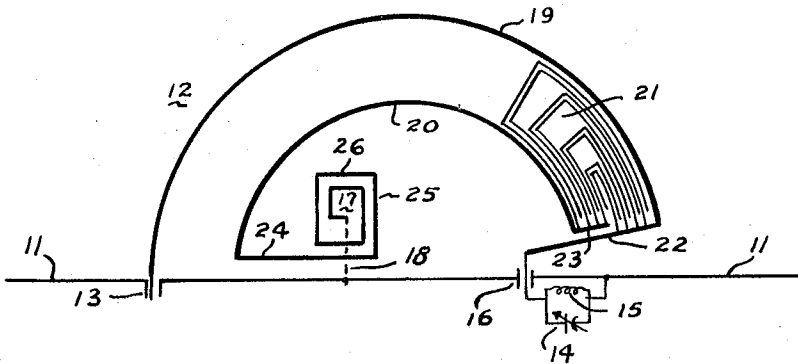


[54] **TUNABLE OMNIDIRECTIONAL ANTENNA**
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[73] Assignee: **The United States of America as represented by the Secretary of the Air Force**
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[51] Int. Cl. **H01q 9/00**
[58] Field of Search..... **343/705, 708, 745, 747, 748, 343/752, 830, 845**

[56] **References Cited**
UNITED STATES PATENTS
3,210,764 10/1965 Anderson et al.....343/708
Primary Examiner—Eli Lieberman
Attorney—Harry A. Herbert, Jr. and Robert Kern Duncan

[57] **ABSTRACT**
Two loaded, concentric, semicircular, radiating members provide a physically planar omnidirectional antenna having a relatively uniform nominal impedance and a tunable operation over approximately a 3:1 bandwidth with a protrusion above the ground plane of less than one-tenth wavelength at the high frequency end of the operating bandwidth.
5 Claims, 11 Drawing Figures



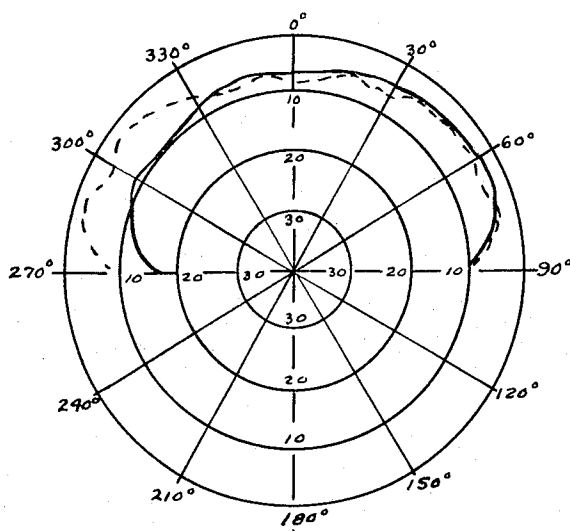
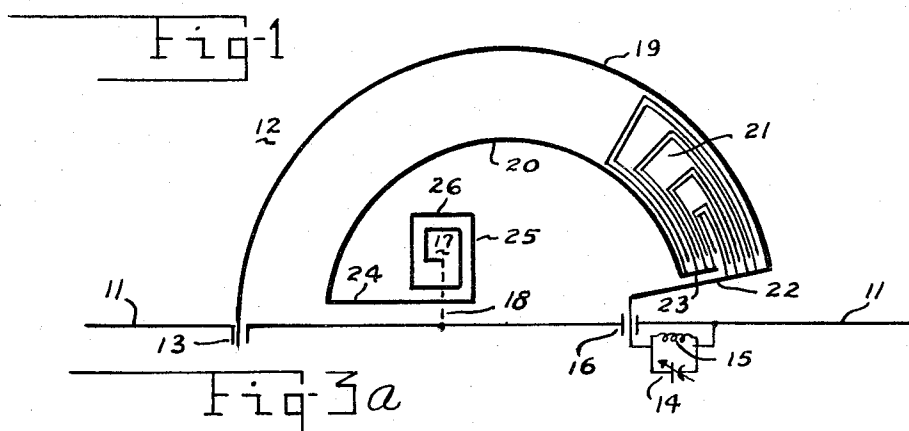


