United States Patent

Boyer

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[54] **TUNABLE RADIO ANTENNA**

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[21] Appl. No.: **702,963**

[52] **U.S. Cl.** **343/742,** 343/867, 343/748, 343/750

[51] **Int. Cl.** **H01q 11/12**

[58] **Field of Search**..................343/742, 741, 748, 850, 744, 343/855, 867, 750, 755

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Primary Examiner—Herman Karl Saalbach
Assistant Examiner—Saxfield Chatmon, Jr.

[57] **ABSTRACT**

A tunable, resonant antenna in which reduction in height and multiple frequency band operation is achieved by using a symmetrical in-phase array of two or more electrically short, vertical wave radiator elements of equal length which are brought to electrical resonance by end connection to an equal number of horizontal transmission line sections so folded in alignment as to be non-radiative, such transmission line sections being commonly terminated in a shunt variable reactor located at the center of the symmetrical array to provide change of the resonant frequency.

20 Claims, 16 Drawing Figures

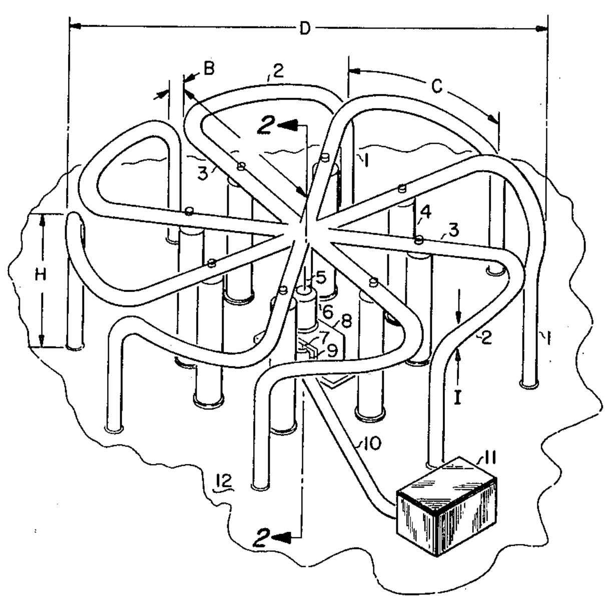

FIG 1

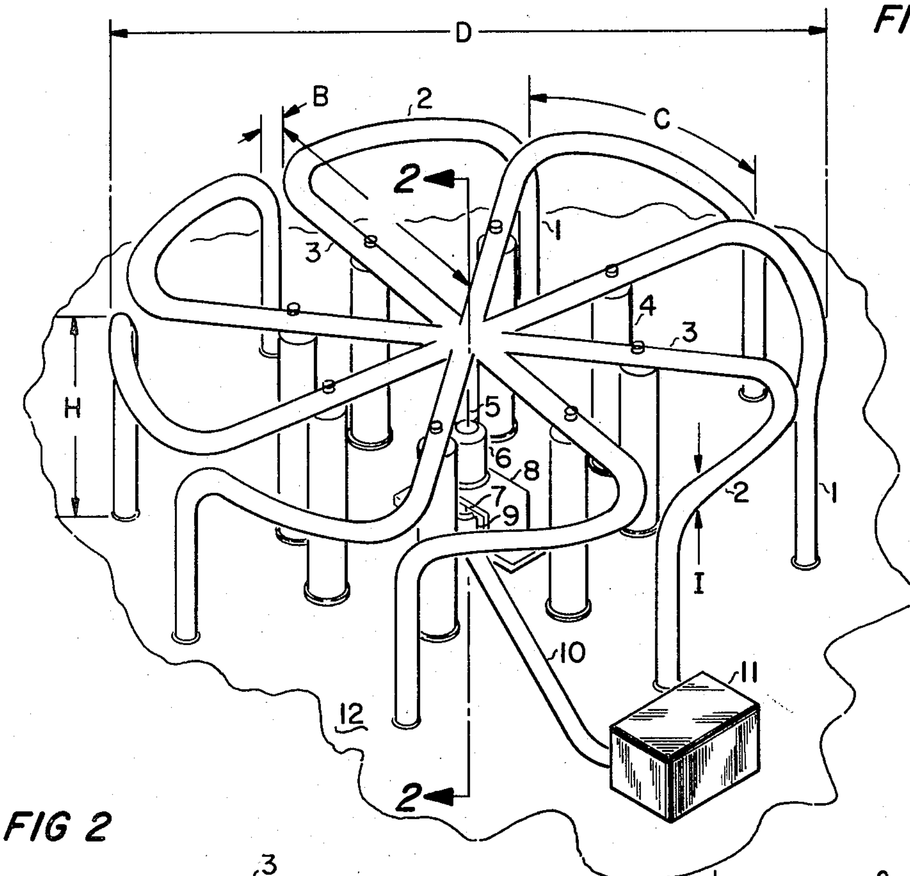

FIG 2

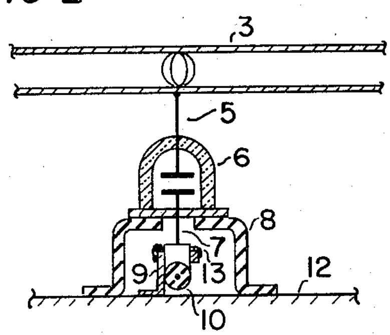

FIG 3

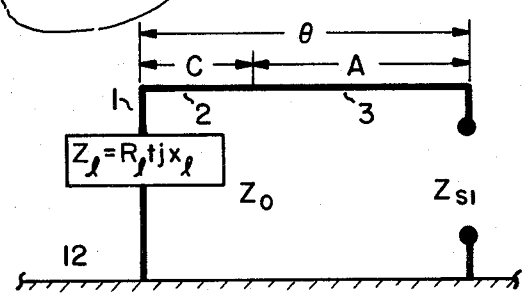

FIG 4

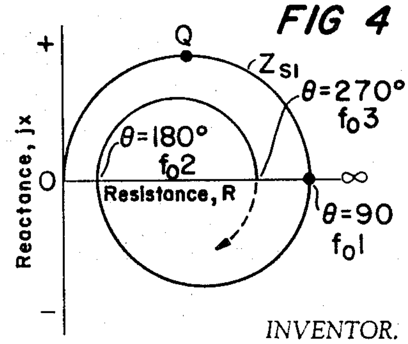

FIG 5

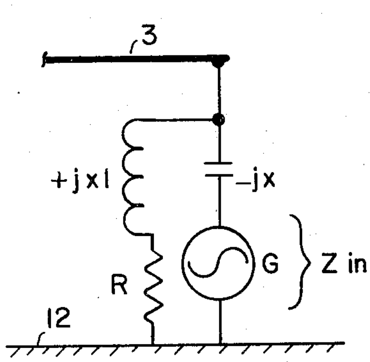

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FIG 6

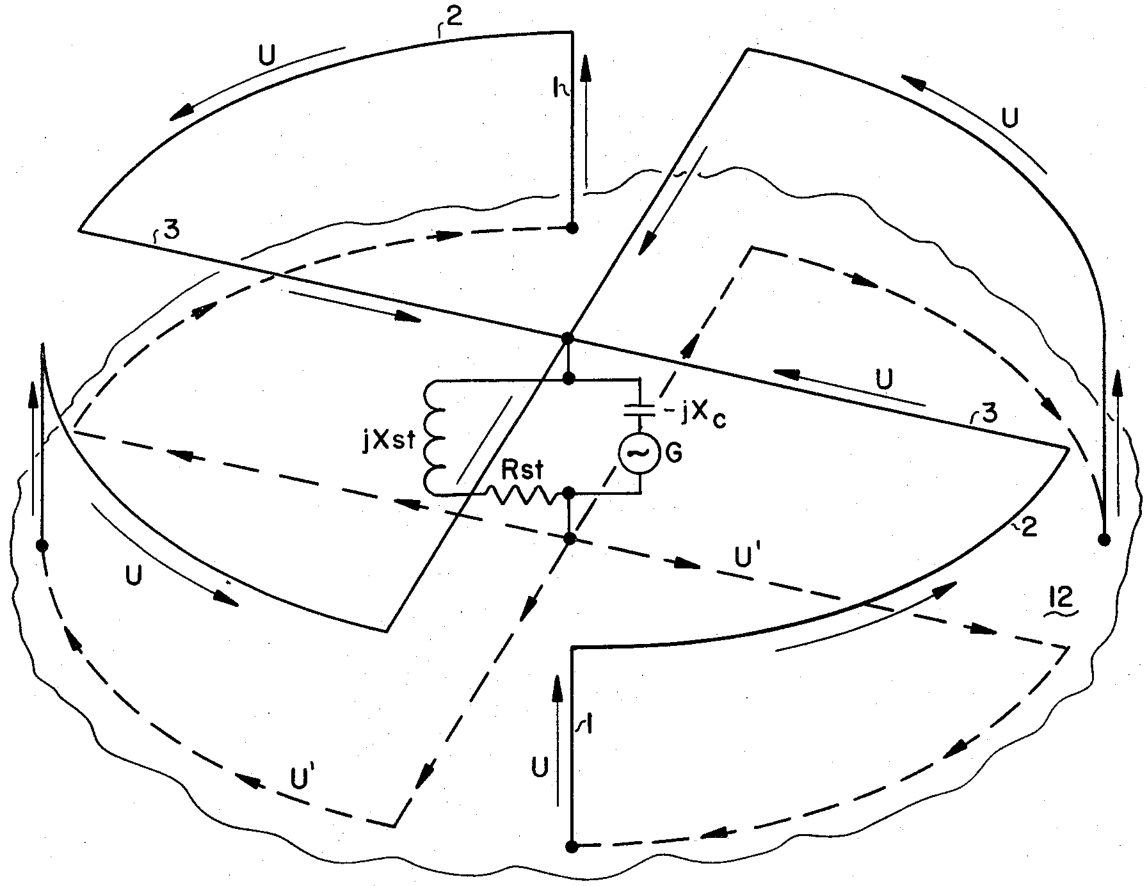
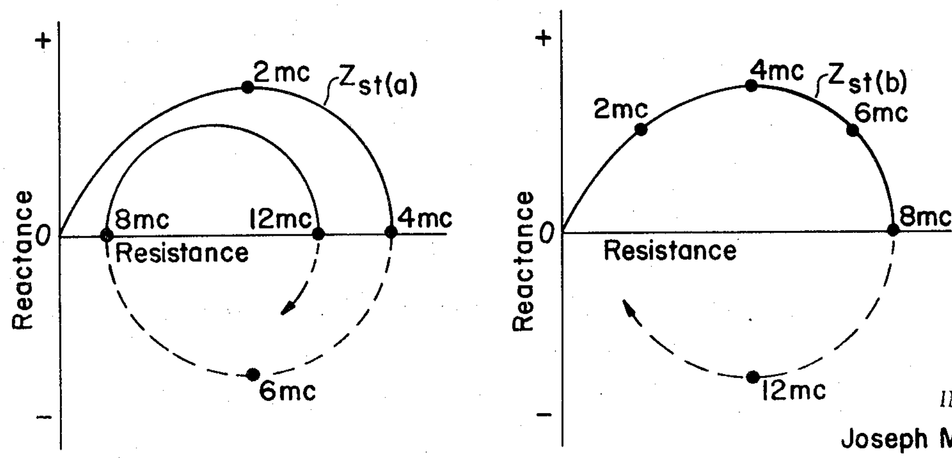


