Beam and Polarisation Reconfigurable Microstrip Antenna Based on Parasitics

Marion Allayioti[1], James R. Kelly[1], Raj Mittra[2]

[1] Department of Electronic Engineering, Institute for Communication Systems
Guildford, United Kingdom
{m.allayioti, j.r.kelly}@surrey.ac.uk
[2] Computational Electromagnetic Laboratory, University of Central Florida,
Orlando, USA
and King Abdulaziz University,
Jeddah, Saudi Arabia
rajmittra@ieee.org

Abstract. This paper presents a dual-notch polarization and beam reconfigurable microstrip antenna. It uses parasitics which incorporate switches to steer its beam away from boresight and dual-notches which, again, incorporate switches to reconfigure between linear and circular polarization. The antenna is a low profile microstrip patch antenna which only uses a single feed, allowing it to be compact and simple in terms of its structure.

Keywords: beam steerable antennas, circular polarisation, polarisation reconfiguration, microstrip patch antennas, dual-notch antennas

1 Introduction

Pattern and polarisation reconfigurable antennas have received a lot of attention from researchers. More specifically, beam steerable and antennas that can reconfigure their polarisation between linear and circular (LP/CP). They can be used for a wide range of applications such as radars, satellite communications and portable devices with satellite communication applications (i.e. incorporating GPS receivers) [1]. These type of antennas can be used for high data rate applications due to their high gain. Also, beam steering can be used to avoid interference or noisy environments. Simple, compact and high gain single feed beam and polarisation reconfigurable antennas are of great significance because they do not need complex feeding networks as conventional circularly polarised antennas need [2], [3]. For example, when it comes to portable devices, compact antennas are very important due to size constrains. Furthermore, low power consumption is also very important in such applications. One of the main challenges that beam and polarisation reconfigurable antennas impose, is attaining CP and preserving it while reconfiguring the antenna's main beam direction [4]. Furthermore, attaining a good impedance match while reconfiguring between the polarisation modes and preserving a good alignment between the 10 dB return loss bandwidth and the 3 dB AR bandwidth are also challenging [2], [3].

This paper presents a solution which uses parasitics to steer the beam away from boresight, and dual-notches to attain CP within a steering range of the antenna. Preserving CP has been especially challenging in this design, where parasitics are used for beam reconfigurability, which affect the resonant frequency of the antenna. It was also challenging to attain a good alignment between the 10 dB return loss and the 3 dB axial ratio (AR) of the antenna while switching ON and OFF different pairs of parasitics.

2 Antenna Concept, Structure and Dimensions

A microstrip patch antenna incorporating two pairs of notches (namely dual-notch microstrip patch antenna) is proposed here and can be seen in Figure 1. CP can be preserved for some steering angles. The dual-notch mictrostrip patch antenna is fed by using a coaxial feed. The notches are located on a line angled at 45^0 to the location of the feed. The antenna is designed for left-hand CP (LHCP) operation. Righ-hand CP (RHCP) operation can also be excited by simply mirroring the position of the dual-notches with respect to the feed-location. Figure 1shows the structure of the proposed antenna. Appropriate switching of the parasitic elements controls the direction of the main beam of the antenna both in LP and CP mode, while appropriate design of the dual-notches controls the circular polarisation capability of the antenna. Some of the modes of operation of the antenna can be found in Table 1. Switches positioned on the driven element control the reconfiguration of the antenna between LP and CP

The size of the notches controls the CP operation of the antenna. Acceptable AR can be achieved when the ratio between the length and the width of the notches is large. The size of the notches of the dual-notch microstrip patch antenna were chosen so that the ratio between their length (Ln) and width (Wn) is large; hence the width of the notches (Wn) is chosen to be smaller than the length of the notches (Ln). All four notches are equal in size. Furthermore, the notches are positioned 0.5 mm apart from each other. The spacing k, between the notches can be as small as 0.1 mm without it severely affecting the AR of the antenna. However, there is an upper limit to the values that the spacing k can take. According to a parametric study that was done as part of this work the spacing between the two notches can be up to 1.5 mm in order to keep the AR below 3 dB. The dimensions of the dual-notch antenna are shown in Table 2. The position of the feed is chosen so that there is an acceptable impedance matching at the antenna's operating frequency. The feed must not be placed in the centre of the antenna but in a position where the input impedance of the antenna is 50 Ohm; this is at any (0, y) point on the driven element taking (0, 0) to be the centre of the driven patch of the antenna.