Fig-3b

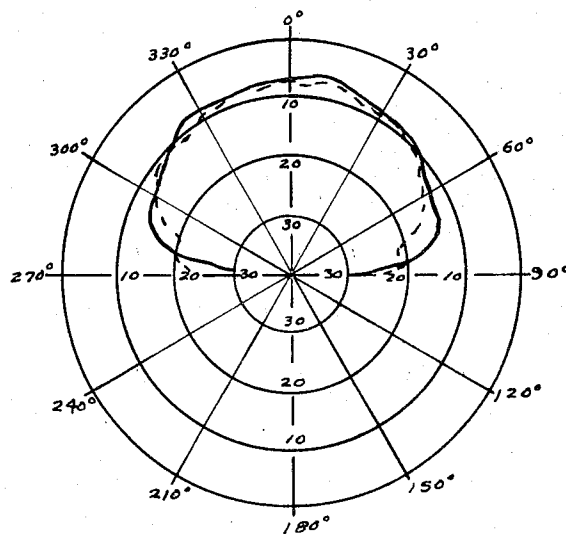
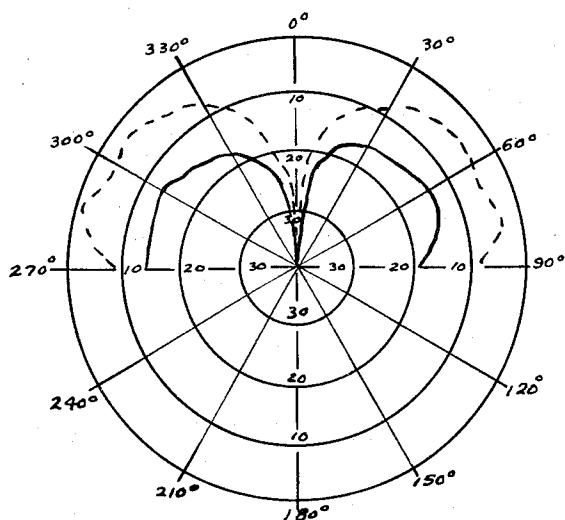


