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3,389,394

MULTIPLE FREQUENCY ANTENNA

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FIG. 1

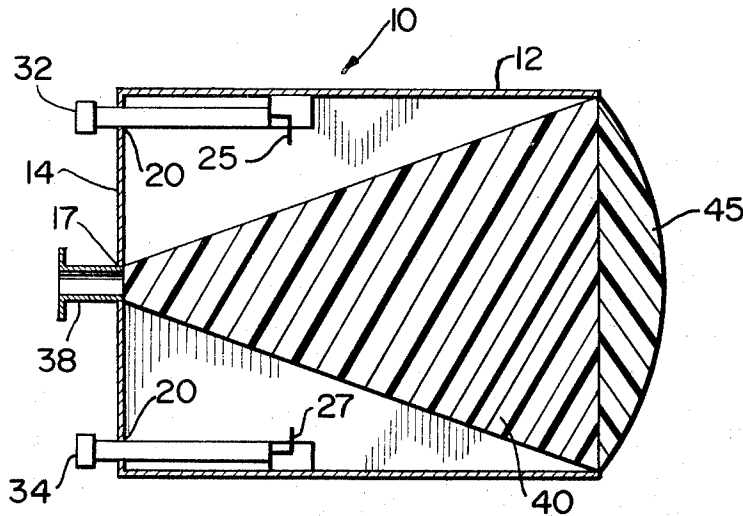
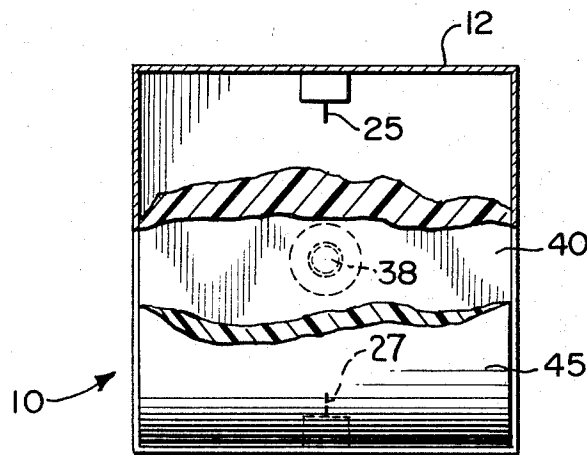


FIG. 2



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ATTORNEYS

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MULTIPLE FREQUENCY ANTENNA

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8 Claims. (Cl. 343-725)

The present invention relates generally to antennas and more particularly to antennas which are simultaneously operable at two or more widely separated frequency bands.

The most serious problem involved in any attempt to provide a multiple frequency band antenna system is the prevention of interference between signal paths in the two or more bands of interest at the antenna or within the feed system. This includes not only the problem of interaction between transmitters, receivers, or both transmitters and receivers, utilizing a common antenna; but the problem of independent transmission, reception, or a combination of both, in such a system, with high aperture efficiency of all frequencies. Where alternate transmission and reception is permissible, as in radar systems, the former problem is solved by the use of duplexers, which are simply switching arrangements for connecting the antenna to the transmitter during the transmission interval with simultaneous disconnect of the receiver from the antenna, and vice versa during the reception interval. For continuous and simultaneous transmission and/or reception, on the other hand, it is conventional practice to utilize duplexers, which are circuit configurations designed to permit the required power feed to and/or from the antenna without interaction between the transmitters or receivers. A typical example of the latter usage is in television broadcasting, where a bridge arrangement (duplexer) for the turnstile antenna permits simultaneous transmission of picture and sound information, with suppression of interaction between the two transmitters.

Such arrangements, however, leave unsolved the problem of maintaining simultaneous, yet independent, transmission and/or reception using a common aperture-type antenna, with desirable high aperture efficiency at all frequencies. It is therefore a primary object of the present invention to provide an antenna which is adapted to operate with improved antenna efficiency on simultaneously used, widely spaced frequencies.