FIG 9



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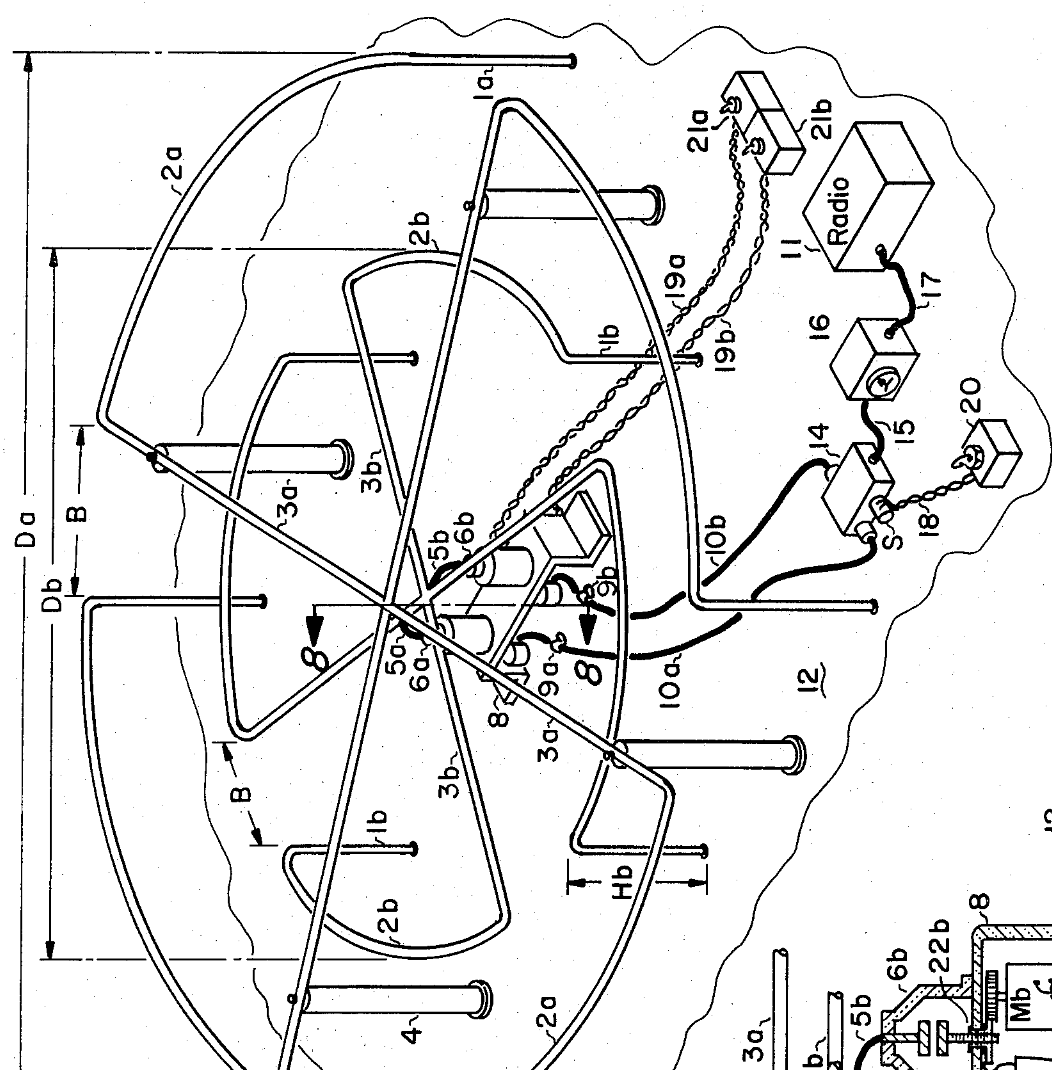