Fig-3c



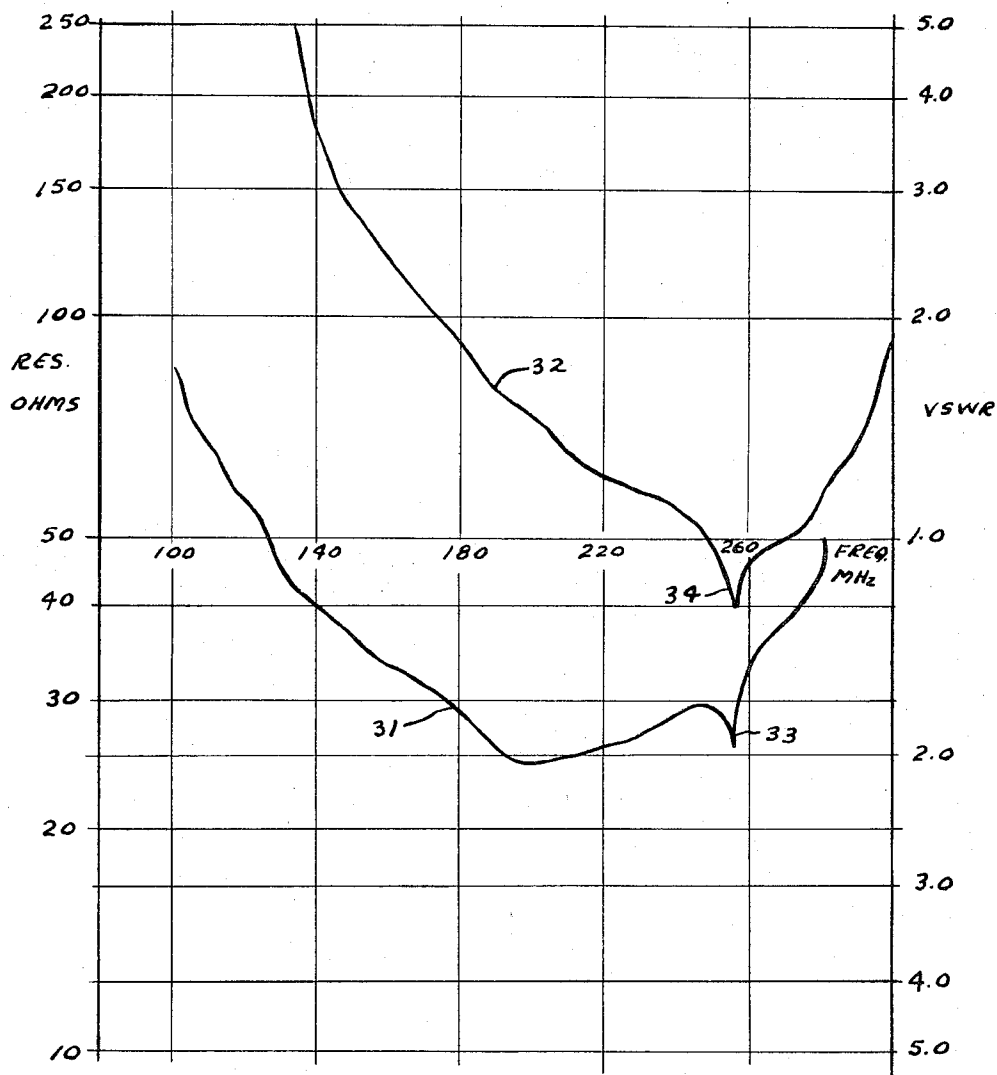
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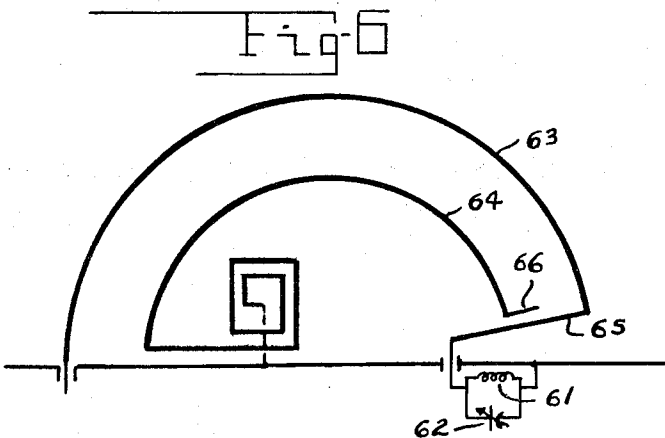
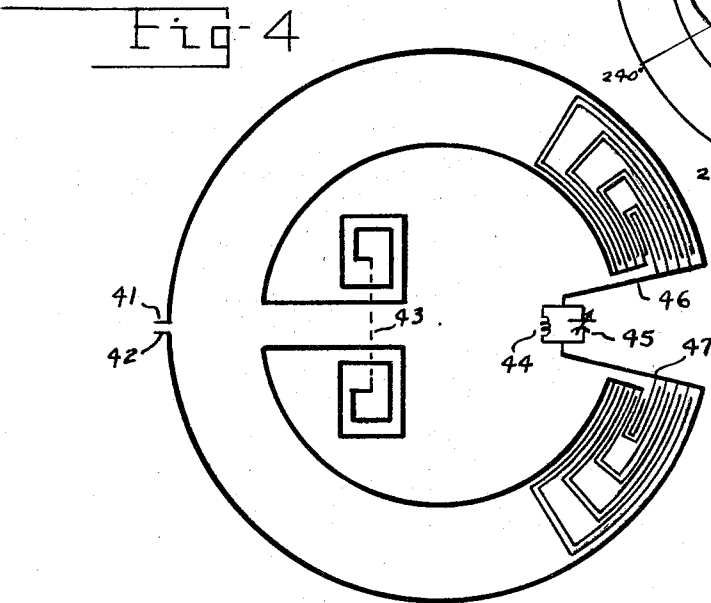
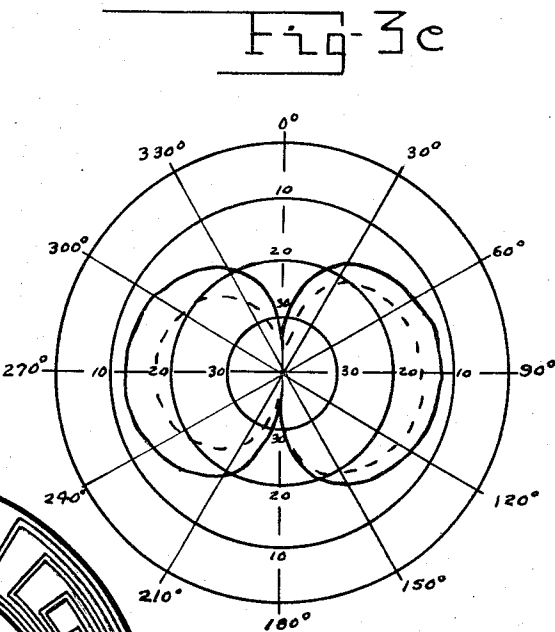
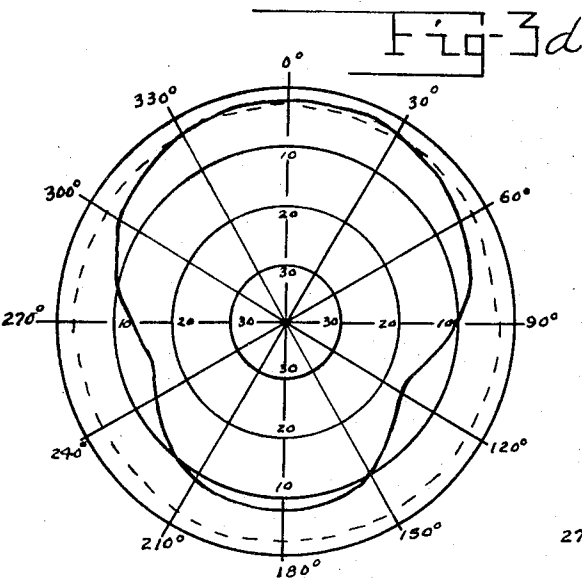
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Fig-2