In one prior art system, signal path isolation is maintained for the widely separated microwave frequencies of interest by the use of concentric circular waveguides in a combining network. One waveguide terminates in a high frequency conical horn formed by a conductive cylindrical core having a flared inner diameter along a portion of its length, the core being inserted in the other waveguide and forming therewith a coaxial region for sustaining low frequency TM_{11} mode waves. The low frequency feed system includes orthogonally arranged coaxial probes coupled via a phasing network to the transmitter to produce circularly polarized waves in the coaxial region between the outer surface of the metal core and the inner wall of the larger diameter waveguide. The high frequency feed system includes a coaxial probe extending into a circular waveguide extension of the horn and coupled to a receiver, the waveguide extension including a conventional device for converting the received circularly polarized waves to linearly polarized waves. The mismatch between the low and high frequency feeds is said to prevent cross-coupling of energy between transmitter and receiver from the signal frequencies of interest.

Here, again, the problem of obtaining high aperture efficiency at all frequencies of interest remains unsolved. The metal horn for launching the high frequency signals

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forces the E field to fall to zero at the conducting walls in the H plane, resulting in aperture efficiencies considerably less than 100 percent. Moreover, the high frequency horn acts as a significant aperture block for the low frequency signal; and although this effect can be matched out, it is accomplished at the expense of reduced bandwidth and increased sidelobe levels. High sidelobe levels result, in any event, from the aperture block of the large center conductor required to sustain the TM_{11} mode.

Accordingly, it is a further object of the present invention to provide a multiple frequency band antenna having structure and configuration for substantial elimination of aperture block by one feed of the radiation at another frequency.

Another object of the invention is to provide an antenna capable of simultaneous operation at two or more widely separated microwave frequencies with high aperture efficiency and low volume requirements.

Briefly, an embodiment of the present invention comprises an open ended waveguide excited by an appropriate low frequency feed, and a dielectric horn which serves as a guide for the higher frequencies introduced by another waveguide at the closed end of the first-mentioned waveguide. The dielectric horn is disposed in coextensive and coaxial relationship with the open ended waveguide and is operative to prevent the coupling of high frequency signal energy to the low frequency feed by the use of total internal reflection phenomena. To correct the phase distribution across the radiating aperture, a dielectric lens may be securely placed adjacent the "mouth" of the horn.

Advantages of antennas according to the present invention include high aperture efficiency at all frequencies of the multiple and simultaneously usable bands of interest, with any desired polarization; low volume and weight; minimum cross-sectional area, attributable to high efficiency; capability of being arrayed with like units to provide high gain and low grating lobes; angle of arrival sensing capability when used in an array; applicability to airborne satellite communications and telemetry.

The above and still further objects, features and attendant advantages of the present invention will become apparent from a consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a sectional view of one embodiment of an antenna in accordance with the invention; and

FIGURE 2 is a view, partly in section, looking into the aperture of the antenna of FIGURE 1.

Referring now to the drawings, wherein like reference numerals designate like components in the two figures, the antenna comprises an open ended waveguide 10, of rectangular shape in the embodiment shown, although this is purely by way of example, having conductive side walls 12 and an end wall 14. An axial hole 17 and a plurality of holes 20 adjacent the perimeter are provided in end wall 14 to permit entry of other components of the antenna. The waveguide may be flared at the open end, if desired.

Waveguide 10 is excited by balanced dipole probes 25 and 27 coupled by respective coaxial lines through holes 20 to suitable coaxial connectors 32 and 34 and thence to an appropriate low frequency microwave transmitter. Any desired polarization of the transmitted low frequency signal may be obtained by suitable placement of feeds in accordance with conventional techniques. For example, two pairs of orthogonal probes may be employed, if desired. Balanced dipole probes constitute in this embodiment, low frequency feeds each driven 180° out of phase with the signal driving the opposite dipole, and are vertically oriented to excite a TE mode in waveguide 10, the wave launched toward the open end of the guide.