FIG 7

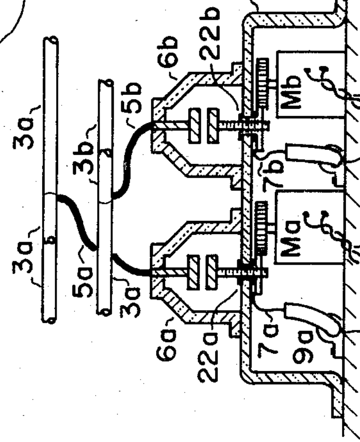

FIG 8

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FIG 10

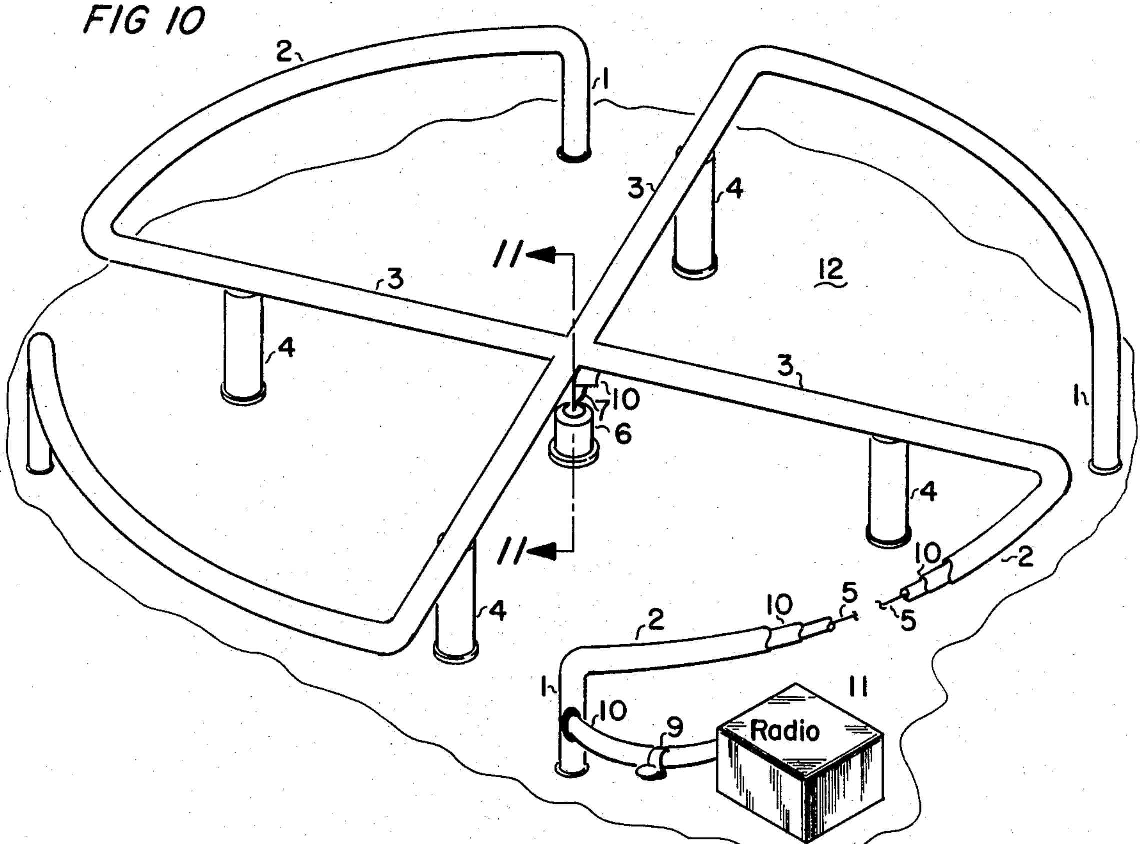

FIG 11

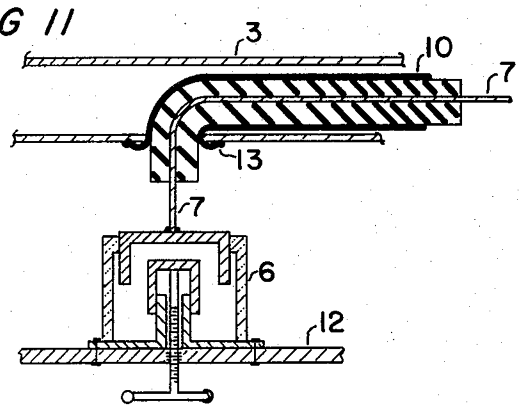

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FIG 12

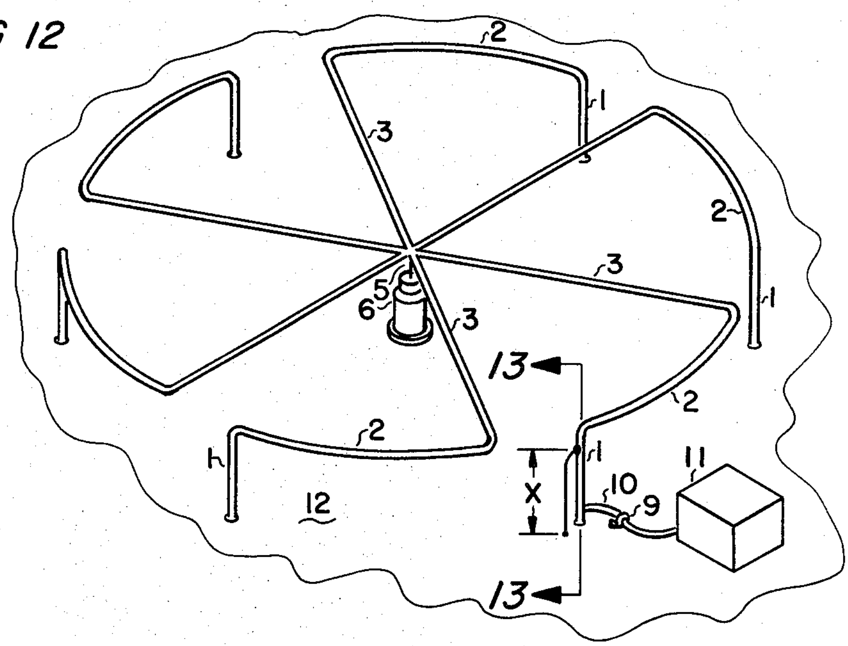

FIG 13

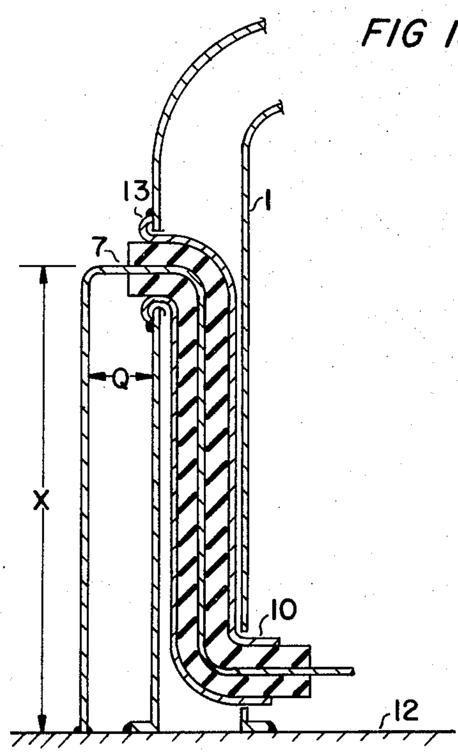

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FIG 14

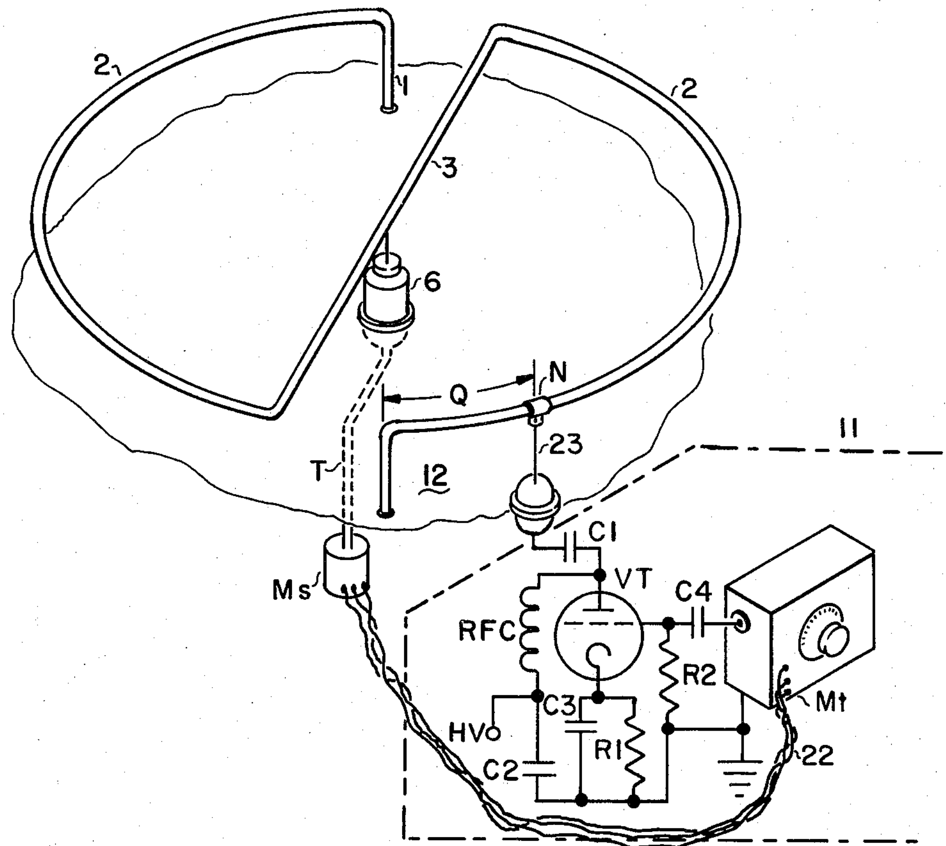
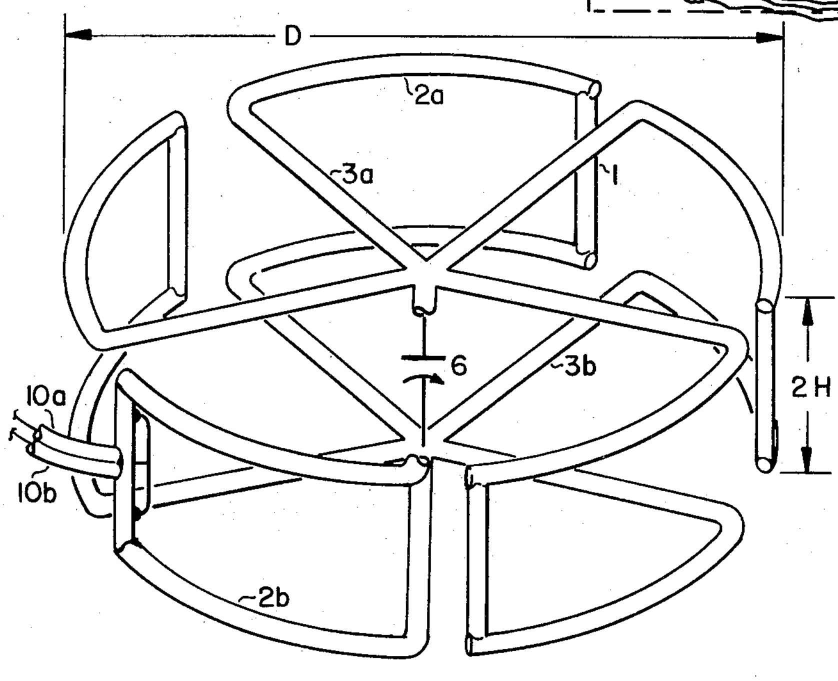


FIG 15



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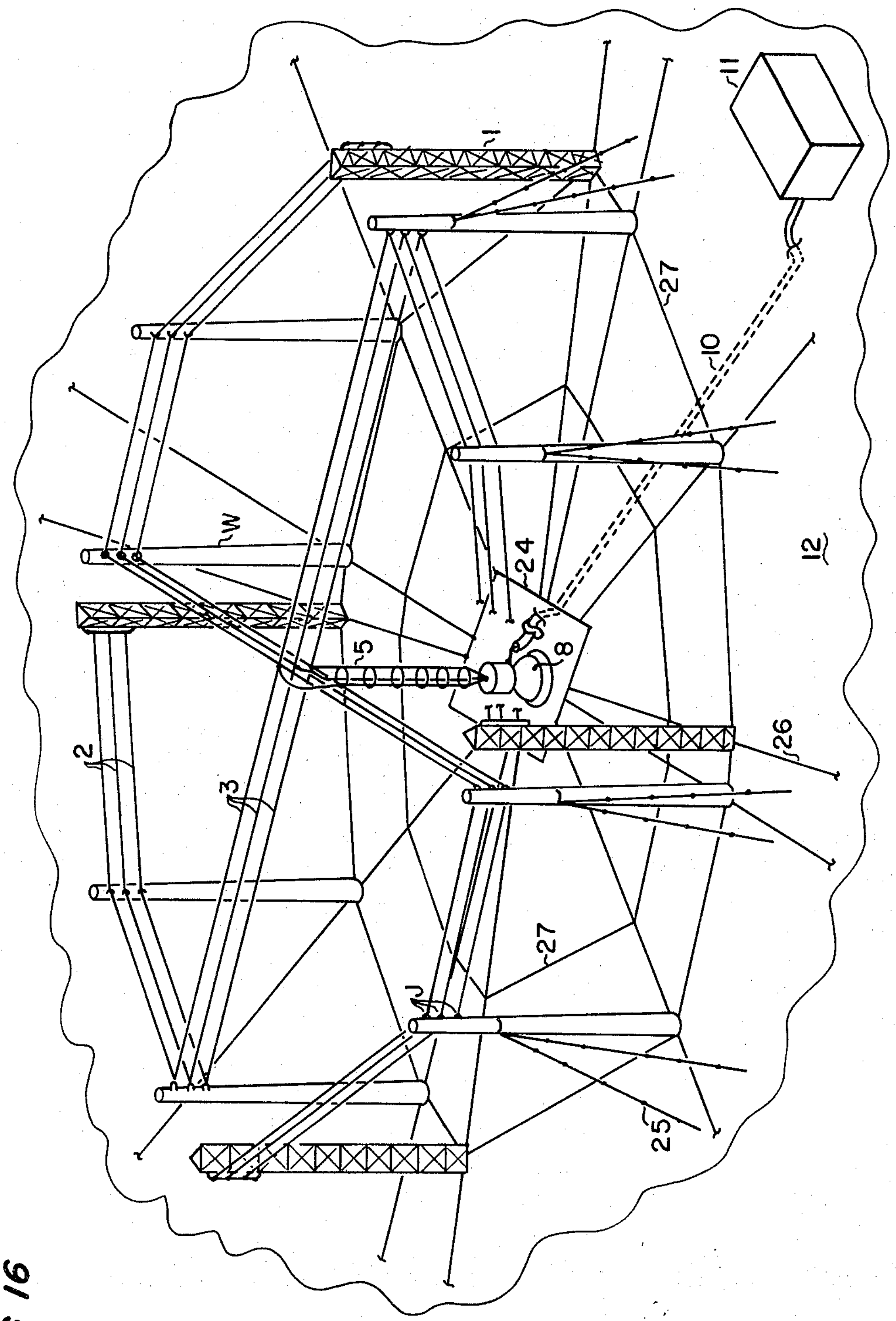

FIG 16

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TUNABLE RADIO ANTENNA

This invention relates to antennas for the radiation and reception of electromagnetic wave energy. More particularly, the invention is directed to antennas of small electrical height capable of being tuned rapidly over a broad band of the radio frequency spectrum.

