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PATCH ANTENNA WITH RECONFIGURABLE POLARIZATION

G. Monti, L. Corchia, and L. Tarricone

Department of Innovation Engineering
University of Salento
Via Monteroni, Lecce 73100, Italy

Abstract—A reconfigurable patch antenna consisting of a square patch with two cross-shaped diagonal slots is presented. The proposed design approach is based on the use of two pairs of switches in order to obtain both frequency and polarization reconfigurability. Specifically, three different polarization states have been obtained: a Right-Hand Circular Polarization, a Left-Hand Circular Polarization and a Linear Polarization. Experimental results, referred to a realization on a FR4 substrate of the layouts corresponding to the useful switch configurations, are reported.

1. INTRODUCTION

Reconfigurable antennas play a key role in modern telecommunication systems. Frequency and polarization reconfigurability represent attractive features.

For instance, in digital multimedia broadcasting systems the capability to switch from a linear polarization to a Right-Hand Circular Polarization (RHCP) is required to the antenna; similarly, in mobile communications the use of antennas with polarization diversity is fundamental for reducing multipath fading loss.

Due to their low-cost, low profile, light weight, and easiness of fabrication, microstrip patch antennas are one of the most promising candidates for achieving reconfigurability.

Indeed, though a standard rectangular microstrip antenna exhibits a linear polarization, several design approaches have been proposed in order to achieve circular polarization, as well as dual-band performance [1–11].

Corresponding author: G. Monti (giuseppina.monti@unisalento.it).

As for reconfigurability, a very large number of solutions have been proposed for achieving both frequency as well as polarization diversity; for the sake of brevity only a few of them are here referenced [12–18]. Among these in [12] the use of a PIN diode turning on/off a rectangular slot has been proposed to achieve dual-frequency operation. In [13], Micro Electro-Mechanical Switches have been used to design a frequency reconfigurable antenna.

For polarization diversity, in [14] a reconfigurable feeding line has been proposed in order to switch the polarization of a patch antenna between a RHCP and Left-Hand Circular Polarization (LHCP). Furthermore, in [15] an attractive design approach guaranteeing both frequency and polarization diversity has been presented. Specifically, the antenna proposed in [15] consists of a rectangular patch with a U-slot and truncating corners: a switch turns the U-slot on/off providing frequency reconfigurability, while three switches are used to turn on/off the truncated corners providing polarization reconfigurability.

The solution here proposed is based on the use of a square/rectangular patch with two crossing diagonal slots. Two pairs of switches are used to turn on/off the slots. Consequently, depending on the switch configuration the antenna can be excited with an RHCP or an LHCP polarization mode.

Furthermore, by using a reconfigurable feeding line a linear polarization combined with a dual-frequency operation can be also obtained.

The paper is structured as follows: in Section 2 the geometry of the antenna here proposed is described, later on in Section 3 simulated and experimental results are given and some conclusions drawn in Section 4.

2. DESIGN APPROACH

The basic geometry of a microstrip antenna consists of a dielectric substrate sandwiched between a square/rectangular radiating patch and a ground-plane. The length (l) and the width (w) of the rectangular patch determine the antenna operating frequency and its radiation resistance. The simplest design approach consists in setting L equal to $\lambda/2$ and in feeding the patch so to excite the TM_{010} mode of the structure, thus resulting in a broadside radiation and a Linear Polarization (LP) [1–3].

A Circular Polarization (CP) can be obtained by a proper design of the feeding network and by adjusting the dimensions of the patch in such a way to excite two orthogonal modes with a phase difference of 90°. For instance, a square patch feed at two adjacent edges can be used.

Alternatively, CP can be obtained with a single feed network by using a corner-chopped patch or a patch with a thin rectangular slot along the diagonal.

