

[54] OMNI-STEERABLE CARDIOID ANTENNA

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[51] Int. Cl. H01q 21/24

[58] Field of Search.....343/797, 789, 854, 754

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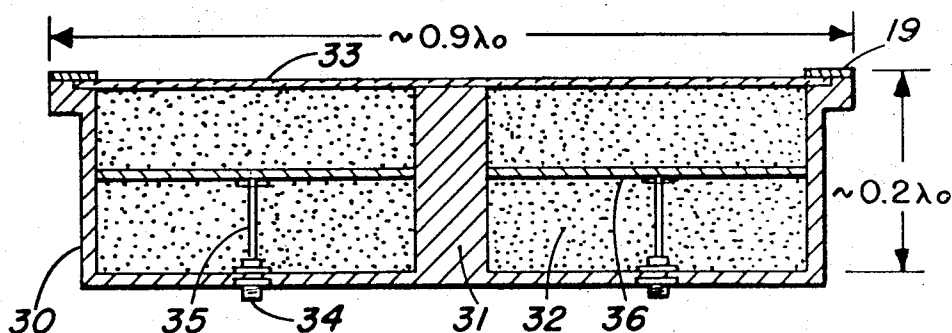
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[57] ABSTRACT

An airborne IFF transponder antenna system which produces either omnidirectional or steerable-cardioid azimuth plane patterns, by the use of a flush dual-mode coaxial-line type cavity radiator which operates in the TEM mode and in the crossed TE₁₁ mode.

12 Claims, 11 Drawing Figures



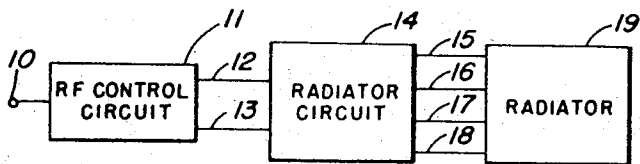


FIG. 1

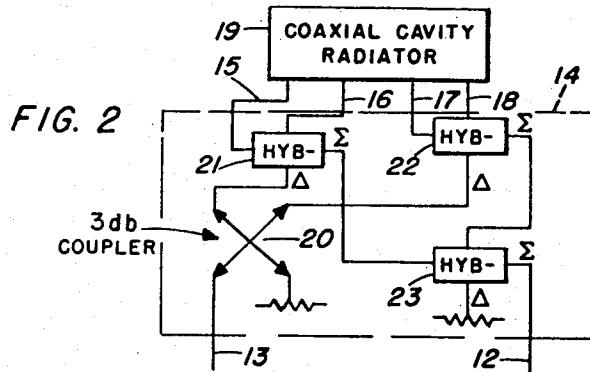


FIG. 2

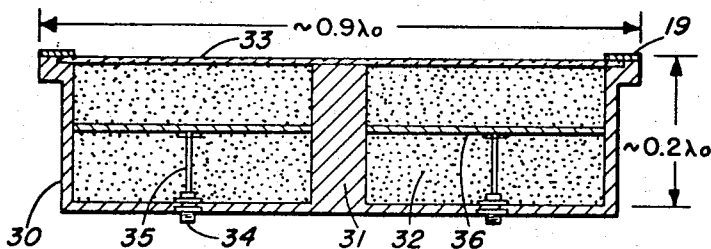


FIG. 3

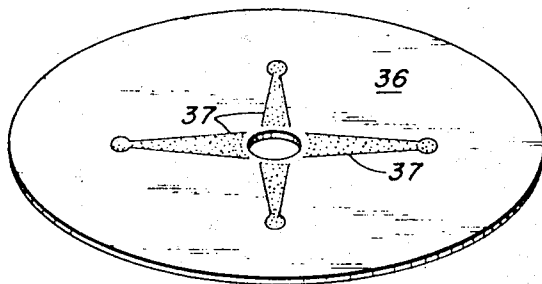


FIG. 4a

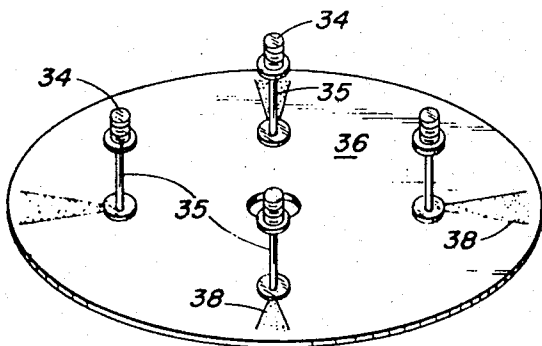


FIG. 4b

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OMNI-STEERABLE CARDIOID ANTENNA

