Patch Antenna Based on Metamaterials for a RFID Transponder

Eduardo UGARTE-MUÑOZ[1], *Francisco Javier HERRAIZ-MARTÍNEZ*[1],
Vicente GONZÁLEZ-POSADAS[2], *Daniel SEGOVIA-VARGAS*[1]

[1] Dept. of Signal Theory and Communications, Carlos III University of Madrid. Avenida de la Universidad 30, 28911, Leganés, Madrid, Spain
[2] Departamento de Ingeniería audiovisual y comunicaciones, Universidad Politécnica de Madrid. Carretera de Valencia Km.7, 28031, Madrid, Spain

dani@tsc.uc3m.es

Abstract. *In this paper a self-diplexed antenna is proposed for a RFID transponder application. The development cycle is divided into two stages: antenna design and filters design. The antenna is based on a square microstrip patch filled with metamaterial structures. The inclusion of these structures allows simultaneous operation over several frequencies, which can be arbitrarily chosen. The antenna working frequencies are chosen to be 2.45 GHz (receiver) and 1.45 GHz (transmitter). In addition, the antenna is fed through two orthogonal coupled microstrip lines, what provides higher isolation between both ports. Some filters based on metamaterial particles are coupled or connected to the antenna feeding microstrip lines to avoid undesired interferences. This approach avoids using of an external filter or diplexer, providing larger size reduction and a compact self-diplexed antenna.*

Keywords

Metamaterials, self-diplexed antennas, RFID, microstrip patch antennas.

1. Introduction

In recent years automatic identification procedures (Auto-ID) have become very popular in many industrial services, purchasing and distribution logistics, manufacturing companies... The barcode labels, that were a revolution in identification systems some years ago, are being found to be inadequate in an increasing number of cases. Barcodes are extremely cheap, but they have a limited storage capacity (only a number) and cannot be reprogrammed.

The optimal solution is the storage of data in a chip, which can be read out without mechanical contact (contactless). These contact-less ID systems are called RFID (Radio Frequency Identification) [1], [2]. A RFID system is formed by two devices: the transponder and the reader. The transponder is placed inside the object to be identified, which transmits the data to the reader when it is interrogated.

Till now, RFID systems in microwave range usually work at the same frequency in both links, using a procedure called modulated backscatter. This approach hinders the design of the reader and requires higher transmission power from the transponder to allow a proper information reception at the reader side.

Another widespread method is based on a frequency doubler in the transponder (as a diode) to answer the reader using a frequency which is the double of the interrogation one (1:2 ratio). Although this system is simple, it is not optimum since the most power restricted link (from the transponder to the reader) is the one with larger path losses what limits the system reach.

Therefore, by taking into account all mentioned reasons, the optimal solution is the use of a dual-frequency system in the RFID transponder. This approach allows the design of transponders which are interrogated at a frequency f_0 and transmit at a lower frequency (f_0/n, where n is an arbitrary number not forced to be an integer number). This fact reduces the losses in the power restricted link and diminishes the power requirements in the transponder. There exist different approaches to manufacture this dual-frequency system. The simplest one consists of two different antennas, but this design cannot be integrated into a small device and is very expensive. Another solution is the use of a dual-frequency antenna with a diplexer. It would be desirable to develop a self-diplexed dual-frequency antenna to achieve smaller size and cheaper devices.

In this paper, a self-diplexed dual-frequency patch antenna for a RFID transponder is proposed. These characteristics are achieved by using a microstrip patch with metamaterial structures.

Metamaterials [3] have been used to develop microwave circuits and antennas with unusual properties [4-14]. Moreover, due to the frequency-selective response of metamaterial based Transmission Lines (TLs), miniaturized filters can be developed [9-11]. Recently, the authors have proposed the use of conventional microstrip patches filled with metamaterial structures to achieve multi-frequency operation [13], [14]. The design procedure of the self-diplexed antenna is as follows:

1. Design of the dual-frequency antenna at 1.45 GHz and 2.45 GHz with two isolated ports (e.g. isolation higher than 20 dBs). The receiving frequency (2.45 GHz) is one of the standardized bands in RFID reception, while the transmitting band of an RFID transponder is not defined in the standard [1]. We have decided to transmit at 1.45 GHz, because this band allows us to filter the undesired resonances with simple structures. Moreover, the path losses at this frequency are considerably smaller than at a frequency closer to the receiving one. This antenna will be designed with a patch antenna filled with metamaterial structures and fed through two coupled microstrip lines. This feeding approach implies an improvement with respect to the authors' previous works to obtain higher isolation between ports, because the antennas presented in [13], [14] are fed through coaxial probes what does not provide large isolation between ports (12 dB approx. in [14]).

