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CIRCULARLY-POLARIZED STACKED ANNULAR-RING MICROSTRIP ANTENNA

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Abstract—In this paper, we propose the aperture feeding as a technique for bandwidth enhancement of multi-band microstrip ring antennas. In particular, we present a dual-band stacked annular-ring microstrip antenna fed by four bow-tie apertures with circular polarization. Furthermore, we show that the size and shape of the substrate that supports the radiating elements of the antenna plays an important role in the quality of the axial ratio.

1. INTRODUCTION

Circularly-polarized microstrip patch antennas are widely used in navigation systems and satellite communications due to their low cost, light weight and ease of fabrication. Circular polarization is usually obtained either using a single feeding point and perturbing the regular structure of the microstrip antenna [1, 2], or using two different feeding points with equal amplitudes and 90° phase shift (without perturbing the regular structure of the antenna) [3–5].

The main drawback of microstrip antennas is the size. For this reason, new designs for achieving a reduction in size have been presented in recent years [6, 7]. In particular, microstrip ring antennas have become very attractive because for a given frequency, a ring antenna has a smaller patch size as a microstrip square antenna [8–10]. However, ring microstrip antennas suffer limitations in impedance and axial-ratio bandwidths. The input impedance of ring microstrip antennas depends on the width of the rings. As width is reduced, input impedance increases and therefore it is more difficult to obtain good impedance match. Various techniques have been employed in literature in order to enhance impedance matching and axial-ratio bandwidths.

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In [11, 12] capacitive feeding was used in a multi-band ring stacked configuration obtaining narrow bandwidths. In [13] a circular parasitic patch was suspended above an annular-ring to enhance the impedance matching and bandwidth. The annular-ring was fed by an equal-split power divider placed inside the ring. 3-dB axial ratio bandwidth of 10.6% was obtained. In [14] circular polarization of a square-ring patch was achieved by a simple microstrip feeding line through the coupling of a square patch in the same plane of the antenna. A 10-dB return loss bandwidth of 1.1% and 3-dB axial-ratio bandwidth about 0.03% was achieved. In [15] a proximity coupling technique was used to feed a reconfigurable circularly polarized microstrip ring antenna, obtaining a 10-dB return loss bandwidth of 5% and a 3-dB axial ratio bandwidth of 1.32%.

Although ring microstrip antennas with good impedance and axial-ratio bandwidths can be found in literature, it must be noted that most of them are single-band.

The aim of this paper is to use aperture feeding as an alternative technique to improve the performance (impedance and axial ratio bandwidth) of multi-band ring microstrip antennas. In particular, a dual-band circularly-polarized antenna based on stacked annular-ring microstrip patches fed by four bow-tie apertures is designed, fabricated and measured. A broadband feeding network has been used to obtain the required phase shift thus allowing to improve the axial ratio in the direction of maximum radiation. This feeding network is based on the broadband phase shifter presented in [16]. We will also show that the size and shape of the substrate that supports the radiating elements of the antenna, i.e., the annular-rings, plays an important part in the quality of the axial ratio for low elevation angles.

2. ANTENNA CONFIGURATION

Our aim is to design a dual-band antenna with right-hand circular polarization. The lower band must cover Galileo (E5a, E5b), GPS (L5) and GLONASS (L3) bands (bandwidth 50 MHz, 4.2%, at the center frequency of 1.189 GHz), whereas the upper band must cover Galileo (E1, E2, L1) and GPS (L1) bands (bandwidth 30 MHz, 2%, at the center frequency of 1.575 GHz).

