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Quad-Mode Antenna for Wide-Scan Sparse Arrays

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***Abstract*—A conical quad-mode antenna excited through four orthogonal transverse electromagnetic modes is presented. The radiation characteristics of each mode are validated through measurements, illustrating the complimentary nature of the four far-field radiation patterns through which near-hemispherical field-of-view coverage can be achieved.**

I. Introduction

The authors recently proposed the use of multi-mode antennas to extend the Field-of-View (FoV) coverage of phased-array antenna elements implemented in sparse configurations [1], [2]. These antennas utilize multiple orthogonal Transverse Electromagnetic (TEM) modes to excite integrated, and co-located, dipole and monopole elements through a multi-conductor transmission line. In [3], the authors introduce a conical quad-mode antenna and illustrate the improved FoV coverage with respect to gain, sensitivity and polarimetric performance that can be obtained through judicious use of the four available TEM excitation modes.

This paper presents the measured multi-mode response of a conical quad-mode antenna design. The presented results affirm the complimentary nature of the four orthogonal excitation modes that enables the quad-mode antenna to achieve near-hemispherical FoV coverage.

II. Conical Quad-Mode Antenna Design

The conical quad-mode antenna design presented in this paper operates at a center frequency of 950 MHz with an operating frequency bandwidth of approximately 35%. As shown in Fig. 1, the antenna comprises two perpendicularly oriented bow-tie antennas printed on a FR-4 substrate positioned above a 2 mm thick aluminium conical monopole sleeve connected to the ground shield of a quadraxial transmission line at the apex. The conical monopole element extends downward up to a distance (h_1) from the ground plane. To excite the antenna, four coaxial connectors are positioned below the ground plane, where the center conductor of each connector is connected to one of the brass inner conductors of the air-core quadraxial feed – each with a diameter of 5 mm. As shown in Fig. 1(b), the four inner conductors of the feed are each terminated in one of the bow-tie arms. Table I summarizes the design dimensions indicated in Fig. 1.

To illustrate the radiation characteristics of the quad-mode antenna consider the simulated field distributions of the four

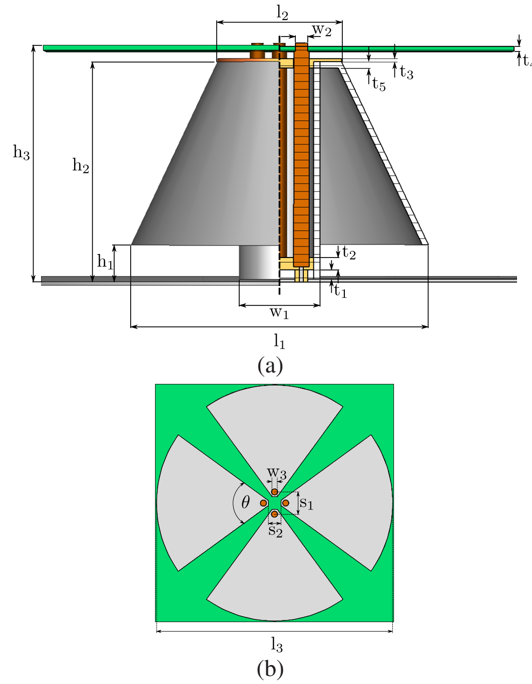

Fig. 1. Conical quad-mode antenna design (a) side view showing inner conductor of quadraxial feed (b) top view of printed bow-tie antennas.

TABLE I
Conical quad-mode antenna design parameters

Parameter	Value [mm]	Description
w_1	26.15	Ground shield outer diameter
w_2	4	Reduced inner conductor diameter
w_3	3.3	Bow-tie inner edge width
t_1	3	Aluminium feed short thickness
t_2	4	Bottom Teflon spacer thickness
t_3	1	Top Teflon spacer extrusion above cone
t_4	1.6	FR-4 substrate
t_5	2	Top Teflon spacer feed extrusion depth
l_1	96	Conical monopole bottom length
l_2	40	Conical monopole top length
l_3	150	Bow-tie dipole length
h_1	11	Conical monopole - ground plane separation
h_2	70	Quadraxial feed height
h_3	75	Dipole height
s_1	14.15	SMA feed center separation
s_2	8	Bow-tie arm inner edge separation
θ	72	Bow-tie arm flare angle