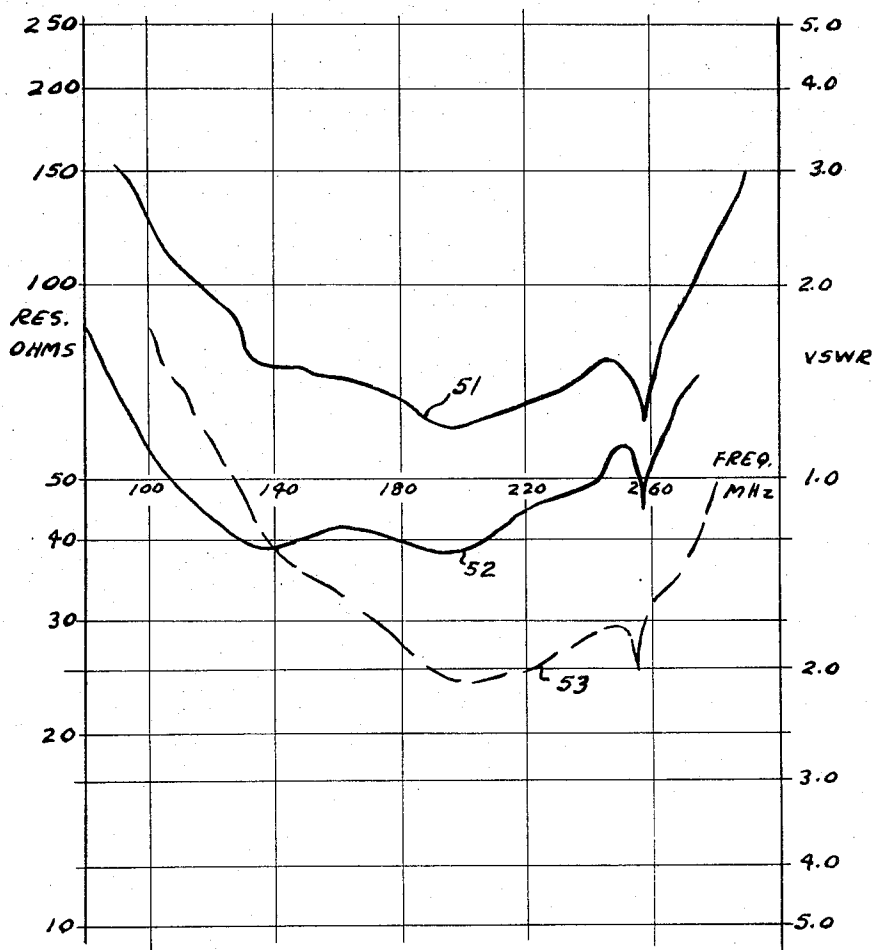


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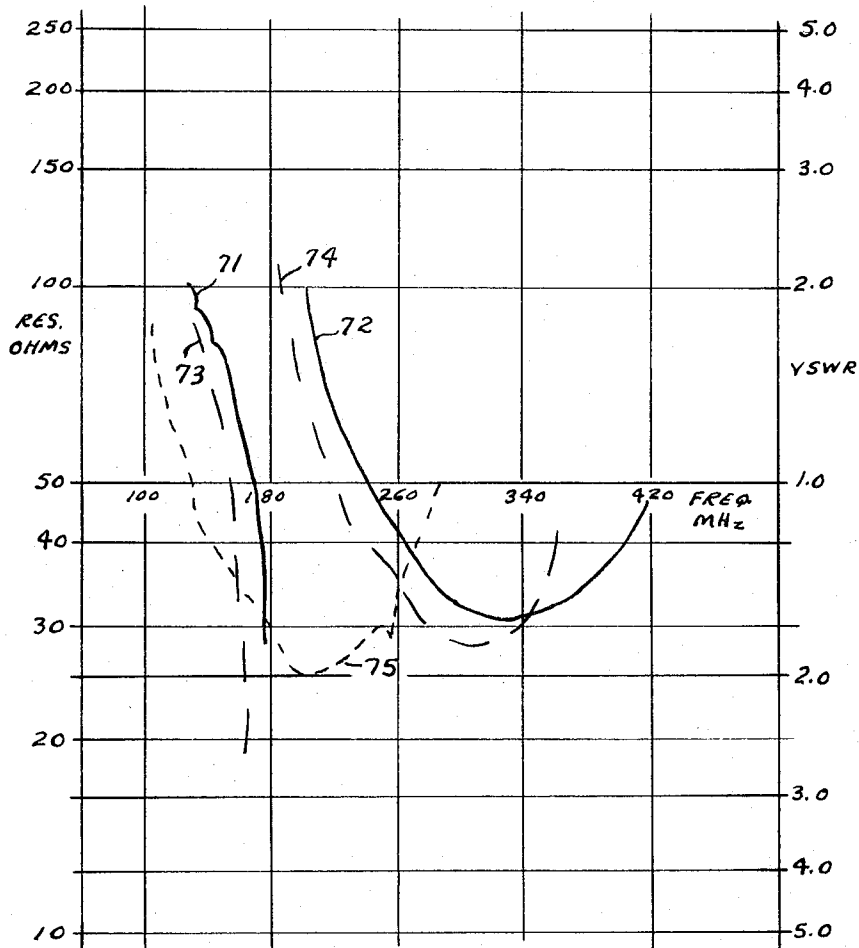
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Fig. 5



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Fig-7



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TUNABLE OMNIDIRECTIONAL ANTENNA

BACKGROUND OF THE INVENTION

The invention is in the field of electrically small omnidirectional antennas for electromagnetic waves.