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to improvements in an IFF transponder and more particularly to a new and improved antenna system which produces either omnidirectional or steerable-cardioid azimuth plane patterns.

2. Description of the Prior Art

Steerable antenna patterns have been achieved by many means in the prior art. One such means is an oversized wave guide having four cavities mounted about the wave guide and coupled thereto. The signal is split into higher order modes by the tuned cavities. Movement of the radiation phase center, from the center of the antenna aperture, by tuning the four cavities in sequence to the frequency of the signal achieves a conical scan. Others have used feedback slot antennas to achieve a TEM single frequency scanning or steerable beam. An array of log-periodic antennas have been used to achieve omni-directional and steerable antenna patterns. This has been achieved by using a common signal source and a manual adjustment of the inductors and capacitors in each of the feeds of the antennas in the array. All the systems in the prior art have achieved steerability by mechanical or electrical manipulation of a single mode signal.

SUMMARY OF THE INVENTION

The present invention is an antenna system which produces either omnidirectional or steerable-cardioid azimuth plane patterns, by the use of a flush dual mode coaxial-line type cavity radiator. To obtain these patterns, four independent appropriately located exciters provide either a TEM mode or crossed (orthogonal) TE_{11} mode which are in both space and time quadrature. The TEM mode excitation provides the omnidirectional pattern mode; and a special combination of the TEM and TE_{11} mode excitation provides the steerable-cardioid pattern mode.

OBJECTS OF THE INVENTION

An object of the invention is to provide an improved feed system for an antenna.

Another object of the invention is to provide a new and improved antenna structure that may be suitably integrated with the outer surface of the vehicle.

A further object of the invention is to provide a microwave radiator which is small in size and employs annular apertures.

A still further object of the invention is to provide a fixed antenna which permits, in the horizontal plane, either a omnidirectional radiation pattern or a unidirectional radiation pattern electronically steerable at any azimuth direction, over wide frequency band.

A still further object of the invention is to provide a radiator capable of transmitting in the TEM mode and the crossed TE_{11} mode.

Other objects, advantages, and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram in accordance with the invention;

FIG. 2 is a diagram showing a preferred embodiment of the radiator circuit;

FIG. 3 is the side view of the coaxial-line cavity radiator;

FIGS. 4A and B are the top and bottom view, respectively, of the printed circuit board of FIG. 3;

FIGS. 5 and 6 are circuit diagrams of the RF control circuit in the omnidirectional and unidirectional modes, respectively;

FIGS. 7A and B show typical radiation patterns for antenna constructed in accordance with the present invention, in the omnidirectional pattern mode;

FIG. 8, A and B, show typical radiation patterns for antenna constructed in accordance with the present invention, in the steerable-cardioid pattern mode.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is illustrated in block diagram form, the antenna system according to the present invention. The RF input/output port 10 is connected to RF control circuit 11. Two conductors, 12 and 13, feed the TEM mode signal and the crossed TE_{11} mode signals, respectively, to the radiator circuit 14. The signal from the radiator circuit 14 is applied to the four ports 15, 16, 17 and 18 of radiator 19. The type of transmission or reception is determined in the RF control circuit by combinations of the signals on lines 12 and 13, as applied through the radiator circuit 14 to the ports 15, 16, 17 and 18 of the radiator 19.