2. Coupled or connected metamaterial particles to the feeding lines to avoid undesired frequencies. Two filtering strategies are investigated: the use of notch filters to eliminate the undesired frequencies close to the working bands and the use of band-pass filters which allow the transmission at the working bands.

The paper is organized as follows. The antenna design and the manufactured prototype are presented in Section 2. Section 3 is devoted to the filters: two proposed filtering approaches are compared and an experimental example is provided. Lastly, Section 4 gives the conclusion.

2. Antenna Design and Experimental Results

The dual-frequency antenna is based on a squared microstrip patch filled with mushroom structures (Fig. 1) [13], [14]. These mushroom structures [15] behave as Left-Handed (LH) media, allowing the propagation of backward waves [16]. If we consider propagation along one main direction, the equivalent antenna Transmission Line (TL) model is composed of a LH section between two RH sections (Fig. 2) [13].

All the antenna eigen-frequencies satisfy the resonant condition:

$$\beta_n L = n\pi \tag{1}$$

where L is the equivalent TL length and n is the resonant index.

If it is taken into account that the propagation constant is positive and linear in the RH sections and negative and proportional to $1/f$ in the LH section, then, the equation (1) can be rewritten as:

$$\beta_n L = \beta_n^{RH} d + \beta_n^{LH} l = k_1 f_n d - \frac{k_2}{f_n} l = n\pi \tag{2}$$

where k_1 and k_2 are constants; d and ℓ are the equivalent lengths of the RH and LH sections, respectively. In this case, it is possible to obtain modes with negative, zero or positive index on the contrary to conventional patches. Specifically, for a LH section composed of M unit cells, n takes values:

$$n = -M + 1, -M + 2, \ldots, 0, +1, +2, \ldots \tag{3}$$

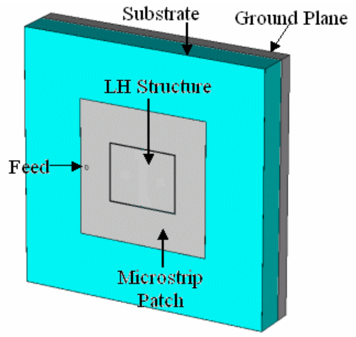


Fig. 1. Microstrip patch filled with LH structures.

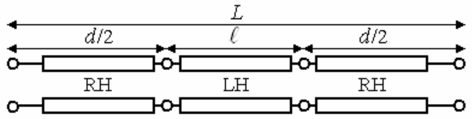


Fig. 2. Equivalent TL model of the antenna.

In our case, M is 2 in order to obtain the $n = -1$ mode as the fundamental one and avoid undesired lower modes. This fundamental mode presents half-wavelength electric field distribution as the fundamental mode of a conventional patch antenna, which leads to a dipolar (broadside and one beam) radiation pattern. Moreover, the equivalent mode to the fundamental one of a conventional patch antenna is also present ($n = +1$). For these reasons, a dual-frequency antenna can be developed by using $n = \pm 1$ modes at the same time. Moreover, if the antenna is fed through two orthogonal ports placed at the two main directions, the modes [-1,0], [0,-1], [+1,0] and [0,+1] (where the first index is related to the propagation along the first direction and the second index to the orthogonal direction) can be excited. For RFID application, $f_{[0,+1]}$ will be set to 2.45 GHz and $f_{[-1,0]}$ to 1.45 GHz. The other resonances will be filtered to avoid undesired interferences.

The final designed antenna is shown in Fig. 3. It is based on a 37.4 mm side length square patch on a PP substrate with $h = 4$ mm and $\varepsilon_r = 2.2$. The dimensions of the mushrooms are 11 mm × 14 mm, the vias radius is 0.35 mm and the gaps are 0.20 mm. The patch is fed through two 50 Ω coupled microstrip lines placed at two orthogonal directions. This feeding technique provides high isolation between both ports. The dimensions of the lines are 6.00 mm × 37 mm (Port 1) and 6.00 mm × 22 mm (Port 2). The Port 1 feeding line is placed 4.70 mm beyond the edge of the patch, while the Port 2 feeding line is placed 1.70 mm inside the patch to improve the match at each port. The substrate is implemented by 2 slits with 2 mm height each one, placing the feeding metallization over the lower slit.