2.1. Antenna Design

Figure 1 shows a detailed drawing of the proposed antenna. The antenna is composed of three substrate layers separated by air gaps. The parasite annular-ring is in the top layer, the active annular-ring is

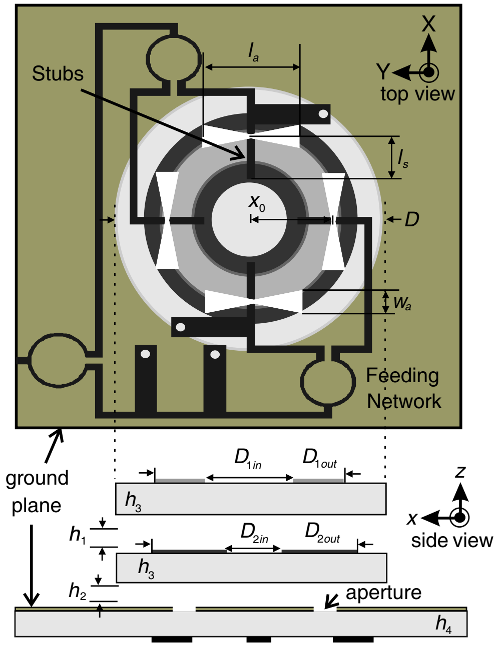

Figure 1. Geometry of the stacked annular-ring microstrip antenna.

in the middle layer whereas the feeding network and the four apertures are placed in the bottom layer. The parasite annular-ring has an inner diameter D_{2in} and outer diameter D_{2out}, whereas the active annular-ring has an inner diameter D_{1in} and outer diameter D_{1out}.

In the first step of the design the antenna is excited through four apertures using four microstrip lines, obtaining a dual-band antenna with two orthogonal linearly-polarized modes. The resonant frequency of the lower band is mainly determined by the parasite annular-ring while the resonant frequency of the higher band is mainly determined by the active annular-ring. The fine tuning of the antenna is carried out adjusting, the lengths of the tuning stubs, the air gaps between layers and the length and width of the apertures so as to get the desired bandwidths.

In general, the shape, length (l_a) and width (w_a) of the aperture are designed to optimize the coupling between stubs and rings. In our case, the apertures bow-tie shaped, which offer, in the lower band, a relative bandwidth 9.5% wider than using conventional rectangular apertures of the same area. On the other hand, in the upper band the relative bandwidth is the same.

The apertures are positioned in the bottom layer, very close to the outer edge of the annular-ring (x_0). The input impedance of the antenna is about 50 Ω close to the outer edge of the annular-ring and decreases when the apertures are moved towards the center of the rings.

When the length of stubs (l_s) is decreased the bandwidth of the lower band is slightly reduced and shifted downwards in frequency whereas the upper band is slightly shifted upwards in frequency. Finally, when the gaps between layers are increased (h_1, h_2) the lower and upper bands are shifted upwards in frequency.

Once the dual-band antenna with two orthogonal linearly-polarized modes is designed, the four stubs must be connected to the respective output ports of the feeding network to generate right-hand circular polarization. Figure 1 shows the feeding network and the stubs together. The feeding network is composed of three Wilkinson power combiners and four broadband 90° phase shifters [16]. It is important to remark that, with this feeding network, we obtain a balanced power distribution in the slots, with maximum error in phase lower than 2° from 1.1 to 1.6 GHz.

Finally, the last step in the design procedure is to determine the shape and size of the substrate that supports the rings (Figure 1). The aim is to improve the axial ratio for low elevation angles. Figure 2 shows the simulated 4-dB axial ratio beamwidth as a function of frequency for the antenna shown in Figure 1 for different substrate shapes and sizes. In the lower band, the beamwidth of each antenna

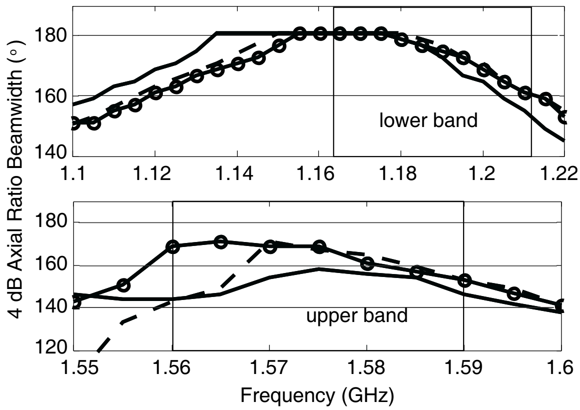

Figure 2. Simulated 4 dB axial ratio beamwidth as a function of the frequency for the dual-band antenna shown in Figure 1, for square substrate with $D = 180$ mm (solid line), circular substrate with $D = 180$ mm (solid line with circles) and circular substrate with $D = 150$ mm (dashed line), $\varphi = 0°$ cut.