Higher microwave frequencies are introduced through a circular waveguide 38, for example, positioned at axial hole 17 of waveguide 10. In order to prevent energy in the high frequency waves from being coupled to the low frequency probes, a solid dielectric member 40 is used to guide the high frequency waves. Member 40 acts as a dielectric horn by producing total internal reflection of the waves passing therethrough between the throat and the mouth of the horn. To this end, member 40 comprises a solid dielectric structure tapered or flared at an angle on the order of the complement of the critical angle of the particular dielectric used, and may be constructed in the shape of a cone or a pyramid. The term "critical angle" is used in its conventional sense, as meaning the angle defining the dividing line between total internal reflection and total or partial transmission of rays incident on the dielectric boundary constituting the flared surface of the guide.

Suitable dielectric guide structure is disclosed in the copending applications of Bartlett et al., Ser. Nos. 413,819 and 438,582, entitled, "Reflector Antennas" and "High Efficiency Dielectric Antenna," filed Nov. 25, 1964, and March 10, 1965, respectively. For purposes of clarity and convenience, however, a brief abstract of the pertinent description will be set forth herein.

In accordance with known optical principles, if an electromagnetic wave (or a ray representative of Poynting's vector for the wave) is incident upon the boundary separating two dielectric media each having a different index of refraction (n_1 , n_2), the ray will either be refracted, reflected, or partially refracted and partially reflected, depending upon the angle of incidence. For angles of incidence greater than $\arcsin n_2/n_1$ (where n_1 is the refractive index of the medium in which the ray is traveling prior to incidence at the boundary), there is total internal reflection of the ray. By use of the Maxwell relationship between dielectric constant (ϵ) and refractive index, and assuming that the second dielectric is air (i.e., $\epsilon_2=1$), as is true in this case, the trigonometric sine of the critical angle is equal to $1/\sqrt{\epsilon_1}$. Hence, by suitable selection of dielectric and flare angle, and proper design of the exciter in accordance with known techniques for placement of the phase center of the high frequency waves at or near the throat of the horn, substantially all of the waves introduced into the dielectric member 40 by waveguide 38 are prevented from leaving the boundary of the horn and are directed toward its mouth. A suitable flare angle, as previously mentioned, is one on the order of the complement of the critical angle, and a suitable dielectric is any having a dielectric constant greater than one, such as polystyrene, Plexiglas, or other ordinary or artificial dielectrics. In general, the dielectric constant of the horn should be greater than that of the medium surrounding its flared surface.

The phase distribution across the mouth of horn 40 is a function of the relative phases of wave components radiated directly to that point from waveguide 38 through the dielectric medium and of wave components internally reflected from the boundary of the dielectric guide. A conventional dielectric lens 45 may be placed across the radiating aperture of the horn to correct this phase distribution. As is well known, the dielectric lens is effective to delay a wave by an amount which depends upon the dielectric constant and the thickness of the dielectric (i.e., the length of dielectric material through which each wave component travels). As in the case of dielectric horn 40, dielectric lens 45 may be composed of an ordinary or an artificial dielectric material, consistent with the function to be served by these elements. The lens may be supported at or attached to the base ("mouth") of the horn in any conventional manner.

By virtue of the use of dielectric horn 40 in the antenna shown in the drawings, the higher frequency waves emanating from waveguide 38 are guided past the low frequency probes (e.g., 25 and 27) to prevent any inter-

action therebetween. The low frequency waves excited in waveguide 10, on the other hand, are not subjected to the same physical constraints as are placed upon the higher frequencies in the dielectric guide, and therefore travel through waveguide 10 with relatively little reflection or absorption caused by the presence of the dielectric horn. It will be noted that the dielectric horn does not significantly affect the low frequency performance since the energy storage fields produced by the dielectric interfaces extend out from the interface by an amount directly proportional to the wavelength and inversely proportional to the angle of incidence. Thus, the low frequency probes can couple to the low frequency signal without interfering with the high frequency waves trapped in the dielectric. Because the dielectric guide is non-conductive, the E field of the low frequency waves is not forced to fall to zero at the dielectric interface, as would otherwise be required by the boundary conditions imposed at a conductive surface.

The overall structure and operation of the antenna results, therefore, in substantial elimination of aperture block by one feed of radiation at the frequency coupled to the other feed. As a consequence of the non-interaction between signal paths, operation is permitted at two or more widely separated frequencies with extremely high aperture efficiency.