There are many instances where it is desirable to employ antenna radiators with radio communications apparatus in which the height of extension of the antenna above the conductive skin of a vehicle or the earth plane is less than one quarter wavelength at the operating radio frequency employed. Skilled practitioners of the prior art have devised ingenious and divers embodiments by which auxiliary means in the form of inductive and capacitive reactive loading is applied to such electrically short antennas to achieve the condition of electrical resonance. It is well known that when inductive reactance means alone is used for establishing resonance in an electrically short antenna, the current flowing on such antenna radiator must fall to zero magnitude at its top extremity. For such case, and when such current distribution is essentially sinusoidal, the radiation resistance magnitude R_e of the resonant, electrically short antenna of height H is,

$$R_e = 20\pi^2 (H/\lambda)^2 \quad (1)$$

where λ is the wavelength of the operating radio frequency. When a large conductive area such as a metal plate or a wire grid is connected to the top extremity of the antenna radiator, the current magnitude at the upper extremity of the antenna radiator is increased and can theoretically approach a uniform distribution in which the radiation resistance increases to,

$$R_e = 80\pi^2 (H/\lambda)^2 \quad (2)$$

Many difficulties are attendant on the employment of such resonating embodiments of the prior art when applied to an electrically short antenna radiator. Well known are the difficulties of changing the tuning of such antennas to new frequencies rapidly, the power loss encountered in inductive loading means, and the need for use of auxiliary impedance matching networks to work such antennas into standard feed transmission lines. More important,however, is that such auxiliary loading means of the prior art add considerably to the total spacial volume occupied by the antenna radiator system while contributing little to the increase in radiative volume which is related to the vital parameter of radiation resistance. Thus, by way of example, employment of the most efficient embodiment of the prior art, that of capacitive loading alone connected at the top extremity of an electrically short vertical antenna radiator working against the earth ground plane, may increase the total spacial volume of the antenna system over that of the electrically short antenna alone, by more than 10,000 times yet increase the radiation resistance by a factor of only four by virtue of modifying the current distribution thereon so as to approach that given in Equation (2).

With these problems in mind, it is the principal object of this invention to provide an improved resonant, tunable antenna radiator of small height which gives an increased radiation resistance over that obtainable from equal height antenna embodiments of the prior art, in which the spacial volume occupied by the invention antenna and those of the prior art are equal.

In this connection I have discovered that by symetrically distributing two or more electrically short, parallel antenna current elements about a geometric center point, such plural antenna current elements being brought into wave resonance by connection respectively to an equal plurality of folded wave transmission lines disposed normal to such antenna current elements and brought to a common electrical join at the geometric center point, the radiation resistance of the total combination of plural antenna current elements is increased usefully over antenna embodiments of the prior art of equal physical height contained within the same total spacial volume.

It is another object of this invention to provide an antenna radiator of reduced height having an input impedance which directly matches the characteristic impedance of standard power feeding transmission lines, or the terminal impedance of radio frequency amplifiers.

It is another object of this invention to provide an antenna radiator of reduced height which radiates a linear polarized wave whose electric field vector component is aligned parallel to the short height antenna radiator.

It is a further object of this invention to provide an antenna radiator of pleasing appearance, suitable for use in mobile vehicle communications installations.

With the foregoing objects in view, together with such additional objects and advantages as may subsequently appear, the invention resides in the parts, and in the construction, combination and arrangement of parts described, by way of example, in the following specifications of certain modes of execution of the invention; reference being had to the accompanying drawings which form a part of said specification and in which drawings:

FIG. 1 is a perspective,broken away view of a conducting plane member such as the metal skin of a mobile vehicle,showing one unbalanced embodiment of the invention.

FIG. 2 is an enlarged,fragmentary,medial sectional view taken on the line **2—2** of **FIG. 1**, and showing details of connection of the coaxial line feeder to the antenna structure.

FIG. 3 is a diagram illustrating the electrical parameters of an unbalanced wave transmission line tuning means of the invention terminated by the impedance of a single antenna radiator current element.

FIG. 4 is a graph illustrating the variation of the real and imaginary components, with frequency, of the impedance appearing across an unbalanced wave transmission line tuning means at the end opposite to that terminated by an antenna radiator current element.

FIG. 5 is a schematic diagram illustrating the components of the impedance appearing across the generator end of an unbalanced wave transmission line tuning means.

FIG. 6 is a diagram of an unbalanced embodiment of the invention showing the current distribution thereon.

FIG. 7 is a perspective, broken away view of a conducting plane member, showing an unbalanced embodiment of the invention, including a system of feeder switching means and independant, dual frequency tuning means of broad range.

FIG. 8 is an enlarged, fragmentary,medial sectional view taken along the line **8—8** of **FIG. 7**, showing details of connection of dual feeder transmission lines to the antenna structure.

FIG. 9 is a graph illustrating the variation of the real and imaginary components of the impedance appearing at the generator end of each of the dual unbalanced wave transmission line tuning means of **FIG. 7**, with change in the operating frequency.

FIG. 10 is a perspective view of an unbalanced embodiment of the invention, showing an alternative method of connection to the coaxial feeder transmission line.

FIG. 11 is an enlarged,fragmentary,medial sectional view taken along the line **11—11** of **FIG. 10**.

FIG. 12 is a perspective view of an unbalanced embodiment of the present invention showing yet another method of connection of the feeder coaxial transmission line to the antenna structure.

FIG. 13 is an enlarged,fragmentary, medial sectional view taken along line **13—13** of **FIG. 12**.

FIG. 14 is a perspective view of an unbalanced embodiment of the invention showing a method of connection to a high impedance output, radio frequency electron tube power amplifier which is located in proximity to the antenna structure.

FIG. 15 is a diagram illustrating a balanced embodiment of the invention excited with dual coaxial feeder transmission lines, and

FIG. 16 is a perspective view of an unbalanced embodiment of the invention, showing a large diameter antenna structure mounted over an electrical image plane formed of conductive wires on the earth surface.

Referring now to the form of the invention shown in FIGS. 1 and 2, the illustrated embodiment of the invention comprises a plurality of radially disposed,linear conductive members 3, the first extremity of each said linear conductive members 3 being terminated in a common, conductive join at the center of an imaginary circle, having an overall diameter D, the plurality of radial linear conductive members 3 all lying in the plane of said imaginary circle, the second extremity of each said radial linear conductive members 3 of total length A terminating at equally spaced points on the circumference of said imaginary circle to form a polygonal geometry figure, each second extremity of said radial linear conductive members 3 being conductively joined to a first extremity of each of an equal plurality of circular segment conductive members 2, each of said circular segment conductive members 2 being disposed on the circumference of said imaginary circle, the second extremity of each of said circular segment conductive members 2 being conductively joined to the first and top extremity of each of an equal plurality of linear conductive members 1, said linear conductive members 1 being parallel to one another and all being directed normal to the plane containing said radial linear conductive members 3 and circular segment conductive members 2, the second and base extremity of each of said linear conductive members 1 being conductively joined, as for example by welding, to a plane of good electrical conductive metal 12, said electrically conducting plane 12 lying parallel to and at a height H below the plane containing said radially linear conductive members 3 and said circular segment conductive members 2. A plurality of non conductive members 4 support and preserve the parallel relationship of the said linear conductive members 3 to the electrically conductive plane 12.

At a point on the electrically conductive plane 12 lying coaxially at a distance H below the common conductive join of said plural radially directed, linear conductive members 3, energy from a radio transmitter apparatus 11, connected by a coaxial line 10,as shown in FIG. 2, is brought to one plate of high voltage capacitor 6 by the inner, insulated conductive member 7 of said coaxial line 10, the outer conductive sheath 13 of the coaxial line being conductively joined to the electrically conductive plane 12 by a conductive collar clamp 9, the second plate of said high voltage capacitor 6 being brought by a conductive wire member 5 to the center common join point of said radial linear conductive members 3 and conductively joined thereto, for example by soldering said high voltage condenser 6 being supported and spaced from the electrically conductive plane 12 by a non conductive member 8.

In the specific example of the invention above described the following dimensions were embodied as indicated by the corresponding letters applied to FIG. 1:

Symbol	Definition	Dimension
A	Radial distance from an element member 1 to the center join point (inches)	27.5
B	Arc length of spacing between circumferential members 2. (degrees)	5.0
C	Length of circular segment members 2 (inches)	19.2
D	Total diameter of antenna (inches)	55.00
H	Total height of antenna (inches)	2.6
I	Outside diameter of conductive members 1, 2, and 3 (inches)	0.5

Assuming now that the radio transmitter apparatus 11 is tuned to a frequency of 45 Megahertz, energy oscillating at this frequency will be applied to the antenna by coaxial cable 10 across the terminals formed by the electrical ground plane 12 and, via capacitor 6, the point of common join of the radial,horizontal members 3. The aforesaid terminals constitute the input connections to the plurality of eight folded wave transmission lines formed by the elevated, horizontally disposed radial conductive members 3, the circular segment conductive members 2, and their electrical image in the ground plane 12. By virtue of such connection,waves will propagate radially outward a distance A, then along each of circular segment members 2 a distance C, to the points on the circumference of the antenna structure where each of the said horizontal transmission lines of total length A + C terminate in a plurality of eight low impedance linear conductive radiator members 1 normally disposed and conductively joined to the electrically conductive ground plane 12.

Now, referring to FIG. 3 where, for the sake of clearness of description, only a single wave transmission line of total length C + A is illustrated, the characteristic impedance Z_o of the aforesaid wave transmission line consisting of a conducting tube member disposed parallel to and at a height H above a highly conducting image plane 12, is known to be,

$$Z_0 = \frac{120}{\pi} \ln \left[\frac{H}{2I} \left(1 + \sqrt{1 - \left(\frac{2I}{H} \right)^2} \right) \right] \quad (3)$$

where l_n denotes the natural logarithm, and the dielectric in the space H is air or a vacuum. As seen in the FIG. 3, the electrical length θ of the said wave transmission line of characteristic impedance Z_o is,

$$\theta = \frac{A + C}{\lambda} (360) \text{ degrees} \quad (4)$$

wherein λ is the radio wavelength at the operating frequency. It will be readily perceived by those skilled in the antenna art that the linear conductive member 1 which terminates the said wave transmission line shown in FIG. 3 of total electrical length θ and characteristic impedance Z_o, itself possesses an impedance $Z_l = R_l + jX_l$, where the complex operator $j = \sqrt{-1}$, in which the real part R_l is composed of two real components: R_e, the radiation resistance, and R_L, the ohmic or loss resistance. As the linear conductive member 1 is carefully selected for reasons of efficiency to have the greatest possible electrical conductivity the ohmic resistive part R_L will be of very small magnitude. Due to the small electrical height H being preferably minute in terms of the operating wavelength λ, recourse to Equation (2) herein shows that the radiation resistance R_e of the member 1 will also be small in magnitude. Finally, as the linear conductive member 1 is, as aforesaid, short in terms of the wavelength λ and therefore far out of electrical resonance, it will also display a reactive impedance component jX_l which can be of considerable magnitude.