It is usual that single notches are used on microstrip antennas to make them CP. The asymmetry that the notches add to the antenna produces CP. Here, dual-notches are used because CP needs to be preserved for steered angles. The basic difference that the dual-notch design has in comparison to a single notch design is that two equivalent notches are positioned along its radiating edge instead of just one. The dual-notches incorporated in the design introduce further asymmetry in the diagonal directions in the circular patch which result into making the AR of the antenna more wide band and also, while also increasing the range of steered angles that the 3 dB AR is able to cover. The introduction of the second notch results into the current flowing along the radiating edge is taking a longer patch than when only one notch is incorporated. Due to this longer current path the current is rotated resulting in CP radiation. The additional increment in the current path is due to the movement of the current around the notches. Increasing the width of the middle segment (between the two notches) does not have considerable affect the current path length.

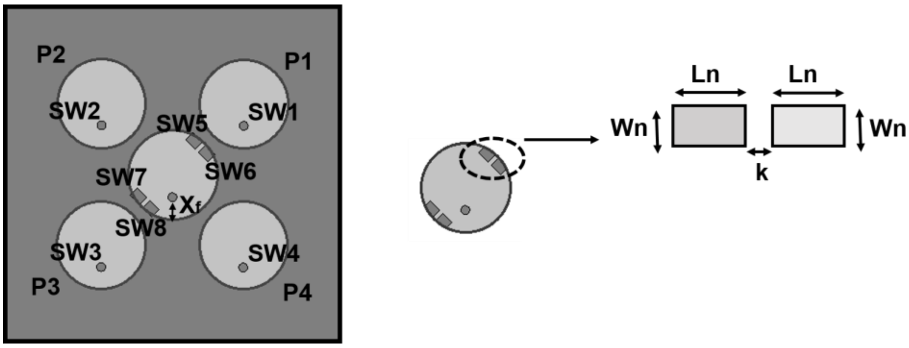

Figure 1: Structure of the proposed dual-notch single element antenna with a close up at the driven element and the notches.

Table 1. Switching configurations of the dual-notch single element antenna.

Operating State	State of Switch								Mode
	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	
LP, Boresight	ON	ON	ON	ON	ON	ON	ON	ON	1
CP, -10^{0}	ON	OFF	OFF	ON	OFF	OFF	OFF	OFF	2
CP, 10^{0}	OFF	ON	ON	OFF	OFF	OFF	OFF	OFF	3
LP, 19^{0}	OFF	ON	ON	OFF	ON	ON	ON	ON	4
LP, -19^{0}	ON	OFF	OFF	ON	ON	ON	ON	ON	5
LP, Boresight	OFF	OFF	OFF	OFF	ON	ON	ON	ON	6
LP, 4^{0}	OFF	OFF	ON	OFF	ON	ON	ON	ON	7

3 Results and Discussion

It is important to note that for the simulation and measurement results presented in Figure 2 and in Figure 3 copper switches are used; when copper is present the switch is ON when copper is not present the switch is OFF. However, PIN diodes can be used in the notches to switch between CP and LP.

Generally, it is important to ensure good alignment between the 3 dB AR bandwidth and the 10 dB return loss bandwid. Figure 2 shows the scattering parameters (S_{11}) of the antenna when the antenna operates at mode 2. It can be seen that the antenna is acceptably matched ($S_{11} < -10$ dB) both in simulation and in measurement and that there is an acceptable agreement between simulation and measurement. Figure 2 shows that the operating frequency of the antenna is 10.3 GHz. From the return loss results parameters it can be observed that the measurement has a better return loss at 10.3 GHz in comparison to the simulation. The return loss results shown in Figure 2 also shows that the 10 GHz bandwidth of the antenna is slightly reduced when the antenna is fabricated and measured compared to the simulated one. The simulated 10 dB return loss bandwidth of the antenna is approximately 0.68 GHz (6.6% fractional bandwidth) whereas the measured one is approximately 10.65 GHz (6.3% fractional bandwidth). This can be attributed to the fact that there is pitting on the fabricated version of the antenna in the copper on the ground plane and the driven element and parasitics of the antenna. This means that copper was not consisted throughout the ground plane and the patch antenna itself. Copper tape was used to cover as best as possible the cuts on the copper. Unfortunately the copper tape does not form a reliable connection to the printed copper and it does not ensure consistency between the fabricated designs which is required in order to achieve the best possible results. This will affect the current distribution of the antenna which determines its radiation performance. Soldering and bumps are also very important when fabricating an antenna at high frequencies (such as 10.3 GHz). The solder bumps were inconsistent affecting the performance of the antenna including the input impedance matching of the antenna.

