Stacked-Patch MIMO Antenna for Dual-Plane Beamsteering

Abel Zandamela, Nicola Marchetti, Adam Narbudowicz
CONNECT Centre,
Trinity College Dublin, Dublin, Ireland
email:{zandamea,nicola.marchetti,narbudoa}@tcd.ie

***Abstract*—This paper proposes a compact stacked-patch multiple-input multiple-output (MIMO) antenna with beamsteering in azimuth and elevation planes. The beamsteering is executed by controlling phase shifts and amplitudes between the antenna's six ports. Full-wave simulated results are presented for $2.4\,\mathrm{GHz}$. The isolation between the ports is better than $16.5\,\mathrm{dB}$ with realized gains up to $6.71\,\mathrm{dBi}$. The antenna provides 360° unidirectional beamsteering in the azimuth plane and a scanning range of 120° is demonstrated in the elevation plane.**

Keywords*—*multimode antennas; MIMO antennas; pattern reconfiguration; antenna miniaturization; smart antennas.

I. INTRODUCTION

The widespread proliferation of modern wireless applications creates an increased demand for the use of miniaturized antennas. These antennas need to exhibit advanced functionalities such as adjusting radiation patterns in both azimuth and elevation planes. These properties are required for application like directional modulation or Angle-of-Arrival-based localization.

Multimode antennas can be a good candidate for digital beamforming with reduced size. In [1], a stacked three-layer circular patch antenna is investigated for null steering applications. The authors in [2] present a stacked-patch antenna for directional modulation systems. In [3], planar multimode antennas are proposed for angle of arrival estimation. In [4]–[6] multimode antennas are investigated to allow beamsteering in compact devices. However, the above structures allow either only null steering or steering in single plane; Moreover some designs use a relatively large antenna size or have a bi-directional radiation pattern (a drawback for many modern wireless systems such as those requiring localization over the entire azimuth plane).

This paper proposes a multimode MIMO antenna comprised of six ports, where each port excites different orthogonal resonant modes. The design allows for compact beamsteering in the azimuth and elevation planes, while exhibiting unidirectional beam patterns. The unidirectional beamsteering over the entire azimuth plane is achieved by superposition of TM_{21}, TM_{02} and TM_{31} resonant modes.

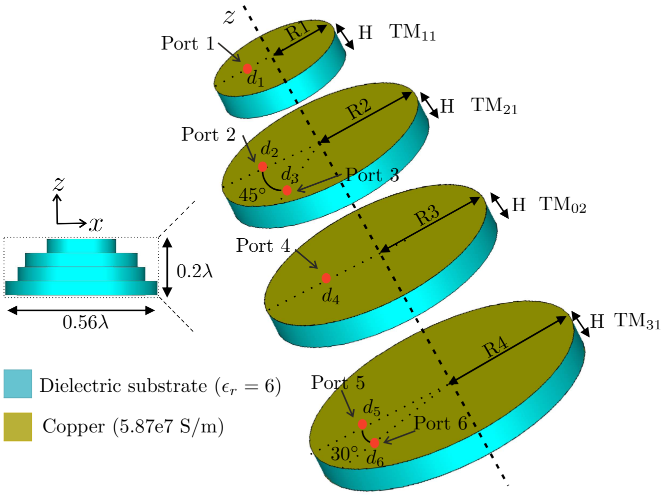

Fig. 1. Proposed multimode MIMO antenna (not drawn to scale). Left: the front-view (xz-plane) with antenna thickness and diameter. Right: zoomed exploded perspective view outlining discs radii, respective radiating modes and marked ports.

II. ANTENNA DESIGN

The proposed multimode MIMO antenna is shown in Fig. 1. It is comprised of four dielectric-loaded circular patch antennas. In the proposed design, each metallic patch is made of copper with thickness of $0.035\,\mathrm{mm}$. The substrate used is ROGERS TMM6 (with relative permittivity $\epsilon_r = 6$, loss tangent $\tan\,\delta = 0.0023$ and thickness $\mathrm{H} = 6.35\,\mathrm{mm}$). The top structure excites broadside TM_{11} mode (radius R1 $= 16.05\,\mathrm{mm}$, fed using port 1), followed by the patch supporting two orthogonal TM_{21} modes (R2 $= 26\,\mathrm{mm}$, fed using ports 2 and 3); The antenna below supports TM_{02} mode (R3 $= 29.8\,\mathrm{mm}$, fed using port 4); Finally, the bottom part supports two orthogonal TM_{31} modes (R4 $= 35.08\,\mathrm{mm}$, fed using ports 5 and 6). The final antenna dimensions are $25.6\,\mathrm{mm} \times 70.16\,\mathrm{mm} \times 70.16\,\mathrm{mm}$, or correspondingly $0.2\lambda \times 0.56\lambda \times 0.56\lambda$, providing low antenna profile compared to the models discussed in [4]–[6]. The design can be further miniaturized by using a substrate with higher relative permittivity [4].

Ports 1 and 4 are respectively located at $d_1 = 8\,\mathrm{mm}$ and $d_4 = 7\,\mathrm{mm}$ (along $-x$ direction) from the center of their respective discs. Port 2 is located at $d_2 = 13\,\mathrm{mm}$ with respect

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to the disc center, port 3 (d_3) is oriented $45°$ with respect to port 2; this is done to excite two TM_{21} orthogonal modes. To excite two orthogonal TM_{31} modes, port 5 is located at $d_5 = 15.5\,\mathrm{mm}$ in respect to the disc center, port 6 (d_6) is oriented by $30°$ with respect to port 5.

