version of the broad-band half-wave dipole would also appear to be feasible; however, the implementation of the design would require an assessment of possible coupling effects within a crossed-dipole arrangement with dual twin-lead transmission line baluns.

CONCLUSION

A fan-dipole (bowtie) element operating over a ground plane has been empirically designed to maximize the impedance bandwidth near the half-wavelength resonance. It has been demonstrated that a bandwidth (VSWR < 2) of 37 percent can be achieved with a simple bowtie element less than a half-wavelength at the center frequency. This design could be useful as a radiating element in a wide-band phased array application or as a wide-band reflector feed or cavity-backed dipole.

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A Compact Flush-Mounting Antenna with Direction Finding and Steerable Cardioid Pattern Capability

H. PARIS COLEMAN AND BILLY D. WRIGHT

Abstract—**A flush-mounting antenna is described which could be used, in lieu of present antennas, to provide direction finding and steerable directional pattern capability in airborne beacon transponder systems. The antenna is comparable in size to the existing, omni-directional antennas presently used for air-traffic control and military identification, friend or foe (IFF) functions. The design and performance of an experimental model of the antenna are discussed.**

INTRODUCTION

Significant advantages could accrue, in airborne beacon transponder systems, through the provision of direction-finding and steerable directional pattern (steerable null) capability in the transponder antenna. We have designed a flush-mounted antenna with this capability.

The antenna is comparable in diameter and depth with the standard, flush-mounted, omnidirectional antenna widely used in air-traffic control and military identification, friend or foe (IFF) applications (an AT740/A) and could be mechanically substituted for this antenna. The standard antenna operates as 1.03 and 1.09 GHz and consists of a cavity backed annular slot of approximately one-half wave-length diameter. The antenna has a maximum depth of 1.5 in (3.8 cm) and diameter of 6.8 in (17.3 cm) exclusive of connectors and mounting flange. Previous flush-mounted or low profile transponder antennas [1], [2], [3], designed to provide steerable (or switchable) beam capability, have been substantially larger than the standard antenna.

We have constructed and tested a model of the new antenna, demonstrating the feasibility of the antenna design. In addition to meeting size restrictions, particular emphasis has been placed upon the attainment of good front-to-back ratios, in the directional patterns, over a wide range of elevation angles. This is to assure good antenna performance in a variety of aircraft situations, and during aircraft maneuvering. Pattern measurements were obtained over a range of elevation angle from 0° to 30° and results show that front-to-back ratios approaching 30 dB are attainable over much of this range. The measured patterns are in excellent agreement with the theoretical cardioid pattern shape. Pattern nulls are well defined and stable in azimuth position. This performance indicates good direction-finding capability. Additionally, the antenna design allows for simple reversion to a standard, omnidirectional in azimuth, radiation pattern.

Manuscript received October 21, 1982; revised November 7, 1983.

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ANTENNA DESIGN AND THEORY OF OPERATION

Fig. 1 diagrams the construction of the new transponder antenna. The antenna was designed to operate from 1.03 GHz through 1.09 GHz, and consists of two concentric, cavity-backed, annular slots [4]. Each slot is excited, with uniform amplitude, by a set of four probes equally spaced around the circumference. The outer slot is fed with a network which provides a constant phase excitation (termed the 0 mode [5]). The inner slot feeding network provides two modes of excitation (termed the ±1 modes) which vary linearly in phase, from 0° to 360°, around the circumference. These two modes differ only in having opposite directions of increasing phase. The 0 mode corresponds to the fundamental transverse electromagnetic (TEM) mode in a coaxial structure while the ±1 modes each correspond to orthogonal pairs of transverse electric (TE_{11}) modes in phase quadrature.

With proper initial phasing of the mode terminals, the circumferential variation of the field in an annular slot with the nth mode energized is

$$E_n(\phi) = a_n e^{jn\phi}, \quad -1 \leqslant n \leqslant 1. \tag{1}$$

It is notable that the circumferential variation in the far-field is of this same form.

Consider a signal incident upon the antenna from the far-field with an angle of incidence $\phi = \phi_0$. An immediate determination of this angle of arrival may be made by comparing the phase at either of the ±1 mode terminals with the phase at the 0 mode terminal. The relative phase at the +1 mode terminal equals ϕ_0, while that at the −1 mode terminal equals $-\phi_0$. This method of direction finding corresponds to earlier work on direction finding with multimodal antennas [6].