Now, by well known theorems of electrical science, the portion τ of the electromagnetic wave energy reflected by a termination Z_l applied across the output terminals of a wave transmission line of characteristic impedance Z_o is,

$$\Gamma = \frac{Z_l - Z_0}{Z_l + Z_0} \quad (5)$$

with the condition $Z_l = Z_0$ resulting in perfect absorption of the incident wave energy by Z_l. Because the real part R_l of the impedance of linear conductive member 1 is very small when compared to Z_o, and the imaginary part jX_l can only store but not absorb wave energy, a large portion of the incident wave energy will be reflected by conductive member 1. As a consequence, the reflected energy will travel back down the horizontally disposed transmission line composed of the said conductive members 2 and 3 and, by the process of wave interference, establish a new impedance Z_s across the structure terminals formed by the common conductive join of the radial conductive member 3 and the conductive plane 12, shown in FIG. 3 as a single rather than a plural conductive structure for the purpose of description only. The said new impedance Z_s has the magnitude,

$$Z_s = Z_0 \frac{Z_l + jZ_0 \tan \theta}{Z_0 + jZ_l \tan \theta} \quad (6)$$

By reference to the dimensions given in Table 1 and the Equations (2), (3), and (4), those skilled in the electrical art will readily determine by use of Equation (6) that at a frequency of 45 Megahertz Z_s will be approximately equal to

$0.525\ Z_o + j\ 9.82\ Z_o$ ohms. FIG. 4 illustrates the variation of impedance Z_s as a function of frequency for the single wave transmission line of FIG. 3. In FIG. 4 the point on the spiral curve marked Q represents a frequency of 45 Megahertz and that marked f_{o3} a frequency of 270 Megahertz.

FIG. 5 illustrates that the coaxial cable 10 and the capacitor means 6, represented in the said FIGURE by the generator symbol G and reactance $-jX_c$ respectively, are connected in series with the impedance $Z_s = R_l + jX_l$. From the laws of electricity in relation to series circuits it is known that electrical resonance occurs at a given radio frequency when the conjugate condition $jX_l = -jX_c$ is satisfied. In the subject invention antenna this condition is obtained by mechanical adjustment of the capacitor means 6. When the said condition of conjugate reactance is met, the input impedance Z_{in} into which the generator G of FIG. 5 delivers power via coaxial cable means 10 is then,

$$Z_{in} = R_l + jX_l - jX_c = R_l + j0.$$

For the case of the single horizontally disposed wave transmission line shown in FIG. 3 of total electrical length $A + C = 64.8$ degrees at the said frequency of 45 Megahertz, the input impedance would be $Z_{in} = 0.525\ Z_o + j0$.

From the foregoing description skilled practitioners will perceive that at the point of common join of radial conductive members 3 of the antenna embodiment shown in FIG. 1, the plurality of eight wave transmission lines of characteristic impedance Z_o and all of identical electrical length θ are connected in parallel. As a consequence of such preferred connection for the subject invention, a total plurality of eight equal impedances Z_s exist in parallel between the point of common join of the radial conductive members 3 and the adjacent point on the conductive plane 12. If Z_t is equal to the total parallel impedance of half of the said plurality of eight impedances Z_s, the final impedance Z_{st} will be,

$$Z_{st} = \frac{Z_t\, Z_t}{Z_t + Z_t} = R_{st} + jX_{st} \qquad (7)$$

and the actual input impedance Z_{in} of the antenna embodiment shown in FIG. 1 is therefore,

$$Z_{in} = R_{st} + jX_{st} - jX_c = R_{st} + j0.$$

Now, referring to FIG. 6, a four radiator current element member unbalanced embodiment of the antenna is illustrated in diagram form for the purpose of making clear the distribution of currents on the conductive members of the said invention antenna. The choice of a four radiator current member embodiment is solely for the purpose of avoiding undue complexity in the FIGURE, and the description following applies equally well to any plurality of radiator current elements and to all embodiments disclosed herein. In FIG. 6 the currents U in each conductive radiator current element member 1 are of equal magnitude and all flow in the same direction at the same instant of time during the alternating cycle of the radio frequency energy supplied to the antenna by generator G representing coaxial cable 10.

As is well known, the electrical image of a vertical current carrying element member aligned normal to and operated over a highly conducting ground plane such as 12 is in the same spacial direction at a given instant of time as that of the current flowing on the actual current member itself. As a consequence, the fields radiated by the plurality of radiator current element members 1 will all be in-phase and additive at great distances from the antenna invention. At the same time, radiation fields produced by the currents flowing on the plurality of horizontally disposed conductive members 2 and 3 of the wave transmission lines preferred in the subject invention antenna to establish electrical resonance in the plurality of said vertical radiator current element members 1 will be partially or completely cancelled at any great distance due to the presence of out-of-phase or oppositely directed currents U′ induced in the conductive image plane 12. Additionally, at angles above the conductive plane 12 the radiation fields produced by current flowing along a given horizontally disposed conductive member such as 2 will be cancelled by the oppositely directed current flowing on a second horizontally disposed conductive member 2 which is aligned diametrically opposite to the said first member 2 on the antenna structure, said diametric alignment being a preferred and purposeful construction of the subject invention's current carrying members. The total electromagnetic function of the subject invention antenna is to produce at any substantial distance, radiation fields which possess an electric vector aligned normal to the conductive plane 12 and decay in intensity by a function inversely proportional to the distance; to provide novel and unique low loss tuning means in the form of horizontally disposed wave transmission lines which have the function of tuning the antenna to wave resonance at the operating frequency while the fields radiated by the said horizontally disposed wave transmission lines are self-destructive in the near-zone of the subject antenna invention, and to provide a plurality of low height radiator current element members in which the radiation resistance of one is additive to all others of the said plurality, thereby providing greater impedance bandwidth at high radiation efficiency than afforded by antenna structures of the prior art whose height H is the same.

I have found by measurement that for dimension D not exceeding 0.20 wavelength the azimuthal radiation pattern of the subject invention antenna will be substantially omnidirectional and the elevation pattern substantially proportional to the cosine of the elevation angle over the conductive plane 12. For operating frequencies for which the dimension D exceeds 0.20 wavelength I have found that the omnidirectional azimuth radiation pattern is essentially retained, now containing small, periodic variations of field intensity with azimuth angle which are of little practical importance insofar as affecting adversely radio communications performance.

Reference to FIG. 4 illustrates the well known law that the sign of the imaginary or reactive part jX_s of the impedance Z_s changes to a negative sign when the total electrical length θ of the horizontally disposed wave transmission line members 2 and 3 of total dimension $A + C$ exceeds 90° at a given radio frequency, the said negative sign of the imaginary part of the impedance Z_s continuing the said polarity until the total electrical length of the said transmission line members attains a magnitude of 180 electrical degrees. Under such condition, skilled practitioners will perceive that an inductive means of positive polarity sign would normally be required in place of the capacitive means 6 in order to tune the subject antenna invention to resonance over the band of frequencies producing the said electrical length extending between 90° to 180° in the said conductive members 2 and 3. Due to the known loss of efficiency encountered and experienced in devising means to vary the magnitude of reactance of inductor means in order to achieve rapid frequency tuning under such conditions, I prefer to cover such said extended frequency range by a modified embodiment of the antenna invention which retains the capacitor tuning means 6.

FIGS. 7 and 8 illustrate, for the purpose of explanation and disclosure such modified embodiment, consisting of two, 4 radiator current element member antenna structures, the said two antenna structures being disposed concentrically with respect to one another over the common conductive plane 12. To identify each of the two said antenna structures the letter (a) will be appended to the members and dimensions of the larger diameter antenna structure, and the letter *b* appended to the members and dimensions of the smaller diameter antenna structure.

In the modified embodiment of FIGS. 7 and 8, I prefer that the total diameter D*a* be twice that of D*b*. I prefer that the total height H*a* not exceed 1.1 times the total height H*b* of the smaller antenna structure. I prefer that the outside diameter I*a* of conductive members **1***a*, **2***a* and **3***a* be approximately equal to the outside diameter I*b* of conductive members **1***b*, **2***b* and **3***b*.

Now, with respect to the connection of feeder transmission line, I prefer that the larger antenna structure of total diameter D*a* be supplied radio frequency power via a capacitor means **6***a* from a coaxial cable means **6***a* in a manner and mode identical to that shown and explained for the embodiment of FIG. **1**. I prefer that the antenna structure of total diameter D*b* be supplied radio frequency power via a capacitor means **6***b* from a coaxial cable means **10***b* also in the manner shown in FIG. **1**. In the modified embodiment of the antenna invention shown in FIGS. **7** and **8**, I prefer that the said coaxial cable means **10***a* and **10***b* be connected to the dual output terminals of a single pole, double throw coaxial switching means **14**, said coaxial switching means being activated mechanically by a solenoid S, which is in turn electrically controlled by a remote switch **20** via a multiconductor cable **18**. The input terminals of the said coaxial switching means **14** being connected to a reflection coefficient meter **16** by a section of coaxial cable **15**, the said reflection coefficient meter being in turn connected to the radio apparatus **11** by means of a section of coaxial cable **17**.

In one preferred form of the modified embodiment of the subject invention, the capacitor turning means **6***a* and **6***b* are adjusted from a distance, as for example by gears, by means of rotary force delivered by reversible electric motors M*a* and M*b* respectively as shown in FIG. **8**, said motors M*a* and M*b* being connected by multiconductor cables **19***a* and **19***b* respectively to remote control switches **21***a* and **21***b* respectively. As the two antenna structures shown in the modified embodiment illustrated by FIG. 7 are preferably disposed concentrically over the conductive plane **12** to conserve space, I prefer that the point of common conductive join of the radially disposed members **3***a* be joined to the upper plate of capacitor tuning means **6***a* by a conductive wire **5***a*, said conductive wire **5***a* being dressed in such manner that it avoids contact with the point of common join of the radially conductive members **3***b*. In the same sense, I prefer that the upper plate of the capacitor tuning means **6***b* be joined to the point of common join of radially disposed conductive members **3***b* by a conductive wire **5***b*, said wire **5***b* being also dressed to avoid contact with the conductive members of the larger antenna structure of total diameter D*a*.

