Compact Stacked-Patch Antenna for Directional Modulation in Azimuth and Elevation Planes

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***Abstract*—This work proposes a compact stacked-patch antenna capable of beamsteering in the vertical and horizontal directions. These characteristics are studied to realize directional modulation (DM) schemes in the vertical and horizontal planes, using a structure of 0.56λ diameter. The design offers a unidirectional beamsteering across the entire xy-plane, with a scanning range of 118° and 112° in the xz and yz-planes, respectively. A peak realized gain of 6.75 dBi is achieved, with an isolation better than 15 dB at the center frequency of 2.4 GHz. The directional modulation performance shows a beamwidth with Bit Error Rate (BER) $< 10^{-2}$ of 33° in the horizontal plane, and 50° for the elevation planes. This performance is proposed to improve the secrecy and privacy of data transmission in the growing field of small Internet of Things (IoT) technology.**

I. Introduction

Physical Layer Security (PLS) techniques are becoming a popular approach to complement encryption-based methods by improving the secrecy of the transmitted data in the presence of eavesdroppers. Directional Modulation (DM) is a promising beamsteering-based PLS-technique with the ability to transmit the standard baseband constellations symbols towards a pre-specified secure direction while simultaneously scrambling the same constellations pattern, in directions other than that of the legitimate receiver [1], [2]. Because DM offers improved secrecy based on physical-layer characteristics, it is a particularly attractive technique for small IoT devices due to their limited computational power and energy constraints.

However, most of the proposed DM schemes are centred in the azimuth-plane [1]–[4]. This is because of the inherited beamsteering limitations of linear array structures [1], [2], which are not capable of dual-plane beamscanning, and the compact designs proposed in [3], [4] are only capable of single plane (azimuth) scanning properties. DM schemes for dual-plane beamsteering have been studied using planar arrays in [5] and frequency diverse arrays in [6]. However, due to the use of large array structures, requiring element spacing of typically 0.5λ, these methods are not suitable for small IoT packaging.

This study proposes a compact stacked-patch antenna of 0.56λ diameter for azimuth and elevation planes DM schemes. The antenna is comprised of 7 ports, and the beamsteering is achieved by controlling the amplitudes and phase shifts of each port. Dual-plane beamsteering capabilities are demonstrated with a scanning range of $360°, 118°$ and $112°$ for xy, xz, and yz-planes, respectively. The proposed DM scheme shows

This work was supported by Science Foundation Ireland under grant no. 18/SIRG/5612 and in part by the 2021 IEEE AP-S C.J. Reddy travel grant for graduate students.

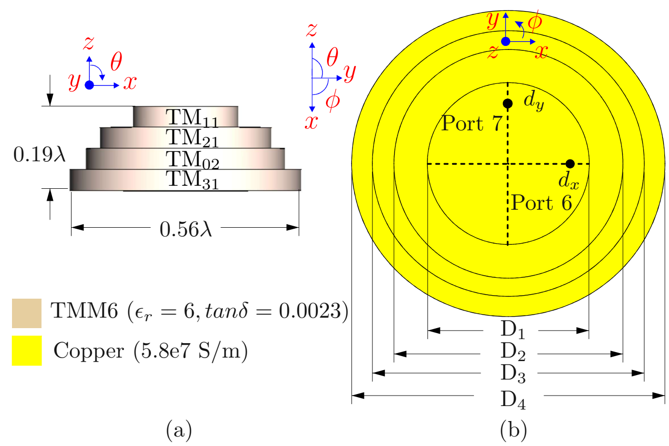


Fig. 1. Proposed stacked-patch antenna (not drawn to scale). Left: front-view with antenna dimensions and different radiating modes. Right: top-view outlining top disc feeding and all discs diameters (in mm: D1 = 32.2, D2 = 52.4, D3 = 60.80, and D4 = 70.16).

beamwidths $< 50°$ for Bit Error Rate (BER) $< 10^{-2}$ across the azimuth and elevation planes.

II. Antenna Design

The proposed antenna is shown in Fig. 1. The design is based on the structure discussed in [7], and consists of four dielectric-loaded circular patches. The main difference compared to [7], is that the top patch ($D1 = 32.2\,\text{mm}$) is fed using two ports (ports 6 and 7), which are located at $d_x = d_y = 12\,\text{mm}$, away from the disc center and oriented by 90° in respect to each other. This feeding technique excites two broadside TM_{11} modes, which are exploited for full scanning in the elevation plane. The other patches excite the TM_{02} mode, two orthogonal TM_{21} modes, and two orthogonal TM_{31} modes, with the sets of TM_{21} and TM_{31} modes being fed with $\pm 90°$ phase shift to ensure the required phase variations for compact beamsteering [8].