The standard monopole or commonly called stub antenna that is currently in use at UHF and VHF frequencies has many deficiencies particularly for aircraft applications when used for large angular coverage. For example, the normal quarter wavelength of the monopole, while acceptable for large slow flying aircraft, is highly objectionable for aerospace vehicles and high performance aircraft because of the induced drag. Further, the typical monopole has a null perpendicular to its ground plane, and the frequency range is fairly narrow with only moderate means of tuning.

SUMMARY OF THE INVENTION

The invention provides a small, less than one-tenth wavelength protrusion, antenna that has essentially a hemispherical radiation pattern without any nulls over the antenna ground plane except for the obvious and generally insignificant case of transverse polarization in the plane of the radiation elements. Radiation as used herein is to be interpreted in the broad sense to include both transmission and reception. The antenna may be tuned over approximately a 3 to 1 bandwidth by a single conventional variable capacitor. The individual frequency bandwidth is approximately 5 percent, for a 3db impedance bandwidth, and the efficiency of the antenna is equivalent to the greatly more complex antennas that have been attempted to be used to provide similar operating characteristics. In addition for reception the frequency tuning provides a filtering action within the antenna that reduces intermodulation and cross talk between the desired signal and an adjacent undesired signal. The antenna is ideally suited for aircraft-satellite communication. Located atop the fuselage of an aircraft, virtually the whole upper hemisphere is covered.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a pictorial-schematic representation of a preferred embodiment of the invention;

FIG. 2 is a plot of the resistance and voltage-standing-wave ratio (VSWR) characteristics of a typical embodiment as shown in FIG. 1 tuned to resonate at frequencies over the normal operating bandwidth of the embodiment using two different inductors;

FIGS. 3a, 3b, 3c 3d, and 3e show the directional pattern characteristics of a typical embodiment of the invention as shown in FIG. 1;

FIG. 4 is a pictorial-schematic representation of a free space embodiment (without ground plane) of the invention;

FIG. 5 is a plot of operating characteristics of a typical embodiment as shown in FIG. 4 with a comparison typical characteristic curve of the embodiment of FIG. 1;

FIG. 6 is a pictorial-schematic representation of a simplified embodiment of the invention; and

FIG. 7 is a comparison plot of typical operating characteristics of an open wire embodiment and a printed circuit board embodiment as shown in FIG. 6, and a printed circuit board embodiment as shown in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The generally preferred embodiment of the invention, particularly for use with aircraft or other vehicles, is shown in FIG. 1. The ground plane 11 is normally the skin of the aircraft or the outside surface of the vehicle. The antenna elements 12 protruding from the surface are preferably constructed by the conventional etched circuit board process, however they may be formed from wire and be self supporting, or the wire may be cemented to an insulating board for support. It is essentially a planar structure. The printed circuit board, or supporting insulating board, is fastened to the ground plane by conventional means. A conventional coaxial

feed line connects to the ground plane and the antenna by a conventional connector 13. An L-C network comprising variable capacitor 14 and an inductor 15, located inside the vehicle, i.e., below the ground plane, tune the antenna to resonance at the particular desired frequency of operation. The L-C network is connected with the antenna radiating element through a conventional feed-through insulator 16. The spiral loading element 17 is terminated (connected) to ground by conductor 18. Normally, conductor 18 is located on the back side of the printed circuit board for insulating purposes, hence it is shown dotted in the drawing. Normal care should be used in selecting the material of the printed circuit board to ascertain that it is compatible with the desired frequencies over which the antenna is to be used. Generally low loss teflon and epoxy fiberglass materials are satisfactory. Two typical board materials that have been found to be suitable for frequencies in the ranges of 100 to 400 MHz are the military type G-10 and the commercially available Cincinatti Milling Machine Grade A manufactured by the Cincinnati Milling Machine Company. One mill copper on one-sixteenth inch thick dielectric board has been found to be very satisfactory. A light, thin, conventional radome in the form of a thin blade is generally placed over the antenna for protection.