is very similar, meanwhile, in the upper band, circular substrates have wider beamwidth than the square substrate. Besides, the reduction in the diameter of circular substrates reduces the beamwidth. However, it is important to point out that the size of the circular substrate can be reduced significantly with a low degradation in the beamwidth.

2.2. Antenna Prototype

The proposed antenna is fabricated on Taconic TRF-45 ($\varepsilon_r = 4.5$, $\tan\delta = 0.0035$). The thicknesses of the substrates are $h_3 = 3.26\,\text{mm}$ and $h_4 = 1.63\,\text{mm}$ respectively. The feeding network is designed at the center frequency of both bands (1.4 GHz). Initially, each annular ring is designed to resonate approximately at the center frequency of each band. Next, the size and place of the aperture along with the length of the stubs and the air gaps between layers are adjusted, following the tendencies explained in the previous section, to obtain the specified bandwidth and center frequency of each band. The final dimensions of our antenna are (Figure 1): $h_1 = h_2 = 4\,\text{mm}$, $D_{1in} = 44\,\text{mm}$, $D_{1out} = 80\,\text{mm}$, $D_{2in} = 15.6\,\text{mm}$, $D_{2out} = 71.2\,\text{mm}$, $w_a = 12\,\text{mm}$, $l_a = 50\,\text{mm}$, $x_0 = 35\,\text{mm}$ and $l_s = 10\,\text{mm}$.

The substrate that supports the rings has circular shape with a diameter $D = 100\,\text{mm}$. Figure 3 shows the fabricated antenna. It should be noted that 3 nylon screws and 9 nylon nuts are used to achieve the air gaps between layers.

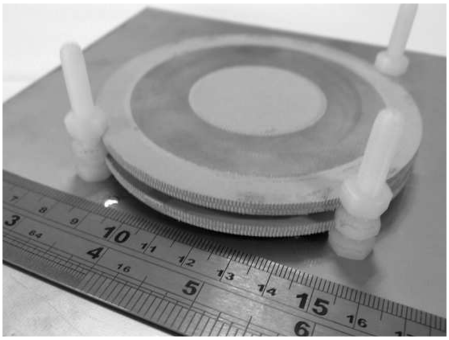

Figure 3. Fabricated antenna.

3. EXPERIMENTAL RESULTS

Figure 4 shows the measured reflection coefficient for the designed antenna. Note that the response is matched from 1.1 to 1.7 GHz, due to the feeding network behavior.

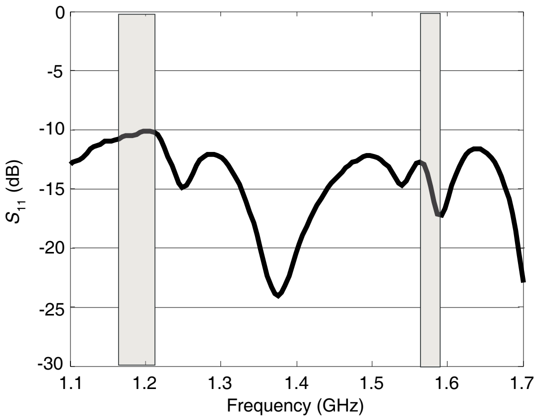

Figure 4. Measured input reflection coecient for the fabricated dual-band circularly-polarized antenna.