III. Results Discussion

The antenna is simulated using the time-domain solver in CST Studio Suite. At the center frequency ($2.4\,\text{GHz}$): the isolation is $> 15\,\text{dB}$; the $-10\,\text{dB}$ impedance bandwidth is $5\,\text{MHz}$; and the total efficiency for the ports exciting TM_{11}, TM_{21}, TM_{02}, and TM_{31} modes is respectively: 93%, 83%, 89%, and 40%. The low efficiency of the TM_{31}, can be explained by the increased phase-variations of these modes while using a compact structure (0.56λ diameter). The beamsteering

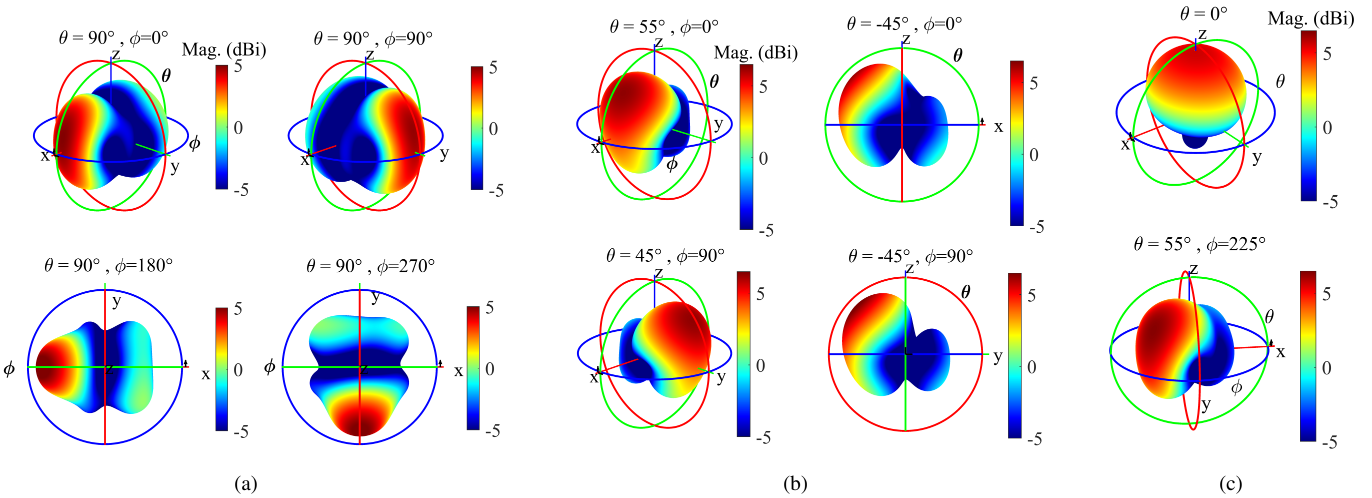
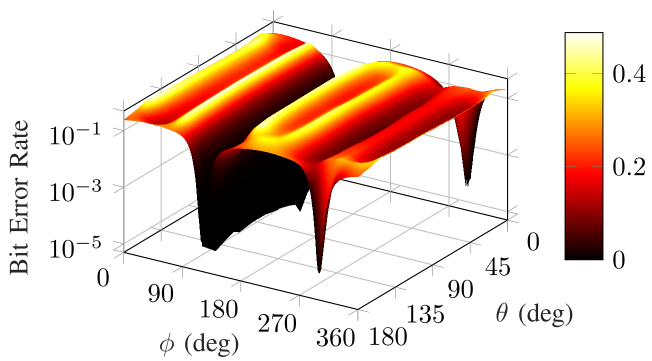
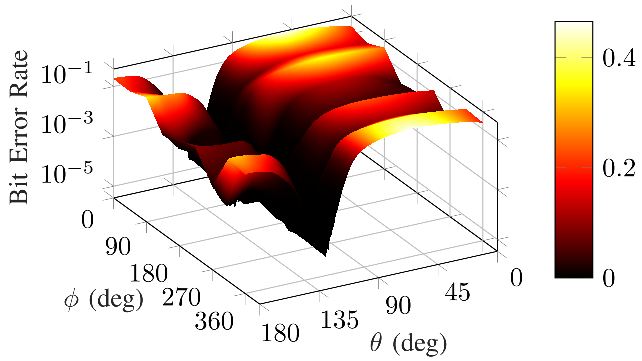


Fig. 2. Realized gain of 10 selected beams at 2.4 GHz showing the beamsteering in the: (a) xy-plane; (b) xz-plane (top) and yz-plane (bottom), and (c) at broadside ($\theta = 0°$) and $\theta = 55°, \phi = 225°$. Note that the coordinate axes were rotated to best highlight features of each generated beam.



(a)



(b)

Fig. 3. BER calculations using 12 dB SNR showing the DM performance in the: (a) azimuth plane, for the legitimate receiver at $\phi = 120°$; (b) elevation plane for the legitimate receiver at $\theta = 120°$.

performance is shown in the 3D far-fields plots of Fig. 2. The scanning range is $360°, 118°$, and $112°$ for xy, xz , and yz-planes, respectively.

The directional modulation performance is shown in Fig. 3. The results are obtained using Quadrature Phase Shift Keying (QPSK), with the BER calculations for different directions of the investigated planes conducted using a data stream with 10^5 transmitted symbols, and a 12 dB Signal to Noise Ratio (SNR) with additive White Gaussian Noise. The results show that using a compact structure of only 0.56λ diameter the proposed system is capable of secure data transmission in the azimuth and elevation planes. The secure data transmission is achieved without leakage into undesired eavesdroppers directions and shows beamwidths with BER $< 10^{-2}$ of 33° in the azimuth plane [see Fig. 3(a)], and 50° in the elevation plane [Fig. 3(b)]. More importantly, this performance is achieved using a compact structure suitable for small IoT packaging, when compared to models discussed in [5] (array comprised of 21×20 elements with 0.5λ spacing) and [6] (array of 10×7 elements with 0.5λ spacing).

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