Now, to aid in the explanation of the operation of the modified embodiment of the invention antenna shown in FIGS. **7** and **8**, let it be assumed that the modified embodiment is to be used in the high frequency portion of the radio spectrum, with the lower limit of operation being at a frequency of 2 Megahertz. For this mode of usage, the dimensions of the modified embodiment of the subject invention antenna are,

Symbol	Dimension	Symbol	Dimension
D(*a*)	= 51.5 feet	D(*b*)	= 25.7 feet
B(*a*) = B(*b*)	= 5 degrees	I(*a*)=I(*b*)	= 3 inches
H(*a*)	= 39 feet	H(*b*)	= 23 feet

Let the radio apparatus **11** be tuned to the frequency 2 Megahertz. The cable switching means **14** is activated by remote switch **20** so that radio frequency power is supplied only to the antenna structure of diameter D*a* via coaxial cable **10***a*. The antenna structure of diameter D*a* may now be operated and tuned by the use of motor control switch **21***a* and thereby the rotation of capacitor means **6***a* over the band of radio frequencies extending from 2 to 4 Megahertz in the mode and manner aforesaid for the embodiment of the invention shown in FIG. **1**. Reference to FIG. **9** shows that when operation is desired at a frequency higher than 4 Megahertz, the imaginary part of the impedance $Z_{st'a}$, of the larger diameter antenna structure become negative in sign, thus calling for an inductive tuning means to be substituted for capacitor means **6***a*.

I prefer that for operation at a frequency higher than 4 Megahertz, coaxial switch **14** be activated via remote control switch **20** so that coaxial cable **10***a* is disconnected, radio frequency power from radio apparatus **11** being now switched to coaxial cable **10***b*, thereby exciting the smaller antenna structure of total diameter D*b*. With reference to FIG. **9**, it will be clear to those skilled in the art that by means of such switching provision, the frequency range of 4 to 8 Megahertz can be covered using the smaller antenna structure of diameter D*b*, tuning being accomplished by capacitor means **6***b* via motor M*b* and remote switch **21***b*. FIG. **9** shows that such operation is possible because the smaller antenna structure displays a reactive part of impedance $Z_{st'b}$, of positive sign until a frequency of 8 Megahertz is reached. For operation at frequencies higher than 8 Megahertz, in like manner, switching means **14**, **20** and the dual switches **21***a* and **21***b* would be employed to again activate the larger diameter antenna structure which presents the imaginary part of the impedance $Z_{st'a}$, with a positive sign for frequencies extending from 8 to 12 Megahertz.

I have found by means of measurements ,that one precaution should be taken in such wide band operation of the modified embodiment of the subject antenna invention shown in FIGS. 7 and 8. When one of the dual, concentric antenna structures is being employed for operation over a given and suitable range of frequencies, there may be found specific frequencies at which the deactivated antenna structure falls into sympathetic resonance by means of parasitic coupling between conductive current carrying members. When such difficulty is encountered it is necessary to activate the tuning motor M and thus the capacitor means **6** of the deactivated antenna structure and thereby change the setting of the capacitor means **6** of the deactivated antenna structure sufficiently to destroy the condition of sympathetic resonance in the deactivated antenna structure.

Referring now to FIGS. **10** and **11**, an alternative preferred scheme for feeding radio frequency power to the subject invention antenna is shown. Again, although a 4 radiator current element member structure is shown to avoid complexity in the drawing, any plurality of conductive members **1**,**2**, and **3** may be used. The alignment and disposition of conductive members of the antenna structure are identical to those shown in the embodiment of FIG. **1**, with the exception that the lower plate of capacitor tuning means **6** is conductively joined to the conductive plane **12**, the upper plate of capacitor tuning means **6** being joined,for example by soldering, to a conductive wire member **7**, said conductive wire means **7** being the inner conductor of coaxial cable **10**, the outer conductive sheath **13** of the said coaxial cable being conductively joined, for example by soldering, to the outer surface of radial conductive members **3** at the point of common join of the said members, said coaxial cable **10** emerging via a hole cut into the outer surface of the conductive members **3** for the said purpose, said coaxial cable **10** then being disposed and conveyed within the hollow interior of any one conductive member **3** and thence along its extent and continued into the hollow interior of a circular segment member **2**, said circular segment member **2** being that particular member joined to the extremity of the said conductive member **3**, said coaxial cable **10** by such means being conveyed to the point where the said circular segment conductive member **2** is joined to one of the plurality of four normally disposed linear conductive members **1**,said coaxial cable **10** at such point of join being then bent and continued into the hollow interior of the said one linear conductive member **1**. The said coaxial cable **10** emerges from the interior of the said hollow conductive member **1** via a hole cut into the wall of said hollow conductive member **1**, said hole being located at the base extremity of the said conductive member **1** at the point where the said member is conductively joined to the conductive plane **12**. At the said point of emergence, the outer conductive sheath **13** of the said coaxial cable **10** is conductively joined to the conductive plane **12** by conductive clamp **9** and then brought to the remote radio apparatus **11**.

In the embodiment of the subject invention shown in FIGS. 10 and 11, capacitor means 6 is adjusted by means of a lead screw and knob located on the underside of the conductive plane 12; as for example, when the said conductive plane 12 forms the metal roof of a mobile vehicle.

By way of explanation of the operation of the alternative scheme of feeding radio frequency power to the embodiment of the subject invention shown in FIGS. 10 and 11, those skilled in the art will perceive that capacitor means 6 is in series with the input terminals of the antenna structure at the point of common join of the radial conductive members 3, the difference between the aforesaid embodiment of FIG. 1 and that of FIGS. 10 and 11 being that the series circuit has been reversed. As a consequence, no change in the electrical mode of operation of the modified embodiment of the subject invention is found from that aforesaid for the embodiment shown in FIG. 1, although mechanical reasons may dictate the use of one or the other embodiment shown in FIG. 1 and FIGS. 10 and 11 respectively.

By experiment, I have found yet another preferred method for feeding radio frequency power to the subject invention antenna structure. This alternative scheme is shown in the modified embodiment of FIGS. 12 and 13. In the said modified embodiment the lower plate of capacitor means 6 is conductively joined to the conductive plane 12. The upper plate of the said capacitor means 6 is joined to the point of common join of radial conductive members 3 by means of a conductive member wire 5. The coaxial cable 10, conveying radio frequency power from the radio apparatus 11, is brought to the base extremity of one of the plurality of six normally disposed conductive members 1, and here the conductive sheath 13 of the said coaxial cable is conductively joined to the conductive plane 12 by means of a conductive clamp 9. Referring now to FIG. 13, said coaxial cable 10 is brought into the hollow interior of the said one conductive member 1 via a hole cut into the wall of the said one conductive member, said hole being located at the point of join between the said one conductive member and the conductive plane 12, said coaxial cable 10 being bent sharply and thence conveyed within the hollow interior of the said one conductive member a distance X, at which point the said coaxial cable is again bent sharply and emerges onto the exterior surface of the said member via a second hole. At the said point of elevated emergence, the conductive sheath 13 of the said coaxial cable is conductively joined to the external surface of the said conductive member 1, for example by means of soldering. The inner conductive wire member 7 of the said coaxial cable 10 is aligned parallel to the conductive plane 12 and normal to the surface of conductive member 1 a short distance Q, which I have not found to be critical if said distance does not exceed the outside diameter I of the said conductive member 1, the said conductive wire member 7 thence being bent sharply and conveyed parallel to the surface of the said one conductive member 1 to terminate in normal disposition conductively in the conductive plane 12, for example by means of soldering.

In the alternative power feeding embodiment shown in FIGS. 12 and 13, the connection of the coaxial cable means 10 to the antenna structure differs from that aforesaid for the embodiments previously described, in that the input of power is in shunt rather than in series. Skilled practitioners will perceive that the wire member 7 forms an inductive loop of width Q and height X, the external conductive surface of the said one conductive member 1 being a common current path of the input connection. Transfer of the power supplied by the radio apparatus 11 via coaxial feed cable 10 is thus by means of magnetic induction. I have found that the dimension X which yeilds an input impedance $Z_{in} = Z_{oc}$, where Z_{oc} denotes the characteristic impedance of the coaxial feed cable 10, can be determined by trial measurement using an impedance bridge or a voltage standing wave ratio meter apparatus. Where the characteristic impedance of the coaxial feed cable 10 is equal to 50 ohms, dimension X will be found to be from 0.5 to 1.0 times the height *H* of the said one conductive member 1, said dimension X being a dependant function of said dimension *H* in terms of wavelength λ.

FIG. 14 illustrates an embodiment of the subject antenna invention which differs from the usual practice of locating the radio apparatus such as 11 at a distance from the antenna radiator. In FIG. 14 the antenna structure serves dually as a wave radiator and as the resonant circuit of the radio apparatus 11, such combination being known to the recent prior art as an antennafier. In antennafier combinations of the prior art, however, the antenna is fixed in tuning, regardless of whether the antenna employed is of broad band nature such as, for example, a discone or of narrow band nature such as a monopole or dipole. In the modified embodiment herein disclosed, use of the subject antenna invention removes the tuning limitation of the antennafier and thus constitutes a novel and useful improvement of the art as shall here be described.

In FIG. 14 the disposition and alignment of conductive members 1,2, and 3 as well as the tuning means 6 are as aforesaid for the embodiment of the subject invention illustrated in FIG. 12, the said capacitor means 6 being adjusted by the rotary forces applied by means of a flexible torque shaft T from a servo motor M_s, said servo motor being driven in turn synchronously via electrical signals conveyed by multiconductor cable 22, from the servo transmitter M_t located within the radio apparatus 11, the angular rotary motion of the said servo transmitter being linked to the shaft of the frequency adjustment control means, as for example by means of gears, so as to track in frequency change with the said frequency adjustment means control of the radio apparatus 11. By such combination of means, skilled practitioners of the electrical and mechanical arts will perceive that as the transmitter radio apparatus means 11 is changed in frequency tuning the subject invention antenna tunes in synchronization, thereby maintaining the conjugate impedance relationship $jX_{st} = -jX_c$ by remote adjustment of capacitor means 6, the subject invention antenna thereby serving dually as an efficient wave radiator of low height and also as the resonant tuned circuit of the electronic amplifier stage of radio apparatus 11, there only remaining to be said the means by which the radio apparatus of active electronic nature is connected to the said modified embodiment of the said antenna invention.