More specifically, in the case of a diagonal slotted patch, depending on the relative position of the feed with respect to the slot, either RHCP or LHCP can be obtained. Furthermore, the presence of the slot determines a difference between the two path lengths associated to the patch diagonals; as a consequence, the resonance frequencies of the two orthogonal modes differ of a quantity fixed by the length/width ratio of the slot.

Accordingly, the radiating structure here proposed exploits the possibility to govern the radiation properties of a square patch by means of two reconfigurable diagonal slots.

2.1. Antenna Geometry

The geometry of the proposed antenna is illustrated in Fig. 1. It consists of a square patch with two cross-shaped diagonal slots and

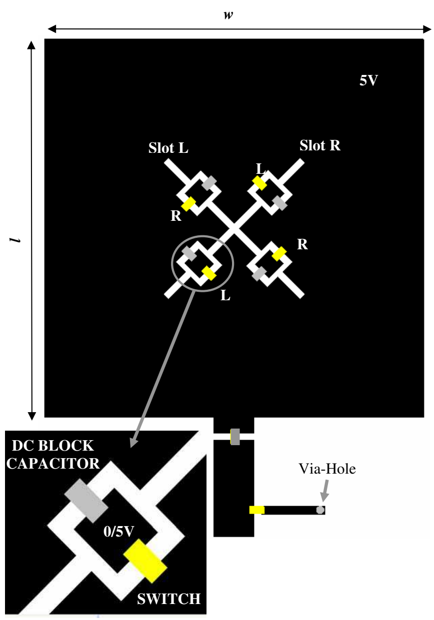

Figure 1. Geometry of the proposed antenna: a patch antenna with diagonal rectangular slots along both diagonals. Two couples (R and L) of switches are used to select the active slot (L or R).

two couples of switches (see Fig. 1). Each slot is turned on/off by the corresponding pair of switches. For instance, referring to Fig. 1, switches L are used to turn off the slot R, while switches R are used to turn off the slot L.

As a consequence, the configuration of the switch states determines the radiation properties of the antenna.

Specifically, when switches L are on and switches R are off the active slot is L and an LHCP radiation mode is obtained; vice-versa, when switches L are off and switches R are on, the active slot is R and the antenna radiates in the RHCP mode.

Furthermore, when all switches are in the same state (off or on) both slots are turned on or off and an LP polarization is obtained. However, the resonance frequency of the LP radiation mode corresponding to both slots in the on state (i.e., all switches off) is governed by the slot dimensions; whereas, the resonance frequency of the LP radiation mode corresponding to both slots in the off state (i.e., all switches on) is governed by the patch dimensions. Consequently, the two possible LP radiation modes of the proposed antenna are characterized by a frequency diversity fixed by the ratio between the slot and the patch dimensions.

It is worth observing that the input impedance of a microstrip antenna operating in a CP mode is generally quite different from the input impedance that the same antenna exhibits when it operates in an LP mode.

Accordingly, we use a reconfigurable feeding network consisting of a simple microstrip line loaded with a short-circuited stub by means of a switch. Referring to Fig. 1, when the antenna is in the RHCP or LHCP operating mode, switch N is turned off, while it is turned on when the antenna is in one of the two LP operating modes.

3. SIMULATED AND EXPERIMENTAL RESULTS

In order to verify the feasibility of the proposed design approach, the four layouts corresponding to the switch configurations respectively selecting the LHCP, RHCP and the two LP (LP 1 and LP 2) operating modes of the antenna illustrated in Fig. 1 have been realized on a FR4 substrate ($\varepsilon_r = 3.7$ @ 1 GHz, $h = 1.6$ mm). A picture of the one corresponding to the LHCP mode is given in Fig. 2.

The antenna and the slot dimensions have been fixed in order to have a resonance frequency of 2.7 GHz for the LHCP, RHCP and the LP1 modes, and of about 3 GHz for the LP2 mode. Specifically, the antenna is a (25.56 mm × 25.56 mm) square patch, whilst the slot is (0.5 mm × 13 mm).

