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Dual-frequency dual circularly-polarised patch antenna with wide beamwidth

X.L. Bao and M.J. Ammann

A dual-frequency dual-circularly polarised patch antenna with wide beamwidth is proposed. The two-layer structure comprises circular patches with offset circular slots connected to rectangular slots. They provide orthogonal perturbations realising RHCP and LHCP for the lower and upper bands, respectively. The wide beamwidth is realised by extending the substrate beyond the groundplane. Measurements show a maximum beamwidth of 180° and gains of 3.9 and 0.5 dBic for zenith and 10° elevation, respectively, for the upper band. The measured beamwidth for the low band is 130° with a maximum gain of 3.9 and −0.7 dBic for zenith and 10° elevation, respectively. The axial-ratio is less than 3 dB in the hemisphere for elevations greater than 10° for both bands.

Introduction: Circularly-polarised microstrip patch antennas have been widely used in satellite navigation systems and GPS. Recently, many studies on circularly-polarised (CP) antennas have been reported, such as wideband CP antennas [1] and dual-frequency dual-CP antennas [2]. In [2] the microstrip-fed dual-sense dual-frequency operation was achieved in a single layer, whereas this proposed probe-fed antenna employs two layers and is less constrained, with a larger range of frequency-ratios attainable and wider beamwidth. Broad beamwidth antenna characteristics are very valuable in base station [3] and GPS [4] applications and can improve the coverage area in wireless communication systems. Typically, microstrip antennas provide a 3 dB beamwidth of 110°, and gain at 10° elevation ($\theta = 80°$) is −3 dBic. Researchers have used many techniques to achieve broad beamwidth characteristics, such as an antenna with a pyramidal ground structure and a partially enclosed flat conductor wall achieving axial-ratio (AR) beamwidths greater than 130° in two planes [4], a broad beamwidth patch antenna with auxiliary radiators yielding a 16% beamwidth broadening [5], a hybrid perturbation technique with stacked square-ring antennas [6] and extended dielectric substrate [7]. In this Letter, a wide beamwidth antenna is proposed for applications in telemetry and mobile satellite communications systems. The antenna comprises two circular patches fabricated on high permittivity dual-layer substrates. By extending the length of the substrate, the proposed dual-frequency dual-circularly polarised antenna can provide very wide beamwidth with an axial ratio of less than 3 dB over the entire hemisphere for both frequency bands.

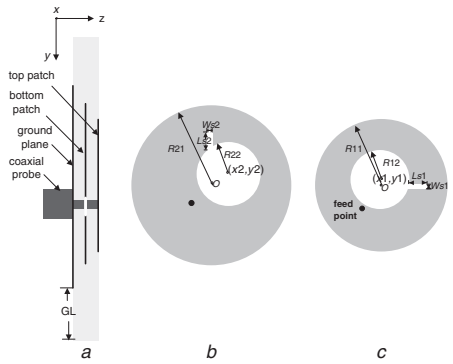

Fig. 1 *Geometry of proposed dual-frequency dual-circularly polarised antenna*

a Substrate
b Bottom patch
c Top patch

Antenna dimensions and geometry: The configuration of the proposed antenna is shown in Fig. 1, which consists of a two-layer circular patch, each layer with an embedded circular-slot connected to a narrow rectangular slot. The rectangular slots are rotated by 90° with respect to each other. The top patch is fed by a 50 Ω coaxial probe. The slot combination provides the necessary perturbation and two orthogonal degenerate resonant modes with a 90° phase difference, yielding CP characteristics. To achieve RHCP and LHCP characteristics simultaneously, two similar patches are placed on different layers. The circular slots in the top and bottom layers are offset (values in Table 1), which helps to provide good matching in the two different frequency bands.

Table 1: Dimensions of proposed antenna

Parameters (mm)	Top Patch					Bottom Patch					Feed point (mm)
	*R*11	*R*12	*Ls*1	*Ws*1	Circular slot offset (*x*1, *y*1)	*R*21	*R*22	*Ls*2	*Ws*2	Circular slot offset (*x*2, *y*2)	(2.9, 2.9)
	13.0	3.2	5.3	0.8	(0, −1)	18.0	4.1	0.8	3.4	(−4, −4)	

The half-power beamwidth (HPBW) is heavily dependent on parameters such as the groundplane size and substrate materials. Usually, as the groundplane size decreases, the HPBW will increase for the same patch antenna, and a high permittivity substrate can also reduce the antenna size and groundplane size, so it can also help provide a wider HPBW. But the gain will decrease for these conditions. In this Letter, one method to enhance antenna gain under the same conditions (same patch and groundplane size) is to extend the length of substrate. By extending the substrate beyond the groundplane, the width of the radiation beam and gain will also be increased, yielding wide beamwidth with reasonably constant gain across the entire hemisphere. The selected parameters for the antenna are listed in Table 1. It is printed on a Taconic substrate with permittivity 9.5, thickness 1.58 mm and loss tangent 0.0018.