The amplifier stage of the radio apparatus 11 is denoted in the said FIG. 14 by the vacuum tube symbol VT and typical associated circuit components such as the fixed capacitor means C_1, C_2, C_3, C_4, the radio frequency choke means RFC, and the resistor means R_1, and R_2. As is well known, the plate circuit impedance of a vacuum tube is larger in magnitude than the characteristic impedance Z_o of the standard coaxial cables such as that aforesaid for the previously disclosed embodiments herein. Therefore, in the modified feeding scheme illustrated in FIG. 14, one terminal of a fixed capacitor means C_1 is connected to the plate element of the vacuum tube VT, said capacitor C_1 being chosen to display a small magnitude of reactance $-jX$ at the operating frequency of the radio apparatus 11 ,and being constructed for use at high voltage to isolate the direct current potential H.V. of the radio apparatus from the conductive members 1,2,and 3 of the subject invention antenna. The other terminal of said capacitor means C_1 is brought through the conductive plane 12 via a hole and maintained in non-conductive alignment therein by means of a standard feed through insulator, a conductive wire member 23 being used between the said other terminal of the said capacitor C_1 and a conductive clamp N, said clamp N being attached to one of the plurality of two said conductive members 2, said conductive clamp being set a distance Q from the point of conductive join of the said conductive member 2 and the said normally disposed linear conductive radiator member 1.

It will be readily perceived by those skilled in the art that when variable capacitor tuning means 6 is adjusted so that the aforesaid conjugate impedance condition $jX_{st} = -jX_c$ is met at the operating frequency of the apparatus 11, the load impedance Z_{in} into which the vacuum tube means VT operates is a pure resistance. The input impedance Z_{in} is adjusted in absolute magnitude to match the plate impedance of the said vacuum tube VT by adjustment of the said dimension Q. Increase of dimension Q raises the magnitude of the real part of the impedance Z_{in}, thereby permitting any desired value to be obtained.

The divers embodiments disclosed herein of the subject invention antenna have all been of the so-called unbalanced type, in which the conductive members 1,2, and 3 operate against their electrical image in the said conductive plane 12. To free the subject invention from such restriction, FIG. 15 illustrates a balanced embodiment of the subject invention antenna, wherein the conductive plane 12 is replaced by a mirror image disposition of the conductive members 2a and 3a,said conductive members 2*a* and 3*a* being joined to the mirror image disposed conductive members 2*b* and 3*b* respectively by an equal plurality of normally disposed linear conductive members 1 of total length 2*H*. In such balanced embodiment of the subject invention antenna the aforesaid capacitor tuning means 6 will need to be one half the magnitude $-jX_c$ determined for the aforesaid unbalanced embodiments of total height *H* of the subject invention antenna. In the modified embodiment of the subject invention illustrated in FIG. 15, the antenna structure is power fed by a balanced or mirror image embodiment of the alternative feeding scheme shown in FIG. 13, although it will be readily perceived by skilled practitioners that all the aforesaid embodiments of the subject invention as well as all the aforesaid power feeding schemes may be applied in mirror image configuration to the balanced embodiment of the subject invention antenna.

In FIG. 16 is illustrated a modified embodiment of the subject invention for use at the very low radio frequencies where antenna systems of very large physical size may still be small in terms of the operating wavelength. In such applications the antenna structure must be erected over the soil of the earth and the conductivity of the soil enhanced by artificial means. In the modified embodiment of the subject invention shown in FIG. 16, the alignment and disposition of the conductive members as well as the tuning and feeding means follow the teachings disclosed by the embodiment of the invention illustrated in FIG. 1, the plurality of radiator current element members 1 being changed from the aforesaid number eight to the number four for the reason of avoiding complexity in the drawing. To avoid the great cost and mechanical difficulties posed by the use of solid surface tubular conductive members 2 and 3 as aforesaid for the previously disclosed embodiments herein, conductive members 2 and 3 are comprised of multiple conductive wire members. Although a multiplicity of 3 wire conductor members are shown in FIG. 16, skilled practitioners will perceive that the number of the said conductive wire members comprising the said conductive members 2 and 3 required in practice will be dictated by both the total current to be carried by the said multiple conductive wire members as well as the characteristic impedance Z_o of the horizontally disposed wave transmission line formed by the said multiple conductive wire members and their image in the conductive earth plane 12; as is well known, the characteristic impedance Z_o of the said wave transmission line formed of the said multiple wire conductive members can be determined by mathematical calculation of the unit length capacitance between the said conductive wire members and the said conductive earth plane by application of electrostatic potential theory. The normally disposed linear radiator current element members 1 are constructed of standard, constant cross section conductive antenna towers used by the current art, said standard antenna towers being of total height H, one extremity of the said multiple conductive wire members 2 terminating conductively, as for example by welding, to the top or elevated extremity of the said antenna tower members 1, the base extremity of the said antenna tower members 1 being set into and joined conductively to the earth soil or concrete footings. The said multiple conductive wire members 2 are held in polygonal alignment by insulators of standard construction attached mechanically to non conductive support towers such as, for example, telephone wooden poles, said poles being retained in alignment against the mechanical loads of the elevated conductive wire members 2 and 3 by means of back stays 25 suitably broken at short intervals by strain insulators. The multiplicity of conductive wire members 2 are equal in number to the radially disposed wire members 3, the said multiple wire conductor members 3 being conductively joined at the point of common join at the center of the said polygon, one extremity of of a normally disposed down lead 5 comprised of a multiplicity of wire conductor members equal in number to the said multiplicity of said members 2 and 3, being conductively joined to the point of common join, the said multiple wire members of the said down lead 5 being held in alignment and isolated from one another by means of non conductive hoop members , the other extremity of said down lead 5 terminating conductively in the upper plate of capacitor tuning means 6, said capacitor means 6 being supported and isolated from the conductive earth plane 12 by a non-conductive support means 8, the lower plate of said capacitor means 6 being conductively joined to the inner conductor 7 of coaxial cable 10, the outer conductive sheath of said coaxial cable 10 being conductively joined by means of the conductive clamp 9 to the conductive surface of a large size metal screen or plate 24 set on the surface of the earth plane 12, said coaxial cable 10 being used to convey the radio frequency power of the remote transmitter apparatus 11 to the antenna structure. As aforesaid, the conductivity of the earth plane 12 must be enhanced to avoid the loss of radio frequency power in the ohmic resistance of the soil. In the application of the modified embodiment of the subject invention antenna to low radio frequency structures, such enhancement of conductivity may follow standard radio broadcasting practice of the prior art in the providing of radially disposed conductive wire members 26 laid onto or just below the surface of the soil, with the modification from said standard practice being the provision of bridging wire members 27 being conductively connected between the said radial wire members 26 as,for example, by means of soldering. The said bridging wire members 27 are laid in polygon disposition in the area of the earth plane 12 embraced by the antenna structure and extending outward to a total distance radially equal to at least 1.2 times the total diameter D of the modified embodiment antenna structure, the base extremities of the said antenna towers 1 being conductively joined to an adjacent conductive wire member 26, and all said conductive wire members 26 terminating conductively at the said conductive plate or screen 24.

While there has been here described what is at present considered to be the preferred embodiments of the invention, it will be obvious to those skilled in the antenna art that various changes and modifications may be made therein without departing from the principles of the invention. As an example, I have restricted the description of the subject invention antenna to transmitting service in the practice of radio communications,yet skilled practitioners aware of the reciprocity theorem will perceive that the subject invention antenna may be equally well applied to receiving service with all the aforesaid advantages of short height, increased radiation resistance, and wide tuning range in frequency retained.

While in order to comply with the statute, the invention has been described in language more or less specific, as to structural features, it is to be understood that the invention is not limited to the specific features shown, but that the method and means herein disclosed comprises several forms of putting the invention into effect, and the invention is therefore claimed in any of its forms or modifications within the legitimate and valid scope of the appended claims.

What is claimed is:

1. An antenna comprising a plurality of radial conductive members of equal length disposed in a geometric plane, the first extremities of the said plural radial members being joined conductively at a common center point, the second extremities of the said radial members disposed at points of equal angular separation on the circumference of a geometric circle, an equal plurality of circular segment conductive members lying on the circumference of the said geometric circle having the said common center point as an origin, the first extremities

of the said plural circular segment members being conductively joined respectively to the said second extremities of the said radial conductive members, the second extremities of the said circular segment members being spaced equally and respectively from the said points of equal angular separation on the said circumference of the said geometric circle and being conductively joined respectively to the upper extremities of an equal plurality of linear conductive members of equal length, said linear conductive members disposed normal to the said geometric plane and terminating conductively on a conductive planar member disposed parallel to the said geometric plane and spaced less than one quarter wavelength therefrom.

2. A pair of apparatus in which each of the said pair comprise a plurality of linear radial conductive members of equal length disposed in a geometric plane, the first extremities of the said plural radial members being conductively joined at a common center point, the second extremities disposed at points of equal angular separation on the circumference of a geometric circle, an equal plurality of circular segment conductive members lying on the circumference of the said geometric circle having the said common center point as origin, the first extremities of the said plural circular segment members being conductively joined respectively at the said points of equal angular separation on the said geometric circle to the second extremities of the said radial linear members, the second extremities of said circular segment members respectfully joined to the upper extremities of an equal plurality of linear conductive members of equal length, said linear conductive members disposed normal to the said geometric plane, the said geometric plane containing the said plurality of radial members of one of the said pair of apparatus spaced below and parallel to the geometric plane of the other, the said point of common center of one of the said apparatus concentric with the point of common center of the other, the said radial members of one of the said pair of apparatus equal in number and length and aligned parallel with those of the said other apparatus, the said base extremities of the said normally disposed linear conductive members of one of the said pair aligned in end-to-end relationship with the normally disposed linear members of the other apparatus of the said pair, the said base extremities conductively joined.

3. Apparatus in accordance with claim 2, in which the first plate of a capacitor means is connected to the said common center point of join of the said radial members of one of the said pair of apparatus, the first plate of a second and equal capacitor means is connected to the said common center point of join of the said radial members of the said other apparatus of the said pair, the second plates respectively of the two capacitor means forming dual connection points for a balanced transmission line.