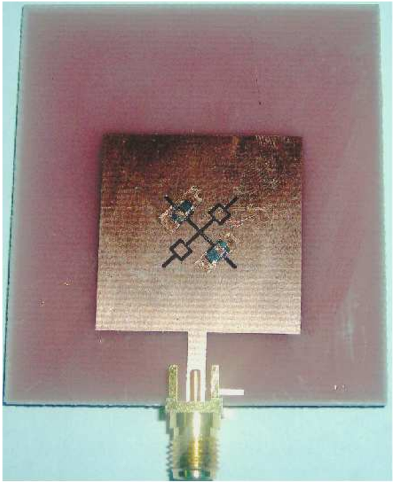

Figure 2. Realized patch antenna corresponding to the LHCP mode.

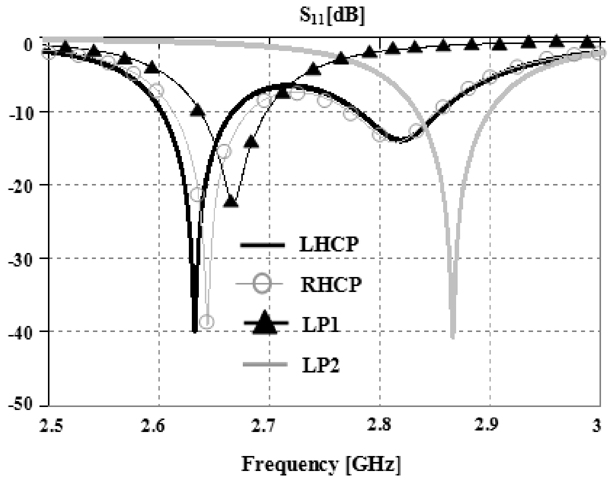

Figure 3. Measured return loss of the realized layouts corresponding to the four switch configurations illustrated in Table 1.

The measured return loss are given in Fig. 3: values smaller than −20 dB have been achieved for all switch configurations.

As for the radiation properties, they have been calculated with the full-wave simulator CST-Microwave Studio by taking into account both the PIN diodes and the DC block capacitors.

More specifically, referring to Avago HMPP-3890 RF PIN diodes, the switches have been modelled as a series resistance ($R = 1\,\Omega$) in the on state and a series capacitance ($C = 0.1\,\text{pF}$) in the off state. Simulations have been performed for each useful combination of the switches.

Results achieved in this way are illustrated in Figs. 4–8. In Fig. 4, the axial ratio of the proposed antenna is reported; it can be noticed that full-wave simulation results confirm the polarization properties expected for the four operating modes.

As for the antenna gain and directivity, they are illustrated in Figs. 5–8: excellent performances have been calculated for both the CP and the LP modes.

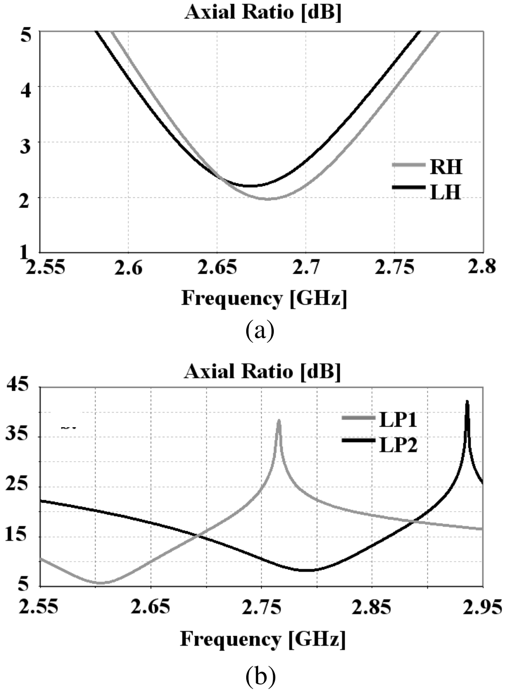

Figure 4. Axial ratio calculated by means of full-wave simulations performed with CST-Microwave studio. (a) Results obtained for the antenna in the RHCP mode (i.e., switches R on and switches L off) and in the LHCP mode (switches L on and switches R off); (b) Results obtained for the antenna in the LP1 mode (i.e., both switches R and L off) and LP2 (i.e., both switches R and L on) mode.