On the other hand, the several mode terminals may be fed with a power divider, with the relative amplitudes of the mode excitations adjusted so that the resultant field becomes

$$E(\phi) = 1 + 1/2(e^{j\phi} + e^{-j\phi}) = 1 + \cos\phi \tag{2}$$

for any elevation angle. The azimuth radiation pattern at this elevation angle is, thus, cardioid in shape. Inserting a phase shift of $\gamma_{+1} = -\phi_0$ in the line between the power divider and the +1 mode terminal and $\gamma_{-1} = \phi_0$ in the −1 mode line yields

$$E(\phi) = 1 + \cos(\phi - \phi_0). \tag{3}$$

The cardioid pattern may be steered in azimuth by adjustment of these phase shifters. A diagram of the arrangement for forming

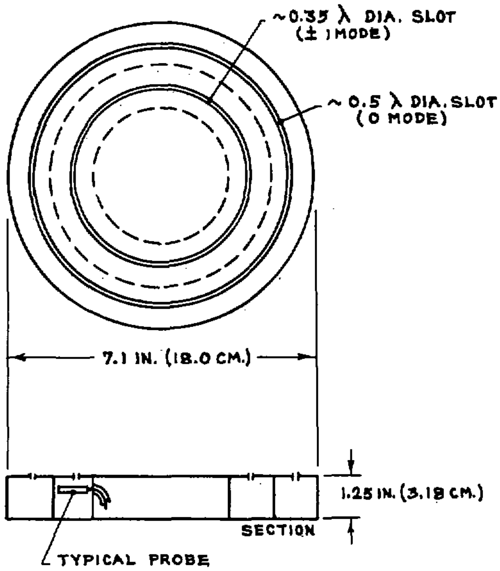

Fig. 1. Diagram of construction of flush-mounting, multimodal, transponder antenna.

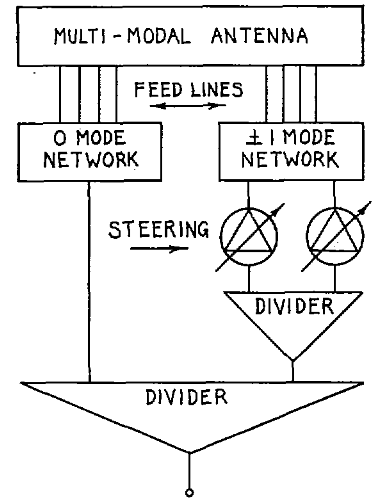

Fig. 2. Diagram of a typical antenna system, utilizing the multimodal antenna.

the cardioid pattern, and steering this pattern in azimuth, is shown in Fig. 2.

An important objective of the antenna design was the attainment of good front-to-back ratios, in the steerable cardioid shaped pattern, over a wide range of elevation angle. Attainment of this objective required good matching of the far-field amplitudes, when each mode was excited separately, over the same range of elevation angle.

Although the form of the azimuth field, at any elevation angle, is independent of slot diameter (provided the correct excitation of the slot is obtained) the elevation pattern of the slot depends upon the mean diameter of the slot and the mode of excitation. For example, an annular slot of 0.5 wavelength mean diameter, situated in an infinite ground plane, has a maximum in the horizontal plane and an axial minimum when excited with the 0 mode. This diameter slot is ideal for providing the omnidirectional, constant phase pattern required for the 0 mode and, as discussed previously, is the configuration normally used for the flush-mounted, transponder antenna. This slot configuration was retained as the 0 mode radiator, and could be used to provide omnidirectional coverage.

An 0.5 wavelength diameter slot, on the other hand, has an omnidirectional minimum in the horizontal plane and a circularly polarized maximum in the axial direction, when excited with either of the ±1 modes. This makes it unsuitable as the ±1 mode radiator. Accordingly, a 0.35 wavelength diameter slot was chosen as the order 1 mode radiator. This is sufficiently small to fit within the 0 mode annular slot and sufficiently large to avoid cutoff of the ±1 modes. This choice of diameter also provides good elevation pattern matching—over a 0° to 30° elevation angle range—with the elevation pattern obtained from the 0 mode radiator.

ANTENNA CONSTRUCTION AND MEASURED PERFORMANCE

A test model of the antenna was constructed following the diagram of Fig. 1 and the principles discussed above. A photograph of the model, partially disassembled, is shown in Fig. 3. The slots were cut from metal cladding on dielectric material and mounted over fabricated cavities carrying the excitation probes. Series capacitance adjustment of the probes was provided by trimming screws which penetrated the interior of the radially arranged cylindrical probes. Adjustment of these capacitances and the annular slot widths allowed the antenna to be matched reasonably well with the cavity depth held fixed at 1.25 in. This depth is less than the depth of the standard transponder antenna. A voltage standing-wave ratio (VSWR) of less than 2.2 was obtained over the band of 1.03 through 1.09 GHz at the input to the antenna system.

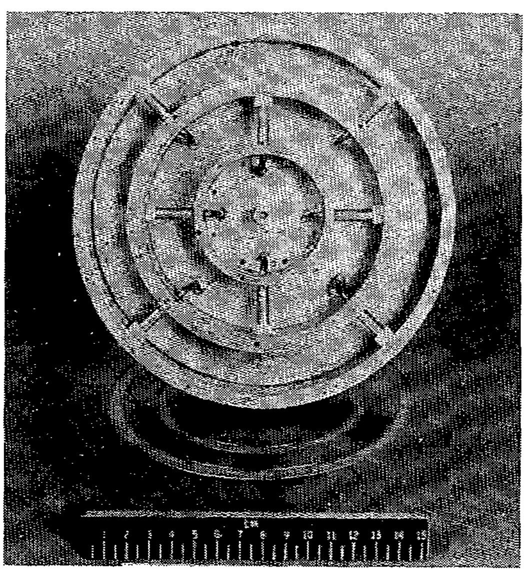

Fig. 3. Photograph of disassembled antenna.