A specific embodiment for operation over the frequency range of approximately 100 to 280 MHz will first be described in detail. It is to be understood that the physical dimensions of the antenna and the values of the L-C network may readily be scaled up or down by those skilled in the art in accord with the particular desired frequencies of operation. As an aid, dimension ratios and relationships will be set forth later. The outside radius of the outer conductor 19 is approximately $3 \frac{3}{4}$ inches and the inside radius of the inner conductor 20 is approximately $2 \frac{1}{2}$ inches. The width of the heavy conductors is approximately $1/10$ inch. This leaves approximately 1.05 inches between the conductor 19 and 20. The parallel loading and coupling section 21 is composed of approximately 0.030 inch conductors with approximately 0.030 spacing between conductors, except for the spacing between the centermost loop which is approximately 0.060 inch. The radial angles that the inner ends of the parallel loading and coupling sections make with the ground plane are approximately 30, 40, 50, and 60 degrees. The angle that the approximately 2-inch long section 22 makes with the ground plane is approximately 10° and the angle between it and the parallel end member 23 is approximately 3° . The center loading section 13 has a bottom member 24 that is approximately 2.20 inches long and it is spaced approximately $1/4$ inch from the ground plane. The spacing between the turns of the center loading section is approximately the same as the conductor width, i.e., approximately $1/10$ inch. The lengths of side member 25 and top member 26 are approximately 1.3 inches and 1.0 inch respectively. The preferred L-C circuit elements (for this specific embodiment), are an inductance 15 composed of a $1/2$ inch diameter two-turn coil of number twelve copper wire having an inductance of approximately $0.075 \mu\text{h}$, and a variable capacitor 14 having a capacitance range from 1 to 30 pf. A conventional air filled tubular variable capacitor has been found to be satisfactory.

Curve 31 of FIG. 2 is a plot of the characteristics of the resistance at resonance and the VSWR of the specific embodiment just described. The effect on the characteristics by changing the inductance 15 from a two-turn coil to a one-turn coil is shown by curve 32. With the one-turn coil, the characteristic resistances at resonance have a nominal higher value, and the usable band width has been shifted slightly toward the higher frequencies. The natural resonance of the antenna, as indicated by the dips 33 and 34 in the curves, remains at approximately the same frequency, i.e., approximately 255 Mhz. The natural antenna resonance is readily observable in the normal course of tuning the antenna, however no discontinuity or gap is present and the antenna may be operated through its resonance without any detrimental effects. Both the one-turn coil and the two-turn coil embodiments will operate satisfactorily into a conventional fifty ohm coaxial line, how-

ever by observing the curves it is readily apparent why the two-turn coil is preferred to provide a nominal match to a fifty ohm line.

The directivity patterns of typical embodiments of the antenna as shown in FIG. 1 are shown in FIGS. 3a, 3b, 3c, 3d, and 3e. The solid curves were made at a frequency of approximately 123 MHz, and the dotted curves were made at a frequency of approximately 300 MHz. In all instances the intermediate curves between these frequencies show a smooth transition between the frequencies. The antenna was located in the center of a 20-foot square ground plane. The distance from the antenna to the measuring probe antenna was a constant fifteen feet, which is well into the far field for this size antenna. For the measurements shown, $\theta = 0^\circ$ is directly overhead and $\theta = 90^\circ - 270^\circ$ is at the ground plane. $\phi = 0^\circ$ is at the feed end of the antenna and $\phi = 180^\circ$ is at the tuning end. The antenna was tuned to resonance at the indicated frequencies (123 MHz solid lines, 300 MHz dotted lines), however even for major excursions from resonance the patterns remain virtually unchanged. Patterns were taken with both variable θ (passing overhead) and variable ϕ (rotating in azimuth). E_θ represents a field probe tangent to a sphere about the antenna in a constant ϕ plane. E_ϕ represents the tangent to a sphere that is always horizontally polarized. All of the patterns are in relative db and the source levels were maintained constant in making the measurements. The parameters for each of the figures is as follows:

FIG. 3a

$f_r = 123$ MHz (solid line)
 $f_r = 300$ MHz (dotted line)
 E_θ Polarization
 Variable θ
 $\phi = 0^\circ$

FIG. 3b

$f_r = 123$ MHz (solid line)
 $f_r = 300$ MHz (dotted line)
 E_ϕ Polarization
 Variable θ
 $\phi = 90^\circ$

FIG. 3c

$f_r = 123$ MHz (solid line)
 $f_r = 300$ MHz (dotted line)
 E_θ Polarization
 Variable θ
 $\phi = 90^\circ$

FIG. 3d

$f_r = 123$ MHz (solid line)
 $f_r = 300$ MHz (dotted line)
 E_θ Polarization
 Variable ϕ
 $\theta = 70^\circ$

FIG. 3e

$f_r = 123$ MHz (solid line)
 $f_r = 300$ MHz (dotted line)
 E_ϕ Polarization
 Variable ϕ
 $\theta = 70^\circ$