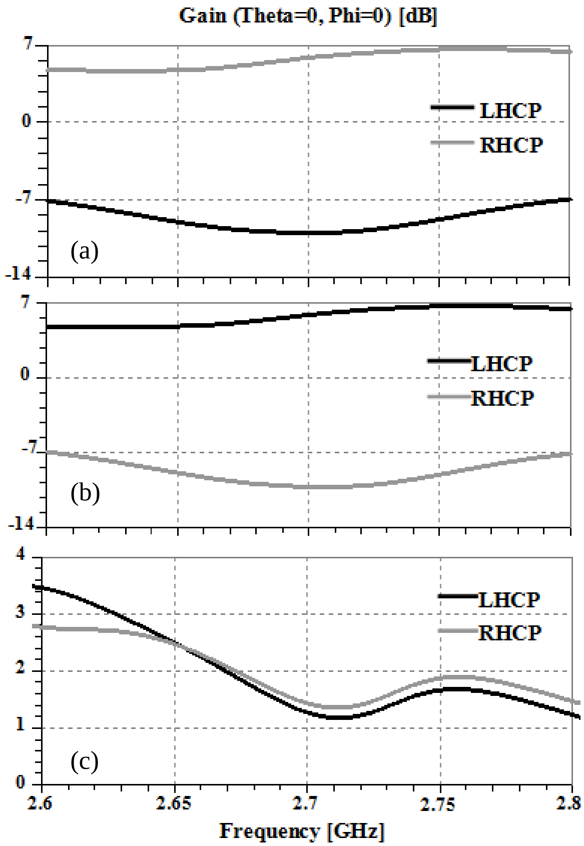

Figure 5. LHCP and RHCP Gain calculated by means of full-wave simulations: (a) switches R on and switches L off, (b) switches L on and switches R off, (c) all switches off.

These results are resumed in Table 1. Referring to the following definitions of the radiation efficiency ($e_{radiation}$) and of the total efficiency (e_{total}):

$$e_{rad} = \frac{G(\vartheta, \varphi)}{D(\vartheta, \varphi)} = \frac{\text{Total Radiated Power}}{\text{Accepted Input Power}}$$

$$e_{total} = \frac{\text{Total Radiated Power}}{\text{Total Input Power}}$$

CST-Microwave Studio calculates values greater than 83% in all switch configurations.

Table 1. Switch configurations vs antenna performance.

	Switch Configuration			
	L on R off	**L off R on**	**L off R off**	**L on R on**
Measured Resonance Frequency (f_0) [GHz]	2.633	2.643	2.667	2.867
Measured Return Loss [dB] @ f_0	−39.9	−39.2	−23	−40.66
RHCP Gain [dB] @ f_0	5.33	5.35	1.74	2.32
LHCP Gain [dB] @ f_0	−9.8	−10	1.67	2.32
Simulated Radiation Efficiency [%] @ f_0	91	91	92.5	83.43
Simulated Total Efficiency [%] @ f_0	91	91	89	83.42