FIG. 2 is a detailed electrical schematic of radiator circuit 14. The TEM mode input over line 12 is fed to the sum input of hybrid junction 23. The outputs of hybrid junction 23 are fed to the sum inputs of hybrid junctions 21 and 22. The crossed TE_{11} mode signal is fed over line 13 to a 3 db directional coupler 20. The outputs of the directional coupler 20 are fed to the difference inputs of hybrid junction 21 and 22. The outputs of hybrid junction 21 are connected to input ports 15 and 16 of the coaxial cavity radiator 19, and the outputs of hybrid junction 22 are connected to input ports 17 and 18 of coaxial cavity radiator 19.

For the omnidirectional pattern mode, the radiator 19 is excited by four equi-phased signals at its four input ports 15 through 18. The TEM mode signal is fed over line 12 into the three hybrid junctions 21, 22 and 23, which generate the equi-phased signals.

For the steerable-cardioid pattern mode, both the TEM mode signal over line 12 and the crossed TE_{11} mode signals over line 13 are fed through the three hybrid junctions 21, 22 and 23 and through directional coupler 20 to the four input ports 15 through 18 of coaxial cavity radiator 19. The RF control circuit 11 is used to combine the TEM and crossed TE_{11} modes to form the cardioid pattern. The azimuth direction of the cardioid minimum is steered by controlling the relative phase between the modes; this is accomplished by the two phase shifters. The elevation angular location of the cardioid minimum can be adjusted by controlling the relative level of the modes. However the cardioid minimum has been placed near the horizon by utilizing a fixed -10 db coupler.

FIG. 3 is a detailed drawing of the coaxial cavity radiator 19. The cavity which is made up of outer conductor 30 and inner conductor 31, and is filled with low dielectric constant foam 32. The top of the cavity is closed by a teflon glass window 33. A toroidal printed circuit board 36 is attached in the coaxial cavity and supported by the foam. RF input 34 is connected by coaxial line 35 to the printed circuit board 36. FIG. 4B shows printed circuit 36 with the four equally spaced coaxial line connectors 35 connected to one-half of a dipole exciter 38. The other halves 37 of the dipole exciters are shown in the top view of 4A of printed circuit board 36.

In designing a radiator assembly which would give optimum performance with a omnidirectional pattern and a cardioid unidirectional pattern, optimum omnidirectional pattern performance was defined as a shaped elevation pattern which provides increased horizon gain at the expense of reducing gain in near zenith directions. Large diameter slots (greater than one wave length) radiate most of their power in near zenith (broadside) directions. Small diameter concentric annular slots about one-half wave length diameter or less would be needed to realize optimum design.

Optimum cardioid performance is here defined to be a cardioid-azimuth pattern with minimum signals response (pattern notch) over a large range of elevation angles. It should be noted to obtain large elevation extent of the angular notch, requires the use of multiple concentric rings. The outer rings must be large in size and, consequently, they reduce horizon gain in the direction of the cardioid maximum. The optimum design for a radiator which produces both modes has been found to consist of a 0.9 wave length diameter aperture backed by about a 0.2 wave length deep coaxial - line cavity. This aperture is equivalent to a one-half wave length diameter annual ring radiator. The cavity is excited by four dipoles symmetrically located every 90° in circumference on a printed circuit board, as shown in FIGS. 4 A and B. It should be noted that one-half of each dipole is printed on each side of a printed circuit board 36 to facilitate the connection of the coaxial line 35.

The impedance radiation frequency for the radiator operating either in the TEM or the cross TE₁₁ modes is equivalent to that of the double-tuned resonant circuit. The dipoles are the primary series-tuned resonators. The aperture and the cavity form the secondary parallel-tuned resonators. Coupling between resonators is determined by the location of the dipoles with respect to the aperture. The displacement from the aperture in effect determines the mutual inductive coupling between the primary and secondary resonators. The equivalent circuit parameter values for both modes, are quite different, thus the radiator design must be a compromise impedance match for both modes.

The average resonant frequency of both TEM and TE₁₁ modes has been found to be 1045 Mhz, which is very close to the design center frequency of 1060 Mhz. This scheme of having the average resonant frequency equal to the design center frequency and having the actual TEM and TE₁₁ resonances detuned high and low, respectively, by about 7 percent result in the best compromise radiator design.