In generalized terms with reference to frequency and wavelength the embodiment as shown in FIG. 1 may be described as follows. The bandwidth of the antenna is approximately 100 percent the nominal center frequency of operation. For example, the particular embodiment previously described has a bandwidth of operation from 100 MHz to 300 MHz giving an absolute bandwidth of 200 MHz about a center frequency of 200 MHz. The radius of the outer or driven radiating member 19 is approximately 0.07 wavelength of the center frequency and it subtends approximately 170° of arc from the feed end at the ground plane to the terminating end 22 that is connected to the tuned circuit. The spacing between the driven member and the concentric inner or excited radiating member 20 is approximately 0.04 wavelength. The total length of the spiral inner loading member from the end of the inner radiating member to which it joins is approximately 0.15

wavelength. These dimension ratios are based on the nominal center frequency of operation. They are not critical. The end of the driven member opposite the feed end drives the excited member through the parallel loading and coupling section 21. The antenna is tuned to the desired frequency of operation by the L-C tuning circuit 15 and 14 which has a natural free resonance range encompassing the desired tuning range of the antenna. (For example, the self-resonant frequency range of a two-turn inductor as previously described, tuned by a 1 to 30 pf capacitor, without any external loading or coupling to other circuits, is approximately 100 MHz to 550 MHz.)

An embodiment of the invention for free space, that is, an embodiment for operation where either a ground plane is not available or it is undesirable to use a ground plane, is shown in FIG. 4. As in the embodiment for use with a ground plane, the radiating conductors may be formed on a printed circuit board by conventional printed circuit techniques, or the conductors may be of open wire construction, either self-supporting or supported by cementing to an insulating board. Generally, the printed circuit board structure is preferred. The structure of this embodiment is the same as that in the ground plane embodiment except that the ground plane is replaced by a duplicate mirror image of the elements normally above the ground plane. The feed, which may be either coaxial line or balanced line such as conventional twin-lead connects to the antenna conductors 41 and 42. The ends of the center loading elements are connected by a conductor 43. Conductor 43 is shown dotted because in the printed circuit board construction it is normally on the back side of the board. Generally, it is more economical to use a one-sided board, that is, a board plated on one side only, and then use a conventional wire lead on the back side of the board to make this connection.

The L-C tuning elements 44 and 45 are normally mounted on the back side of the board and connected by wire leads through holes in the board to the ends of elements 46 and 47 as is conventional in printed circuit board equipment, however front mounting is also satisfactory. Curve 51 of FIG. 5 shows a typical characteristic curve of the free space embodiment of FIG. 4 for an $0.075 \mu\text{h}$ inductance 44. Curve 52 is a typical characteristic for a $0.15 \mu\text{h}$ inductance which provides the generally preferred operating characteristics. In both instances a 1 to 30 pf variable capacitor 45 was used to tune the antenna to the various frequencies. Curve 53 is a repeat of curve 31 of the ground plane embodiment. It is shown for comparison purposes. Commercially available inductors may readily be obtained in the values of $0.15 \mu\text{h}$ and $0.075 \mu\text{h}$. Typical values of inductance for self-supporting, spaced eight turns per inch, number 12 copper wire wound to have a $\frac{1}{2}$ inch inside diameter are approximately $0.045 \mu\text{h}$ for one turn, $0.075 \mu\text{h}$ for two turns, $0.125 \mu\text{h}$ for three turns, and $0.150 \mu\text{h}$ for $3\frac{1}{2}$ turns. These values will vary somewhat depending upon the lead lengths and supporting means. From the information herein those practicing this invention will readily use either commercially available inductors or construct those that will provide the proper impedance to use with radiating structures that will provide antennas having the nominal resistance characteristics over the desired range of resonant frequencies best suited for their particular use.

A simplified embodiment of the invention is shown in FIG. 6. This embodiment is identical with that shown in FIG. 1 except that the parallel loading between the outer and inner circular arc members 63 and 64 is provided by the inductance and capacitance between the terminating member 65 of the outer circular arc member 63 and the terminating member 66 of the inner circular arc member 64 instead of through the 4 element parallel loading and coupling sections 21 of FIG. 1. Typical characteristic curves for an open wire embodiment as shown in FIG. 6 having a one-turn inductor 61 is plotted as shown by the discontinuous curve composed of sections 71 and 72 in FIG. 7. The same type embodiment except fabricated on printed circuit board material provides the discontinuous curve composed of sections 73 and 74. These two curves show that except for the range of frequencies

above approximately 350 MHz the embodiments are essentially equivalent. As in the previous embodiments, a conventional 1 to 30 pf variable capacitor 62 is used to tune the antenna. For comparison, curve 75 is a plot of typical printed circuit board embodiments as shown in FIG. 1. It is to be observed that while the simplified embodiments, i.e., those without the parallel strip loading, do exhibit a stop band in the region of 180 to 200 MHz that the high frequency response is greatly extended, and coverage of the military band of frequencies from 225 MHz to 400 MHz is uninterrupted. Thus, this embodiment provides essentially equivalent frequency coverage, with improved pattern coverage, of this military band of frequencies, with a thin blade protruding only 3/4 inches as opposed to the conventional 9-inch antenna used previously to this invention.

