantially in-phase operation of the system at the operating frequency, whereby the radiation resistance of the system is caused to be substantially higher than a dipole system employing a single pair of elements of similar dimensions.

8. A radio antenna system comprising a plurality of pairs of antenna elements, each element having a length substantially less than a quarter-wavelength of the operating frequency, at least one element of each pair being disposed in substantially parallel relation to at least one element of another pair and spaced therefrom less than a quarter-wavelength, individual inductively reactive tuning means connected between the elements of each pair, means for coupling radio equipment to at least one of said pairs of elements, and means interconnecting said elements at a point remote from the tuning means to provide substantially in-phase operation of the system at the operating frequency.

9. A radio antenna system comprising a plurality of pairs of antenna elements, each element having a length substantially less than a quarter-wavelength of the operating frequency, at least one element of each pair being disposed in substantially parallel relation to at least one element of another pair and spaced therefrom less than a quarter-wavelength, individual inductively reactive tuning means connected between the elements of each pair, means for coupling radio equipment to at least one of said pairs of elements, and means coupling the free ends of the closely spaced elements to provide substantially in-phase operation of the system at the operating frequency.

10. A radio antenna system comprising a plurality of pairs of antenna elements, each element having a length substantially less than a quarter-wavelength of the operating frequency, at least one element of each pair being disposed in substantially parallel relation to at least one element of another pair and spaced therefrom less than a quarter-wavelength, individual inductively reactive tuning means connected between the elements of each pair, common actuating means for tuning said means, individual shielding means for each of said tuning means, means for coupling radio equipment to at least one of said pairs of antenna elements, and means coupling the free ends of the closely spaced elements to provide substantially in-phase operation of the system at the operating frequency.

MALCOLM BRUCE.