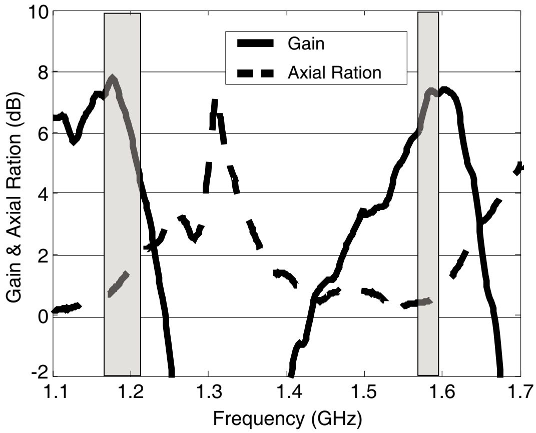

Figure 5. Measured gain (continuous line) and axial ratio (dashed line) as a function of frequency in the direction of maximum radiation (z-axis).

Figure 5 shows the measured axial ratio and gain as a function of frequency. At the lower band (1.2 GHz) the gain is 6 dB and the axial ratio 1.4 dB whereas at the upper band (1.575 GHz) the gain is 6.5 dB and the axial ratio is 0.4 dB. Figure 6 shows the simulated axial ratio as a function of the elevation angle for the antenna prototype. Both bands have a wide angular coverage. The 4 dB axial ratio beamwidth is higher than 156° for all frequencies. It is important

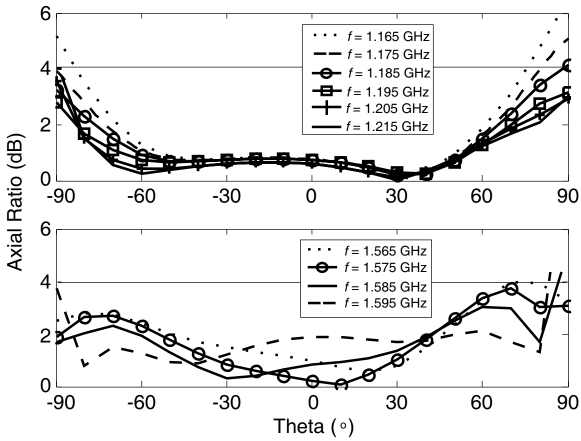

Figure 6. Simulated axial ratio as a function of angle θ, for different frequency values, $\varphi = 0^\circ$ cut.

to point out that the simulated and measured (not shown) axial ratio are in a good agreement except for low elevation angles, where the measured axial ratio is degraded due to the effects of the metallic cage that supports the antenna during the measurement process. This degradation reduces the measured 4 dB axial ratio beamwidth to 110° for the center frequencies of both bands.

Comparing the obtained results with previous dual-band microstrip antennas with circular polarization referenced in the introduction part, it can be verified that our measured reflection coefficient presents a wider bandwidth than [1], and is similar to [3, 4] where feeding networks were also used. On the other hand, the measured gain and axial ratio as a function of frequency is very similar to the gain and axial ratio presented in [3, 4]. However, the proposed antenna has a more compact size thanks to the use of the annular-rings and the reduction of the substrate size. Finally, it must be emphasized that the dual-band antenna shown in [6] presents a compact size because it is composed of only one layer. However, it only has a good axial ratio at boresight in the interesting bands, worse 4 dB axial ratio beamwidth and lower values of gain than our.

4. CONCLUSION

In this paper, a compact dual-band annular ring microstrip antenna with circular polarization has been presented. The proposed antenna covers the bands of Galileo (E5a, E5b, E1, E2, L1), GPS (L1, L5) and

GLONASS (L3). Aperture feeding has been used as an alternative technique to enhance the bandwidth and improve the input impedance of dual-band annular-ring microstrip antennas. A broadband feeding network has been used to improve the axial ratio at boresight. It has also been discussed as the shape and size of the substrate plays an important role in the quality of the axial ratio for low elevation angles. Measurements show as the proposed antenna improves the performance of previous designs that can be found in literature.

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