Discrete component 4 by 4 Butler matrices were used to establish the excitation modes. These networks could ultimately be etched on thin circuit boards and mounted directly behind the radiators. The ±1 modes were combined, in equal amplitude, through a 3 dB hybrid. This mode pair was, in turn, combined with the 0 mode through another 3 dB hybrid (see Fig. 2). Line stretchers were used to adjust the mode phases to form the cardioid patterns. The entire system was mounted in a 4 ft diameter ground plane for testing.

Excellent agreement between measured and theoretical pattern performance was obtained. The pattern measured at 1.03

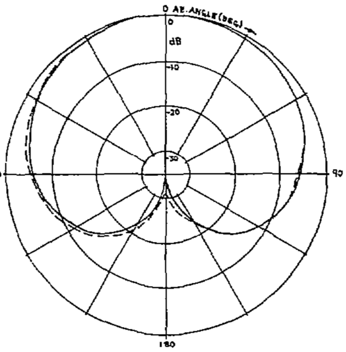

Fig. 4. Azimuth radiation patterns of flush-mounted antenna measured, - - - theoretical.

TABLE I
FRONT-TO-BACK RATIO (IN dB) VERSUS FREQUENCY AND ELEVATION ANGLE

FREQ. (MHZ)	ELEVATION ANGLE IN DEG.			
	0	10	20	30
1030	19.7	31.0	26.4	20.0
1060	25.6	>35	27.6	19.5
1090	23.0	>35	>35	27.6

GHz and elevation angle of 10° is plotted in Fig. 4 along with the theoretical cardioid pattern. The measured pattern is typical of those obtained over the frequency range of 1.03 through 1.09 GHz and elevation angles from 0° to 30°. Contrasted with the infinite theoretical front-to-back ratio, the measured front-to-back ratio of the antenna varied with frequency and elevation angle. This was the principal difference between the various measured patterns. Front-to-back ratios are presented in Table I, for the beam steered in an arbitrary direction. Null depths in excess of 35 dB were observed in some instances. Although the worst measured null was only 19.5 dB deep, most data tended toward 30 dB null depths. The elevation pattern shape agreed closely with that of a monopole over the same size ground plane in the elevation angle range of 0° to 30°. The measured gain of the antenna was −1.5 dB with respect to this monopole. In both instances (monopole or transponder antennas over a 4 ft ground plane) the elevation pattern maximum occurs near 30° with approximately 7 dB less radiation at 0° elevation angle.

SUMMARY

Standard flush-mounted beam transponder antennas, such as those used in air traffic control and military IFF systems, are omnidirectional in azimuth. The feasibility of replacing these antennas with an antenna which has direction finding and steerable cardioid pattern capability has been demonstrated. The new antenna could be flush-mounted as a direct mechanical replacement for the standard antenna and operates over the same band (1.03 through 1.09 GHz). Excellent cardioid pattern performance is obtainable, and simple reversion to an omnidirectional pattern is possible.

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An Orthogonal Mode (Dual-Sense) Helical Antenna

H. PARIS COLEMAN AND BILLY D. WRIGHT

Abstract—**A helical antenna element, fed at both ends and situated above a ground plane, is used to generate both senses of circular polarization.**

INTRODUCTION

An axial mode helical antenna element, situated above a ground plane, and fed at the end nearest the ground plane is a well established radiator of circular polarization [1]. The possibility of simultaneously feeding the end of the helix more remote from the ground plane, thus obtaining the opposite sense of circular polarization by reflection in the ground plane, has been examined. Feasibility of this design has been demonstrated with an experimental model of the helical antenna situated in a conical surround.

DESCRIPTION AND OPERATION

The essential features of the dual-sense helical antenna element are shown in Fig. 1. Feeding of a helix (*C*) at point 1 by means of a transmission line (*A*), with the helix located in front of a conducting ground plane (*D*), is the common configuration. This results in a circularly polarized wave of, say, right hand sense being radiated in direction *A* (the actual sense, of course, depends upon which way the helix is wound). If we feed this same helix at point 2 by means of a transmission line (*B*) a circularly polarized wave of the same sense (right hand) is radiated in direction *B*. Upon reflection from the conducting ground plane, however, the direction of propagation and the sense of circular polarization are reversed. This results in a circularly polarized wave of the opposite sense (left hand), to that obtained by feeding line *A*, being radiated in direction *A*. The feeding of the helix at point 2 may be accomplished by an axially located coaxial line, arranged as shown, without disturbing the usual properties of the helix. Thus, two terminals are provided for the helical antenna which allow the obtaining of dual-sense circular polarization.

EXPERIMENTAL MODEL

An experimental model of the antenna was constructed to verify the operation just predicted. This model was constructed

Manuscript received October 12, 1982; revised November 7, 1983.
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