A parametric study of substrate extension length was made using the finite-integration time-domain solver (CST MWS) and the peak gain, beamwidth and gain at 10° elevation is compared and shown in Table 2. It can be observed that the 3 dB beamwidth and gain at the 10° elevation angle ($\theta = 80°$) are increased as the length of the substrate extension is increased. For the low frequency at 1.450 GHz, the peak gains have increased by 3 dB as the length of substrate size is changed from 40 to 120 mm, but in the high-frequency band at 2.010 GHz, the peak gains have decreased because of the significantly increased beamwidth.

Table 2: Performance comparison for difference substrate sizes

Measured parameter		Substrate size 40 × 40 mm GL = 0	Substrate size 60 × 60 mm GL = 10	Substrate size 80 × 80 mm GL = 20	Substrate size 100 × 100 mm GL = 30	Substrate size 120 × 120 mm GL = 40
Low frequency 1.450 GHz (*xoz* plane)	3 dB beamwidth (°)	116	116	118	124	126
	10 degree elevation gain (dBic)	−4.5	−2.3	−1.2	−1.0	−0.8
	Peak gain (dBic)	1.1	2.5	3.1	3.6	4.1
High frequency 2.010 GHz (*xoz* Plane)	3 dB beamwidth (°)	100	110	140	170	190
	10 degree elevation gain (dBic)	−2.5	−2.0	−0.8	0	0.8
	Peak gain (dBic)	4.8	4.6	4.28	3.5	3.2

Measured results: Based on the numerical results, the antenna was designed and fabricated. The substrate size is 100 × 100 mm and ground plane size is 40 × 40 mm. RHCP and LHCP were realised for the lower and upper frequency, respectively. Fig. 2 shows the measured S_{11}. The frequency range for which the return loss is greater than 10 dB was found to be 1.431–1.464 GHz (33 MHz) for low frequency and 2.001–2.063 GHz (62 MHz) for the upper band. The measured result is in good agreement with the simulated results. Fig. 2 also illustrates that the 3 dB axial-ratio (AR) bandwidth is 9 MHz (1.448–1.457 GHz) and 14 MHz (2.022–2.036 GHz) for the low and high bands, respectively. Measurements show that a wide beamwidth can be provided by the proposed antenna. It is shown in Fig. 3 that for the low band, the beamwidth is 130° for the *xoz* plane and 100° for the *yoz* plane; for the high band, the beamwidth is 180° for the *xoz* plane and 114° for the *yoz* plane. The 3 dB axial-ratio (AR) beamwidth is also improved for the two bands, as shown in Fig. 4. For the low band, the 3 dB AR beamwidth was found to be 182° and 165° in the *xoz* and *yoz* plane, respectively, and for high band, it was 184° and

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175° in the *xoz* plane and *yoz* planes, respectively. The measured maximum gain was found to be 3.9 dBic for both bands.

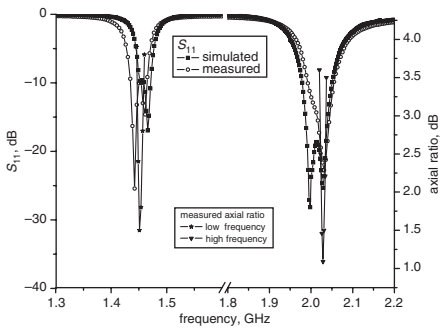

Fig. 2 *Comparison of measured and simulated S_{11} for proposed antenna and measured axial ratio*

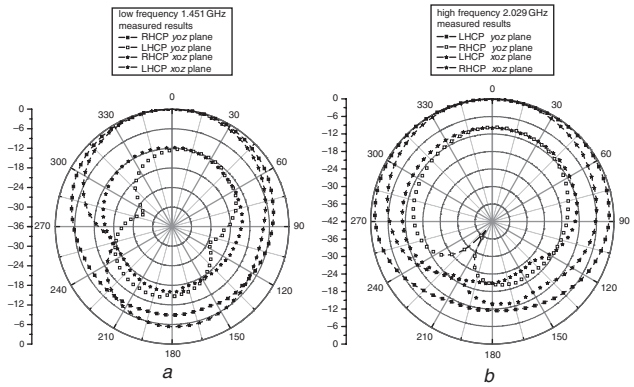

Fig. 3 *Measured normalised radiation patterns*

a 1.451 GHz
b 2.029 GHz

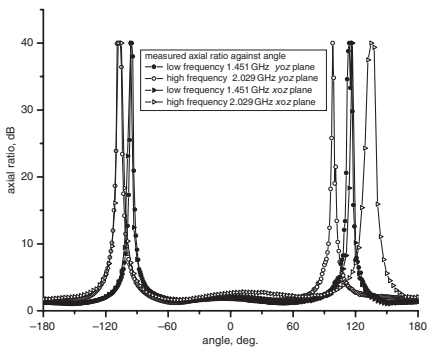

Fig. 4 *Measured axial-ratio against angle at 1.451 and 2.029 GHz*

Conclusions: A novel dual-frequency dual circularly-polarized antenna with broad beamwidth is presented. By using dual-layer patches with orthogonal and offset-centred slots, RHCP and LHCP characteristics are achieved, simultaneously. A broad beamwidth is realised using an extended substrate. The proposed antenna can achieve a HPBW of 180° and 130° for high frequency and low frequency, respectively. The measured 10° elevation gains are 0.5 dBic at 2.029 GHz and −0.7 dBic at 1.451 GHz.

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