As described earlier, the two cross TE₁₁ modes are excited in phase quadrature with a 3 db directional

coupler 20. The reflection at the inputs to the coupler is less than that at the individual TE₁₁ mode ports, because most of the reflected power is dissipated in the terminated port of the coupler. The measured standing wave ratio at the coupler input port is less than 3 db over a band from 900 to 1300 Mhz.

The details of the RF control circuit 11 is shown in FIGS. 5 and 6, which are in the omnidirectional and the steerable-cardioid pattern modes, respectively. The components of the RF control circuit 11 are an RF input/output port 10, two transfer switches 40 and 50, a negative 10 db directional coupler 60, a 0° or 180° step phase shifter 74 and 75, respectively, a 0° - 180° continuously variable phase shifter 84, crossed TE₁₁ mode signal line 13, and TEM mode signal line 12. The 0° or 180° step phase shifter 74 and 75 is constructed of two single-pole double-throw switches 70 and 80, and two cables 74 and 75 that differ by 180° in electrical length at 1060 Mhz.

In the omnidirectional mode of FIG. 5, the input signal through port 10 is fed into transfer switch 40 through terminal 41 and out of terminal 42 to terminal 52 of transfer switch 50. The output of terminal 53 is a TEM mode signal. In FIG. 5 there is no signal from port 10 to the crossed TE₁₁ mode line 13, because of the position of transfer switch 40. In the steerable-cardioid mode, as shown in FIG. 6, input signal from port 10 enters transfer switch 40 through terminal 41 exits through terminal 44 to directional coupler 60. The signal from directional coupler 60 exits through terminal 63 to transfer switch 50 to the TEM mode signal line 12. There is also a signal from terminal 64 of coupler 60 through switch 70 into either the 0° or 180° step phase shifter, 74 and 75, respectively, through switch 80 to the continuously variable phase shifter 84 to the cross TE₁₁ mode line 13. It should be noted that the switching from the omnidirectional mode to the steerable-cardioid mode is achieved by turning the contacts of transfer switches, 40 and 50, through 90° each.

Steerability of the cardioid null over 360° in the azimuth direction is achieved by varying phase shifter 84 from 0° to 180° with switches 70 and 80 connected to the step phase shifter 74 for the first 180° and then switching switches 70 and 80 to the 180° step phase shifter 75.

It has been observed that essentially all the signals introduced at port 10 will be channeled to TEM mode line 12. This circuit path has constant loss and linear phase with frequency over the 900 to 1300 Mhz frequency band. In the steerable cardioid mode the insertion losses of the circuit path to lines 12 and 13 differ by about 11 db. This amplitude difference places the elevation angular location of the radiation power minimum on the horizon. The RF control circuit was designed with the relative transmission phases, to the two lines 12 and 13, linear with frequency and with approximately the same slope, in order to prevent wandering of the azimuth cardioid minimum direction with frequency.

FIG. 7 shows the omnidirectional radiation pattern of the antenna system at 1090 Mhz or in the TEM mode. It may be observed that the antenna does indeed provide nearly identical gain in all azimuth directions; that is, it provides omnidirectional coverage. The elevation-plane patterns presented are typical for any azimuth direction.

Typical-steerable cardioid patterns of the antenna system operating at 1090Mhz is shown in FIG. 8. Again, it may be observed that the azimuth-plane patterns of the antenna are indeed cardioid shaped. The cardioid patterns may be steered by the RF control circuit so that the minima points to any azimuth direction. It is interesting to note that the average 3 db bandwidth of the cardioid maximum is approximately equal to 170°; this compares with the theoretical band-width of 180° for an ideal cardioid-radiation pattern. The elevation-plane pattern presented is for the azimuth direction (0-180°), which contain the cardioid minima. Elevation-plane patterns for other azimuth directions are different.