A typical antenna utilizing concepts according to the present invention for use in the 200 to 290 megacycle and 2000 to 2500 megacycle bands would comprise a square open ended box having side dimensions of approximately 30 inches, with a solid Plexiglas ($\epsilon=2.5$) pyramidal or conical horn having its radiating aperture covered by a Plexiglas lens. For a pyramidal horn the high frequency exciting waveguide (38) is preferably rectangular, while the conical horn shape would preferably utilize a circular waveguide. The low frequency probes (dipole feeds, such as 25 and 27) may be coupled to coaxial connectors at the closed end of the box or at the sides, immediately adjacent the location of the probes themselves, with appropriate feed lines to the low frequency transmitter or receiver, as the case may be.

It is to be emphasized that the shape, dimensions and materials of the component parts of the antenna as set forth herein are purely illustrative. In a cylindrical model of the antenna, waveguide 10 was of circular cross-section having a 4-inch inner diameter, dielectric guide 40 was a solid Plexiglas ($\epsilon=2.5$) cone, lens 45 was solid Plexiglas, and CW feed was employed. The E-plane radiation pattern of the antenna at a low frequency of 2.3 gigacycles showed a gain of 8.7 db with a 3 db beam width equal to 68° ; the H-plane pattern a gain of 8.7 db with 3 db beam width equal to 74° . At the high frequency of 17.2 gigacycles, the E-plane pattern (with low frequency probes in the E-plane) showed antenna gain of 2.3 db, and the same gain for the H-plane radiation pattern (LF probes in the H-plane).

While I have disclosed a specific embodiment of my invention, it would be apparent that variations in the particular details of construction shown and described may be resorted to without departing from the spirit and scope of the invention, as defined by the appended claims.

I claim:

1. A multiple frequency microwave antenna comprising a waveguide, means for coupling low frequency microwave signal energy to and from said waveguide, dielectric guide means disposed in coextensive and coaxial relationship with said waveguide internally thereof, and means for coupling high frequency microwave signal energy to and from said dielectric guide means.

2. The combination according to claim 1 wherein said waveguide is open at one end for radiating low frequency signals therefrom, said dielectric guide means comprising a solid dielectric horn of substantially uniformly increasing cross-sectional area toward the open end of said waveguide to form a high frequency radiating

aperture thereat, and wherein is further included a dielectric lens for correcting the phase distribution across said aperture.

3. The combination according to claim 1 wherein said waveguide has a closed end and an open end, said means for coupling low frequency signal energy comprising a plurality of balanced dipole probes projecting into said waveguide, said dielectric guide means comprising a flared solid dielectric horn having an increasing dimension in the direction of the open end of said waveguide, and said means for coupling high frequency signal energy comprising a further waveguide in electromagnetic signal translating relationship with said horn at the smaller end thereof.

4. The combination according to claim 3 wherein said dielectric horn has a dielectric constant greater than the dielectric constant of its surrounding medium, said horn having a flare angle on the order of the complement of the critical angle defining total internal reflection of electromagnetic waves incident on the flared boundary between said horn and said surrounding medium.

5. The combination according to claim 4 wherein is further included a dielectric lens to correct the phase distribution of waves radiating from the aperture of said horn.

6. An antenna for operation at a plurality of widely separated microwave frequencies with high aperture efficiency at all frequencies, said antenna comprising a wave-

guide for radiating the lower frequencies of said separated frequencies, means for exciting said waveguide at said lower frequencies, and means disposed interiorly of said waveguide for radiating the higher frequencies of said separated frequencies, the last-named means comprising a solid dielectric horn for establishing a boundary with the surrounding medium to substantially confine the propagation of electromagnetic waves interiorly of said boundary between the throat and the mouth of said horn.

7. The antenna according to claim 6 further including a dielectric lens covering the mouth of said horn for correcting the phase distribution of waves at the radiating aperture.

8. The aperture according to claim 7 wherein said horn has a flare angle on the order of the complement of the critical angle defining total internal reflection of electromagnetic waves propagating therethrough, and a dielectric constant greater than that of said surrounding medium.

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