III. RESULTS DISCUSSION

The antenna is simulated using the finite-integration technique from CST Studio Suite. The S-parameters are shown in Fig. 2a. The center frequency is $f_0 = 2.4\,\mathrm{GHz}$, where the isolation is better than $16.5\,\mathrm{dB}$ between all ports and the $-10\,\mathrm{dB}$ impedance bandwidth is $7.5\,\mathrm{MHz}$. The total efficiency for ports 1, 2, 3, 4, 5, and 6 at f_0 is: 92%, 83%, 83.5%, 90%, 38.4% and 38.6%, respectively. The efficiency deterioration for port 5 and 6 is due to the use of higher modes with complex radiation pattern from relatively small volume. This phenomena was observed and discussed in details in [4], [6].

Fig. 2b and Fig. 2c illustrate the dual-plane beamsteering capability of the proposed antenna. The required phase shifts are obtained by exciting the pairs (port 2 and 3) and (port 5 and 6) with $\pm 90°$ phase shift. The TM_{02} mode has a monopole-like radiation pattern (with a roughly constant phase over the entire azimuth plane), while the phases of the TM_{21} and TM_{31} modes change linearly in opposing directions (twice for TM_{21} and thrice for TM_{31}) in the same plane; Superposition of the above modes with amplitude and phase control allow for compact beamsteering in the azimuth plane (see [5] for more details).

The unidirectional beamsteering is depicted in Fig. 2b where four beams are separated by $90°$, with realized gains varying from 4.51 to $4.9\,\mathrm{dBi}$. The beamsteering in the elevation plane is obtained by combining the broadside mode (TM_{11}) with the higher-order modes. The beamsteering for this plane is shown in Fig. 2c, and the input amplitudes (A_{inp}), phase shifts (Δ_{phase}) and realized gains for each of the five investigated configurations are outlined in Table I.

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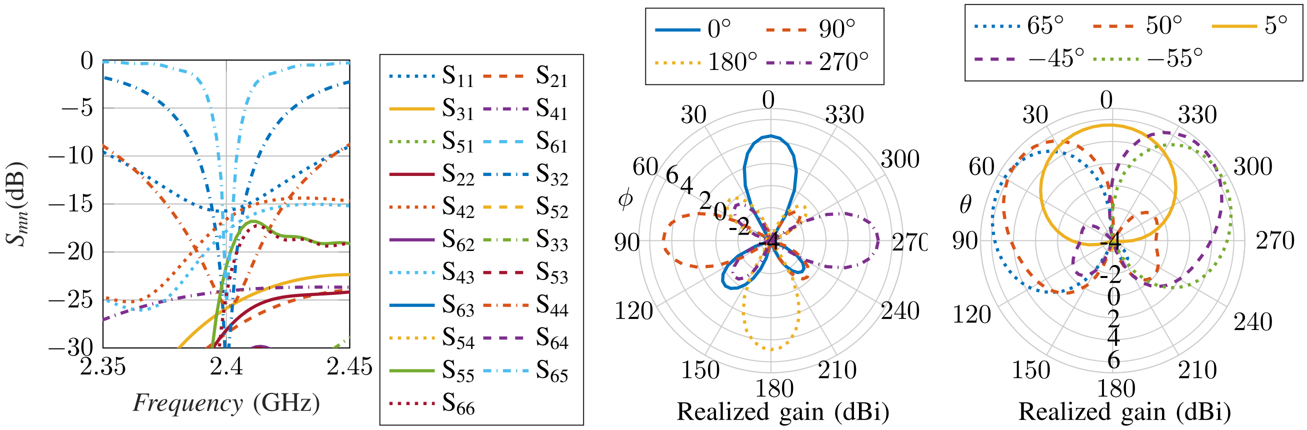

(a) (b) (c)

Fig. 2. Full-wave simulated results of the proposed antenna: (a) S-parameters; (b) Realized gain at 2.4 GHz showing the steering in the azimuth plane (xy-plane in Fig. 1) and (c) Realized gain showing the steering in the elevation plane (xz-plane in Fig. 1).

TABLE I
CONFIGURATIONS FOR xz-PLANE STEERING.

Beam direction	Port 1		Port 2		Port 3		Port 4		Port 5		Port 6		Gain (dBi)
	A_{inp}	Δ_{phase}	A_{inp}	Δ_{phase}	A_{inp}	Δ_{phase}	A_{inp}	Δ_{phase}	A_{inp}	Δ_{phase}	A_{inp}	Δ_{phase}	
65°	1	0°	1	−67°	1	25°	1	148°	1	205°	1	−66°	6.38
50°	1	0°	1	−79°	1	25°	1	145°	-	-	-	-	6.26
5°	1	0°	-	-	-	-	-	-	-	-	-	-	5.51
−45°	1	0°	1	116°	1	216°	1	−23°	-	-	-	-	6.71
−55°	1	0°	1	116°	1	216°	1	−23°	1	210°	1	−56°	6.48

A_{inp} and Δ_{phase} – are the input amplitude and phase shift at each antenna port.