The above disclosed invention is an airborne IFF transponder antenna system which can provide either omnidirectional or steerable cardioid azimuth plane patterns. The particular mode of antenna pattern operation is to be selected by manual control switch located within the aircraft. The omnidirectional pattern is to provide adequate communications signal strength for both air-to-surface and co-altitude air-to-air performance. The steerable cardioid mode of the antenna is to provide a means for decreasing the intensity of both transmitted and received signals in a selective direction.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. It is therefor to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. An antenna system comprising:
coaxial-line cavity radiator means, the cavity being tuned to resonate in two modes;
radiator circuit means connected to the radiator means for providing said radiator means with excitation signals;
RF control means connected to the radiator circuit means and providing a plurality of signals,
said RF control means comprising mode selection means for determining either an omnidirectional pattern or an electronically steerable unidirectional pattern, and phase-shifting means for determining the direction of the steerable unidirectional signal,
said RF control means having an input port.
2. The antenna system according to claim 1 wherein:
said radiator means is tuned to the TEM mode and the two crossed TE₁₁ modes;
said TEM mode is used alone for omnidirection patterns; and
a combination of TEM mode and crossed TE₁₁ modes are used for the steerable unidirectional pattern.
3. The antenna system according to claim 1 wherein said radiator circuit means comprises two input ports, three hybrid junction means and a directional coupler means all of which are interconnected to receive the plurality of signals from the RF control means and provide the excitation to said radiator.
4. The antenna system according to claim 3, wherein:
said hybrid junction means produce equiphase signals for the omnidirection mode; and
said hybrid junction means and said directional coupler means provide the signals for the steerable unidirectional mode.

5. The antenna system according to claim 1 wherein:
said mode selection means comprises two transfer switches and a directional coupler;
said phase shifting means comprises a 0 - 180° continuously variable phase shifter connected by a switching means to a 0° or 180° step phase shifter.
6. The antenna system according to claim 5 wherein:
said RF control circuit has two output ports;
and said mode selection means and phase shifting means are inter-connected to produce
a. one of the radiator's modes on one of the output ports for the omnidirectional pattern and
b. simultaneously, both of the radiator's modes on each of the output ports separately for the steerable unidirectional pattern.
7. The antenna system according to claim 6 wherein:
said radiator means is tuned to the TEM mode and the two crossed TE₁₁ modes;
said TEM modes is used alone for omnidirection patterns; and
a combination of TEM mode and crossed TE₁₁ modes are used for the steerable unidirectional patterns.
8. The antenna system according to claim 1 wherein:
said radiator means is a coaxial-line cavity radiator comprising four symmetrically located dipoles.
9. Dual-mode antenna means for radiating an omnidirectional or steerable-cardioid pattern, as desired, comprising:
radiating means containing a cavity therein and including at least four coaxial-line dipole antenna means located symmetrically around said cavity, said cavity being excited to radiate electromagnetic energy when said dipole means are energized; and
means for feeding signals of two types to said dipole antenna means, the first of which types excites said cavity to radiate an omnidirectional radiation pattern and the second of which types excites said cavity to radiate a steerable cardioid pattern.
10. An antenna as in claim 9, wherein the first type of signal fed to said dipoles excites resonance of said cavity in a TEM mode and the second type of signal fed to said dipoles excites resonance of said cavity in a TEM mode and in a pair of orthogonally related TE₁₁ modes.
11. An antenna as in claim 9, wherein the diameter of the aperture is approximately 0.9 of a wavelength at the center design frequency and the depth of the coaxial-line cavity is approximately 0.2 of a wavelength at the center design frequency.
12. An antenna as in claim 11, wherein said feeding means includes rf control circuit means and radiator circuit means, said radiator circuit means including three hybrid junctions, each with a sum (Σ) and a difference (Δ) input port and each with two output ports, and a 3 db coupler having an input port and at least two output ports,
said TEM signal being fed to the Σ port of the first hybrid junction, the output ports of which feed the Σ ports of the other two hybrid junctions,
said TE₁₁ signals being fed to the input port of said coupler, one of whose output ports feeds the Δ port of the second hybrid junction and the other of whose output ports feeds the Δ port of the third hybrid junction,

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the four output ports of said second and third hybrid junctions each being connected to a different one of said dipole elements.

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