Table 2. Summarised dimensions of the dual-notch single element antenna

Parameter	Dimension (mm)
Xf	2.5
Rd	5.04
Rp	5
Xs	2.54
Dp	0.04λ
Ln	2
Wn	1.15

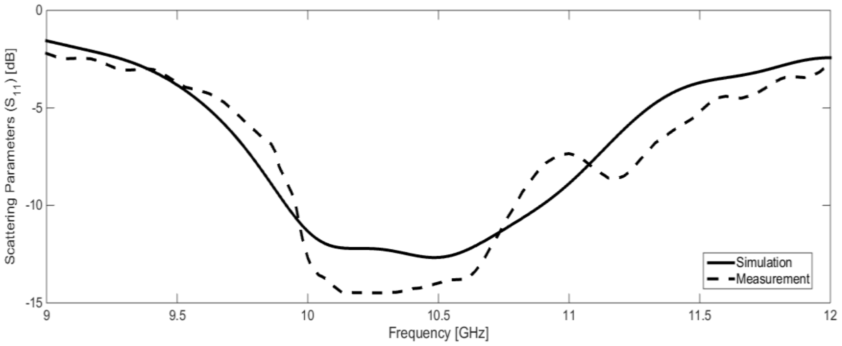

Figure 2: Scattering parameters (S_{11}) when the antenna operates at mode 2; simulation against measurement.

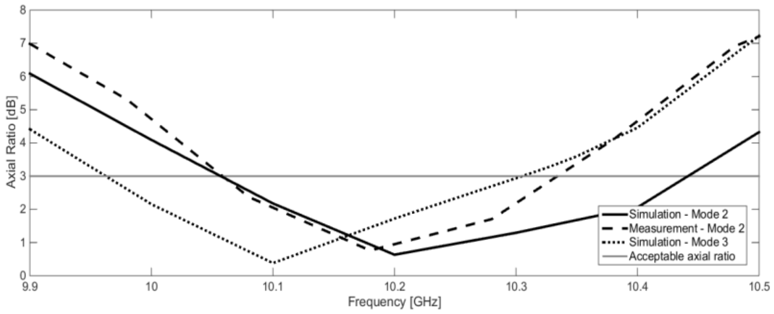

Figure 3: Axial ratio as a function of frequency when the antenna operates at mode 2; simulation against measurement.

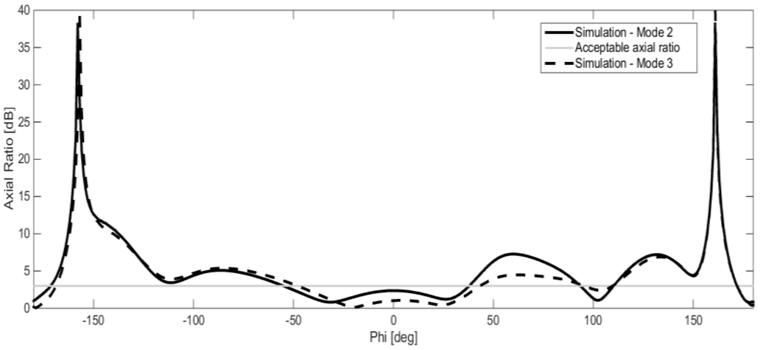

Figure 4: Axial ratio as a function of angle when the antenna operates at mode 2 at 10.3 GHz; simulation against measurement.

Figure 3 shows the simulated and measured AR, when the antenna operates at mode 2 as a function of frequency. The simulated 3 dB AR bandwidth is 0.39 GHz (3.79% fractional bandwidth) and the measured 3 dB AR bandwidth is 0.265 GHz (2.57% fractional bandwidth). The measured 3 dB AR is hence reduced in comparison to the simulated one. This might, again, be due to the anomalies in the copper on the ground plane and the driven element and parasitics. Regardless of this, the measurement confirms the CP capability of the antenna while at the steered angle of -10^0 against a range of frequencies. Figure 4 shows the simulated AR of the antenna at 10.3 GHz in mode 2. It can be observed that the antenna supports CP over a range of steering angles at 10.3 GHz. More specifically, the AR is less than 3 dB from -55^0 up to 38^0. This shows that the antenna is CP for several steering angles.