4. Apparatus in accordance with claim 1, in which the first plate of a capacitor means is connected to the said common center point of join of the said radial members, the second plate of the said capacitor means being a first connection point for an unbalanced transmission line, a point on the said conductive plane member concentric with the said common center point forming a second connection point for the said unbalanced transmission line.

5. Apparatus in accordance with claim 3, in which one conductive member of a two wire, balanced transmission line is connected to the said first connection point, the other conductive member of the said balanced transmission line connected to the said second connection point.

6. Apparatus in accordance with claim 7, in which the insulated inner conductive member of an unbalanced coaxial transmission line is connected to the said first connection point, and the conductive sheath of the said coaxial transmission line connected to the said second connection point.

7. Apparatus in accordance with claim 1, in which one of the said plurality of radial conductive members, one of the said plurality of circular segment conductive members, and one of the said plurality of normally disposed linear conductive members are hollow and form a continuous conduit for a coaxial transmission line disposed within, said coaxial transmission line being brought to the exterior surface of the said hollow members via a hole cut in the wall of the said one radial member at the point of the said common center join, said hole being on the side of the said radial members closest to the said conductive plane, the conductive sheath of the said coaxial line there conductively joined to the perimeter of said hole, the inner insulated conductive member of the said coaxial line disposed normal to the said conductive plane and connected to the first plate of a capacitor means, the second plate of the said capacitor means being connected to the said conductive plane, the other extremity of the said coaxial line passing through a hole in the wall of the said one normally disposed linear conductive member at the point where the said linear member joins to the said conductive plane, the conductive sheath of the coaxial line there connected to the said conductive plane and thence disposed along the surface of the said conductive plane to remote radio apparatus.

8. Apparatus in accordance with claim 8, in which the said other extremity of the said coaxial line passes through a hole in the said conductive plane, the said hole concentric with the said point where the normally disposed linear member joins to the said conductive plane, said coaxial cable being thence disposed on the underside of the said conductive plane to remote radio apparatus.

9. Apparatus in accordance with claim 1, in which the first plate of a capacitor means is connected to the said point of common center, the second plate of the said capacitor means connected to the said conductive plane, one of the said plurality of normally disposed linear conductive members being hollow, the conductive sheath of a coaxial line being connected to the said conductive plane, said coaxial cable passing through a hole in the wall of the base extremity of the said one hollow linear member and conveyed therein, said coaxial line passing through the wall of the said one hollow linear member via a second hole at a predetermined height above the said conductive plane, the conductive sheath of the said coaxial line terminated conductively to the perimeter of the said second hole, the inner conductive member of the said coaxial line being disposed parallel to the said conductive plane a distance substantially equal to the diameter of the said one hollow linear member, said inner conductive member being thence bent sharply so as to be disposed parallel and spaced from the surface of the said one hollow linear member and terminating on the surface of the said conductive plane.

10. Apparatus in accordance with claim 1, in which a first plate of a variable capacitor means is connected to the said point of common center, the second plate of the said variable capacitor means connected to the said conductive plane, a linkage means providing a synchronous join between the mechanical adjustment means of the said variable capacitor and the frequency adjustment means of a radio apparatus, the said linkage so composed as to afford frequency tracking between the said apparatus and the said radio apparatus, said radio apparatus being located on the opposite side of the said conductive plane from the said capacitor, the active electrical terminal of the said radio apparatus connected to one plate of a fixed direct current, potential isolating capacitor means, the second plate of the said isolating capacitor connected to a wire conductive member, said wire member passing through a hole in the said conductive plane and maintained concentrically in non-conductive alignment with the said hole by a non conductive support means, said wire aligned in normal disposition to the said conductive plane and connected by a conductive clamping means to one of the said plurality of the said circular segment members at a predetermined distance from the point of conductive join of the said one circular segment member and one of the said plurality of normally disposed, linear conductive members.

11. A pair of apparatus in accordance with claim 4, the said geometric planes of the said pair being disposed parallel, the said common center of one of the said pair being concentric with the common center of the other of the said pair, the total

diameter of one of the said pair being twice the total diameter of the other of the said pair, the total height of one of the said pair above the said conductive plane being substantially 1.1 times the total height of the other of the said pair above the said conductive plane, the said capacitor means connected respectively to the said common centers of each of the said pair being displaced respectively from the axis of the said concentric common centers sufficiently to avoid conductive contact, and supported and maintained in alignment by non conductive support means, the said conductive members respectively connected between the first plates of the said capacitor means and the said concentric points of common center being respectively dressed to preclude conductive contact, the insulated inner conductive members of dual coaxial cables being connected respectively to the said first connection points of the said two capacitor means, the conductive sheathes of the said dual coaxial cables connected respectively to the said second connection point of the said conductive plane, the said dual coaxial cables terminating in the dual output terminals of a coaxial switching means, the single input terminal of the said coaxial switching means connected by a coaxial cable to remote radio apparatus, mechanical linkage adjustment means provided for the independent remote tuning of the said two capacitor means and remote control means provided for the said coaxial switching means.

12. An apparatus in accordance with claim 1, each of the said radial and circular segment conductive members composed in turn of a multiplicity of flexible wire members, the number of said flexible wire members comprising all the said radial and circular segment conductive members being equal and predetermined, the said normally disposed linear conductive members being composed of conductive lattice towers of constant cross section, the said flexible wire members comprising the said radial and circular segment conductive members being held in geometric alignment by non conductive support means.

13. Apparatus in accordance with claim 13, in which the said radial and circular segment conductive members composed of a predetermined multiplicity of flexible wire members held in alignment by non conductive support means are disposed parallel to and at a predetermined height above a conductive plane comprised of wire members laid substantially on the surface of the earth, the said wire members being disposed radially with respect to a point on the soil concentric with the said common center, the said radial wire members bridged conductively at predetermined intervals by additional wire members disposed in the form of polygons whose origin is the said point on the soil concentric with the said common center, the maximum radial dimension of the said bridging wire members being substantially 1.2 times the radius of the said apparatus.

14. Apparatus in accordance with claim 1, in which the diameter of the said geometric circle bounding the said circular segment members is from 0.009 to 2.00 times the operating wavelength of the said antenna.

15. Apparatus in accordance with claim 1, in which the length of the said normally disposed linear conductive members is from 0.0007 to 0.175 times the operating wavelength of the said antenna.

16. In an antenna for sending and receiving linear polarized radio waves, a plurality of linear conductive antenna members of equal length aligned parallel to one another and in normal disposition to the planes of a pair of parallel geometric polygons of equal diameter and equal number of sides, said linear antenna members disposed to bridge the corners of the said parallel polygons the extremities of each of the said linear antenna respectively to the first dual extremities of an equal plurality of balanced two conductor transmission lines, one of each of the said two conductors lying respectively in one of each plane of the said pair of parallel geometric polygons, each of the said portions of arc followed by the said bent conductors having the same rotational direction on the said circles but being short of joining the next respective corners of the said polygons by a predetermined and equal amount of spacing, each of the dual extremities of each of the said bent conductors of the said balanced transmission lines being there joined conductively to the first dual extremities of an equal plurality of linear, balanced two conductor transmission lines whose conductors are disposed radially to, and lie within the planes respectively of the said pair of geometric polygons, the second dual extremities of each of the said plurality of linear radial transmission lines terminating conductively at the two respective origins of the said pair of polygons to form coaxially aligned, dual terminals, the said dual terminals being respectively connected conductively to the dual input terminals of a balanced reactor, the dual output terminals of the said balanced reactor being connected respectively to a balanced electrical feeder cable joined to remote radio apparatus.

17. Apparatus in accordance with claim 16, in which all conductive members lying in one of the said pair of parallel geometric polygons are replaced by a conductive planar member whose extent is equal to or greater than the diameter of the said geometric polygon it replaces, one set of the extremities of the said plurality of linear conductive antenna members now terminating conductively on the said planar member, the output terminal of the remaining half of the said balanced reactor means connected to the insulated inner conductive member of a coaxial cable, the conductive sheath of the said coaxial cable connected to the said conductive plane member, the coaxial cable joining the apparatus to remote radio sending and receiving equipment means.

18. A multi-frequency, tunable antenna of small electrical height for the radiation of linear polarized waves in which plural, electrically short linear conductive members are aligned parallel to one another, the dual extremities of the said plural linear members equiangularly and normally intersecting the circumferences of two parallel geometric circles of equal diameter, the said dual extremities of the said plural linear members electrically terminating an equal plurality of balanced, two wire transmission lines, the dual conductors of each of the said plural balanced lines being disposed one above the other and spaced apart a distance equal to the length of the said linear conductive members, the said dual conductors of the said balanced lines following equal length segments of the said circumferences of the said parallel geometric circles all in the same rotational sense, then being directed inward radially and equiangularly to the respective origins of the said circles and there the dual conductors of each of the said balanced lines electrically connected in shunt to form dual, coaxially aligned terminals maintained in spacing equal to the spacing of the said dual conductors of the said shunt connected balanced transmission lines, said dual terminals bridged by a variable capacitive reactance means and fed radio power in series connection, the said combination of shunt connected, balanced transmission lines and the said reactive means producing electrical resonance in the said plural linear members terminating the said plural balanced transmission lines on both a fundamental frequency plus higher frequency overtone modes, the said linear members being also in electrical time phase by reason of such excitation scheme, the signal intensity at angles above the said plane of the said parallel circles falling in intensity with increasing angle to zero intensity at plus or minus ninety degrees relative to the plane of the said circles.

19. Apparatus in accordance with claim 18, in which connection means are provided for parallel electrical join between the said antenna array and remote radio apparatus.

20. A polygonal antenna array of plural, electrically short vertical radiator members of equal length, each of the said antenna members brought to in-phase electrical resonance by connection of its extremities respectively to the open terminals of a horizontally disposed unbalanced transmission line, the plurality of the said transmission lines of like electrical nature terminated by the said antenna members being brought to a coaxially aligned common joint at the origin of the said polygon, the said common join bridged by a common

variable reactor tuning means, to a ground plane the disposition of the said electrically short, resonant radiator members which are also terminated respectively on the said ground plane producing non-distructive vectorial wave fields at great distance from the said antenna array, the disposition of the said horizontally disposed resonanting transmission lines resulting in destructive vectorial wave fields at great distance from the said antenna array.

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