The previously explained beam patterns of FIGS. 3a, 3b, 3c, 3d, and 3e apply sufficiently close to those obtained from all the embodiments that they may be considered representative. Gain measurements have been made and the typical values compared to a calibrated standard antenna referenced to an isotropic antenna are, for the printed circuit board embodiment as shown in FIG. 1;

FREQUENCY	GAIN
185 MHz	-5.5 db
220 MHz	-1.5 db
275 MHz	+0.5 db

and for the open wire embodiment of FIG. 6

FREQUENCY	GAIN
201 MHz	-7 db
232 MHz	-5 db
300 MHz	0 db
400 MHz	+1 db

Because of their broad beam coverage embodiments of this invention have widespread ECM (Electronic Counter Measures) applications. As used in a detection system the wide angle coverage allows reception of signals from virtually any direction. As a transmitting antenna it provides broad beam jamming coverage. While the purpose of this invention is not to provide a high-gain communication link, it does provide wide angle coverage at frequencies that would either have to be omitted from certain types of aircraft or seriously degrade the aircraft's performance. Placed atop the fuselage of an aircraft, virtually the whole upper hemisphere is covered. In applications where the antenna is to be used extensively in its lower frequency range, it is suggested that the feed end be pointed forward aiming the reduced pattern area toward the tail of the aircraft where blockage by the tail surfaces inevitably occurs anyway.

For ground based VHF-UHF usage from aircraft, it is suggested that the pattern maximum be aimed at the horizon and thus the lower gain areas would look directly downward where the path loss and distance is a minimum. For military aircraft applications, the replacement of the conventional stub antenna for communicating in the military VHF-UHF frequency band with an antenna of this invention that does not have any nulls in the radiation pattern and a lower profile has been found to be a very worthwhile improvement.

I claim:

1. A planar, electrically small, antenna comprising:

- an outer circular arc member having a feed end and a terminating end;
- an inner circular arc member concentric with the said outer circular arc member;

- means for coupling the said inner circular arc member to the said outer circular arc member at the said terminating end of the outer circular arc member;
- an essentially spiral loading element cooperating with the said inner circular arc member; and
- means cooperating with the said terminating end of the outer circular arc member for tuning the said antenna.

2. The antenna as claimed in claim 1 wherein the radius of the said outer circular arc member is less than one-tenth wavelength.

3. A tunable, electrically small, high frequency antenna for operation over a determined band of frequencies about a nominal center frequency comprising:

- an outer circular arc conductive member having a radius of less than one-tenth the wavelength of the said nominal center frequency and having a feed end and a terminating end;
- an inner circular arc conductive member concentric with the said outer circular arc member, spaced approximately 0.04 wavelength of the nominal center frequency, from the outer circular arc member, and having a first end adjacent the said feed end of the said outer circular arc member and a second end adjacent the said terminating end of the said outer circular arc member;
- means for loading and coupling the said outer circular arc member and the said inner circular arc member positioned at the said terminal end of the outer circular member and the said second end of the inner circular arc member;
- an essentially planar spiral loading element having a length approximately 0.15 wavelength of the said center frequency in essentially planar relationship with the said outer and inner circular concentric arc members connected to the said second end of the inner circular arc member; and
- means including an inductor and a variable capacitor cooperating with the said terminal end of the outer circular arc member for tuning the antenna over the said band of frequencies.

4. A tunable, electrically small, high frequency antenna for operating in cooperation with a ground plane, the ground plane being the exterior surface of a vehicle, the antenna being tunable over a determined band of frequencies about a nominal center frequency, the said antenna comprising;

- an outer circular arc conductive member having a radius less than one-tenth the wavelength of the said center frequency, a feed end located at the said ground plane, and a terminating end located approximately 170° of arc from the said feed end;
- an inner circular arc conductive member concentric with the said outer circular member and spaced therefrom approximately 0.04 wavelength of the said center frequency having a first end adjacent the said ground plane and a second end adjacent the said terminating end of the outer circular arc member;
- a parallel loading and coupling member cooperating with the said terminating end of the outer circular arc member and the said second end of the inner circular arc member, the said parallel loading and coupling member being planar with and located between the outer and inner circular arc members;
- an essentially spiral loading member planar with the outer and inner circular arc members, have a length of approximately 0.15 wavelength of the said center frequency connected with the said first end of the inner circular arc member and terminated to the said ground plane; and
- means including an inductor and a variable capacitor, located below the said ground plane, connected to the said terminating end of the outer circular arc member and to the said ground plane for tuning the said antenna over the determined band of frequencies.

5. The antenna as claimed in claim 4 wherein the free resonance range of the said inductor and variable capacitor

essentially encompasses the frequency range of the said determined bandwidth.

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