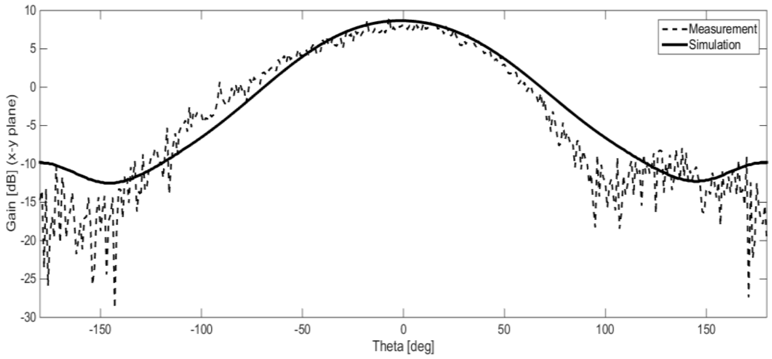

Figure 5: Farfield radiation when the antenna operates at mode 1; simulation against measurement.

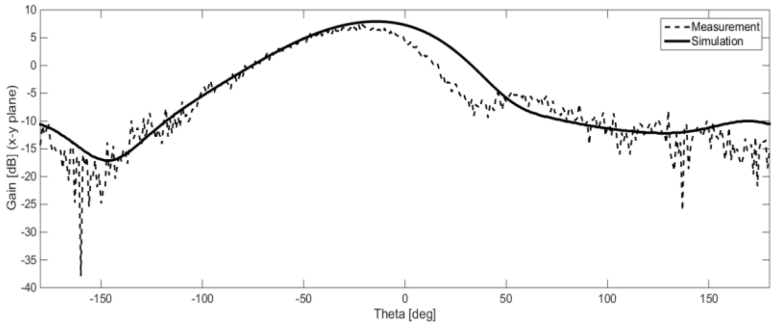

Figure 6: Farfield radiation when the antenna operates at mode 2; simulation against measurement.

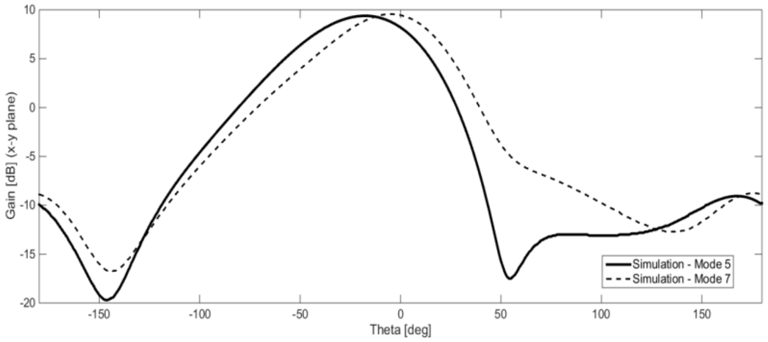

Figure 7: Farfield radiation when the antenna operates at modes 5 and 7; simulation.

Figure 5 and Figure 6 show the radiation pattern when the antenna operates at mode 1 and 2 respectively. It can be observed that there is acceptable agreement between measurement and simulation. Measurement differs from simulation at the back lobe direction due to the presence of cables always affect the radiation performance of an antenna. Current on the ground plane can leak to the cable and because the cable is much longer than the ground the cable becomes a radiator by itself. Figure 7 shows the simulated radiation patterns for two more modes of the antenna. It can be observed that the steering performance of the antenna is limited ($\pm 19^0$). More modes of operation of this antenna exist. Here, we are only showing some of them.

3. Conclusions

Circularly polarized (CP) antennas are desirable for wireless communication system, because they do not require strict alignment between the transmitter and the receiver. Furthermore, they can be used to serve multiple functions which is especially important when it comes to applications such as portable devices. Beam steerable antennas are important for millimeter wave frequency applications. Millimetre wave frequencies suffer from high path loss which does not allow the signal to travel far. Hence, directional antennas are required. To compensate for the limited coverage that a directional antenna has, beam steering much be employed. This paper discusses a circularly polarization and beam steerable antenna. Measurements presented in this paper have verified its circular polarization capability. The antenna can also reconfigure its polarization between linear and circular. The important advantage of the antenna is that it uses a simple single-feed structure which reduces its power consumption and cost. The antenna can be re-designed to also operate at higher frequencies which will make it even more compact in size.

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