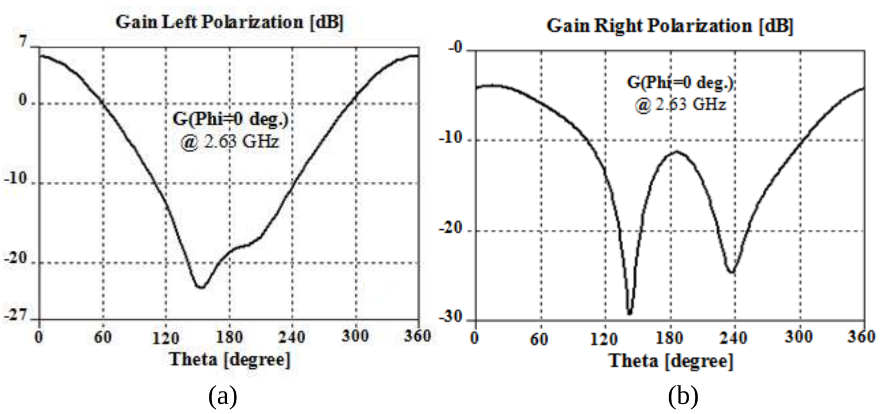

Figure 6. Gain calculated at 2.63 GHz by means of simulations performed with CST Microwave Studio for the switch configuration selecting the LHCP antenna operation mode (i.e., switches L on and switches R off).

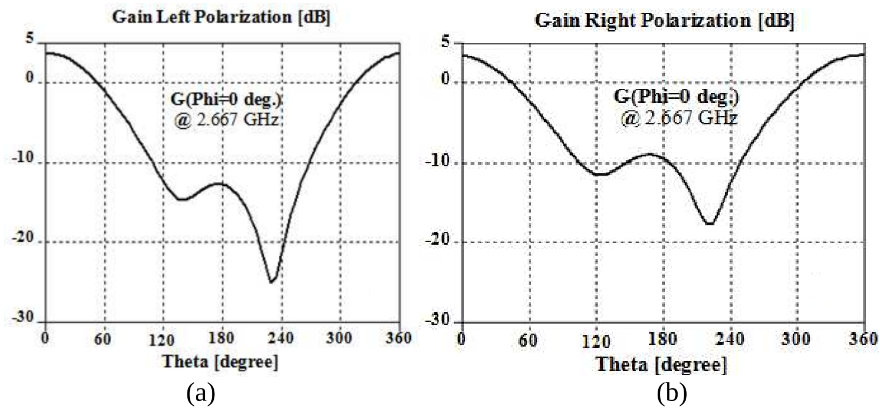

Figure 7. Gain calculated by means of simulations performed with CST Microwave Studio for the switch configuration selecting the LP antenna operation mode at 2.667 GHz (i.e., all switches off).

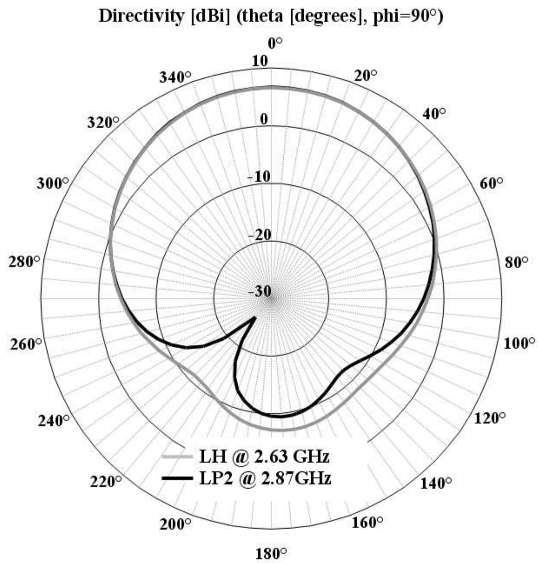

Figure 8. Directivity calculated by means of simulations performed with CST-Microwave Studio for the switch configuration selecting the LHCP and the LP2 antenna operating mode.

4. CONCLUSION

A polarization reconfigurable patch antenna has been presented. The proposed design approach guarantees three different polarization states: a Right-Hand Circular Polarization, a Left-Hand Circular Polarization and a Linear Polarization. Furthermore, frequency diversity has been also achieved for the Linear Polarization state. Both simulated and experimental results have been reported, thus demonstrating the accuracy and robustness of the proposed design strategy.

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