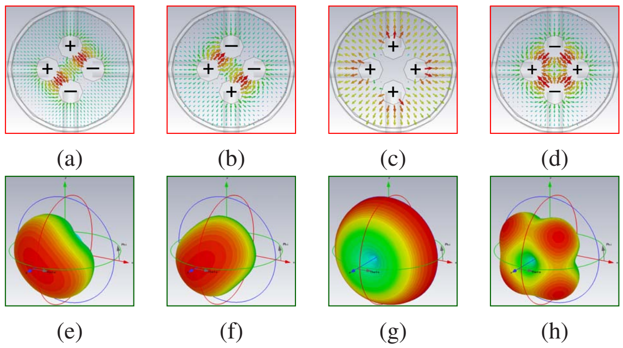

Fig. 2. Field distribution of port excitation modes (a) MM_1, (b) MM_2, (c) MM_3, (d) MM_4 and corresponding radiated far-field patterns of modes (e) MM_1, (f) MM_2, (g) MM_3, and (h) MM_4.

orthogonal TEM port excitation modes with their corresponding radiated far-field patterns [c.f. Fig. 2], as simulated in CST Microwave Studio over an infinite ground plane. As shown in Fig. 2, excitation modes MM_1 and MM_2 result in two orthogonal dipole-over-ground far-field patterns, mode MM_3 radiates in a typical monopole fashion and excitation mode MM_4 radiates power diagonal to the orientation of the bow-tie antennas. It is noted from Figs. 2(e)–(h) that, collectively, these four excitation modes allow for a hemispherical scan-range.

III. Measured Response

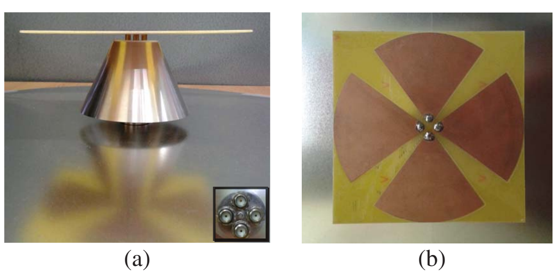

Fig. 3. Manufactured quad-mode antenna (a) side view showing four SMA connectors (b) top view of printed bow-tie antennas.

To verify the simulated response of the quad-mode antenna, the manufactured design is placed on a circular ground plane with a diameter of 450 mm. Figure 3 shows the measured conical quad-mode antenna design as well as the four coaxial connectors through which the antenna is excited.

As reported in [4], the multi-mode response of the quad-mode antenna can be obtained from conventional Single-Ended (SE) radiated far-field pattern measurements where each SE far-field is measured by individually exciting each port with the remaining three ports terminated in a matched load. Figure 4 compares the multi-mode co-polar gain, transformed from SE far-field measurements, to the co-polar gain simulated in CST using the multi-mode port excitations illustrated in Figs. 2(a)–(d). Given the symmetrical design, only the $\phi = 0°$ plane measurements are shown.

The measurements in Fig. 4 are seen to be in close correspondence to the radiation characteristics of the four

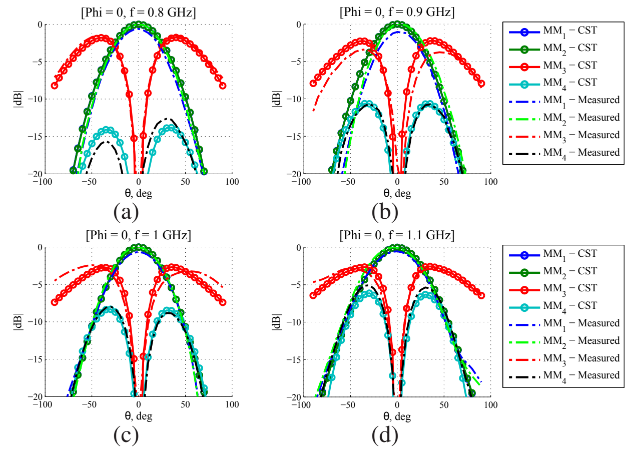

Fig. 4. Measured and simulated co-polar gain (normalized) in the $\phi = 0°$ plane at (a) 800 MHz, (b) 900 MHz, (c) 1 GHz, and (d) 1.1 GHz.

orthogonal excitation modes observed in the simulated results illustrated in Fig. 2. Furthermore, the measurements are seen to agree with the co-polar gain of each mode simulated in CST over the finite circular ground plane. Modes MM_1 and MM_2 are seen to radiate dipole-over-ground patterns across the frequency band with mode MM_3 radiating in a typical monopole fashion. Note that the lower measured gain of mode MM_4 can be attributed to the mismatch of this mode observed within the operating frequency band [3].

IV. Conclusion

This paper presents the design of a conical quad-mode antenna for wide scan-range irregular phased array applications. The radiation characteristics of the four orthogonal excitation modes that collectively allow for hemispherical FoV coverage are introduced and validated through measurements.

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