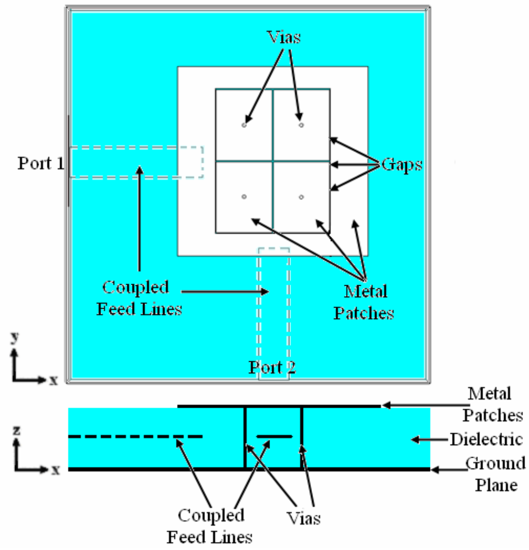
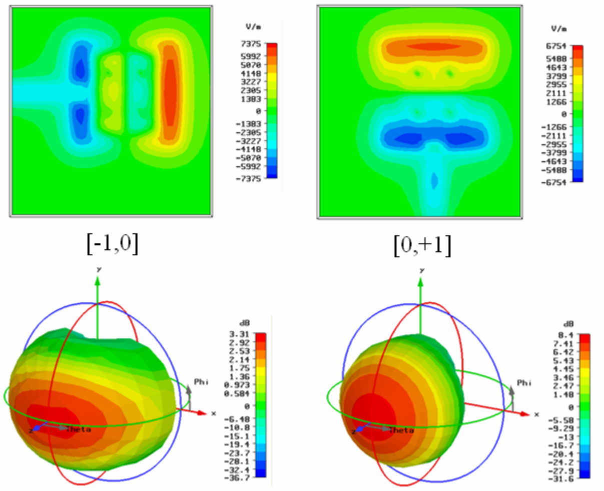


Fig. 3. Final design of the antenna.



[-1,0] [0,+1]

Fig. 4. Simulated electric fields distributions and radiation patters of the proposed antenna of Fig. 3 at the two working frequencies.

The electric field distributions at the two working modes (computed with CST®) are shown in Fig. 4. In both cases the electric field distribution has half-wavelength electric length. The resonant behavior of the mushrooms can be observed in the first mode. This is the reason why this additional mode is obtained. On the other hand, the second mode is basically the conventional one of the patch. Moreover, there is no power transmission between both ports at the working frequencies. This is the reason because it provides high level of isolation between the ports. The simulated radiation patters (CST®) at these two frequencies are also plotted. The patch-like radiation pattern is obtained at both frequencies, as desired. Fig. 5 shows the simulated [S] parameters of the antenna. Return losses are $|S_{11}|$ = -21 dB at $f_{[-1,0]}$ = 1.45 GHz and $|S_{22}|$ = -16.7 dB at $f_{[0,+1]}$ = 2.45 GHz. The isolation is -46 dB at the first working frequency and -20 dB at the second one. A prototype of this antenna has been manufactured (Fig. 6). The experimental [S] parameters of this antenna are also plotted in Fig. 5. It can be seen that simulations and measurements agree.

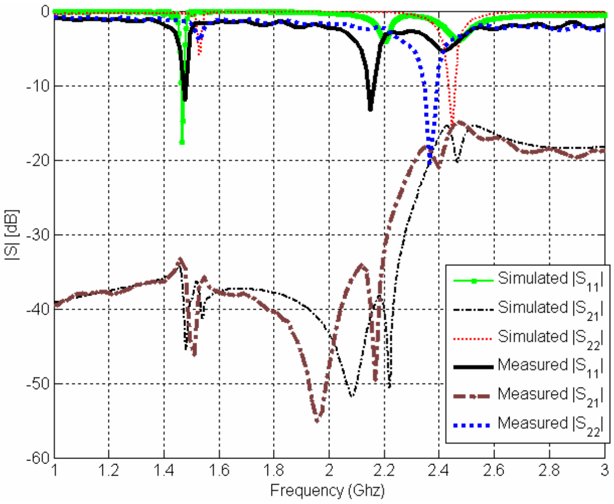


Fig. 5. Simulated and measured [S] parameters of the antenna of Fig. 3.

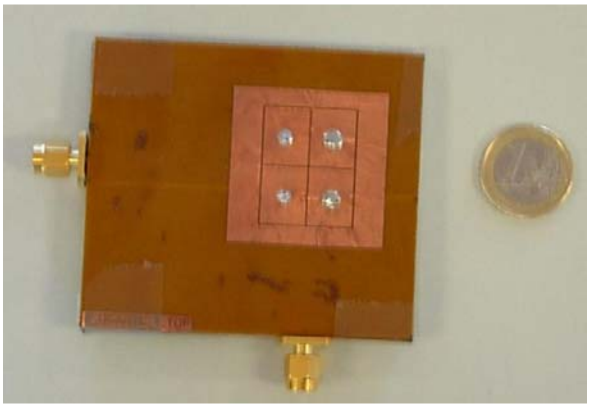


Fig. 6. Picture of the manufactured prototype.

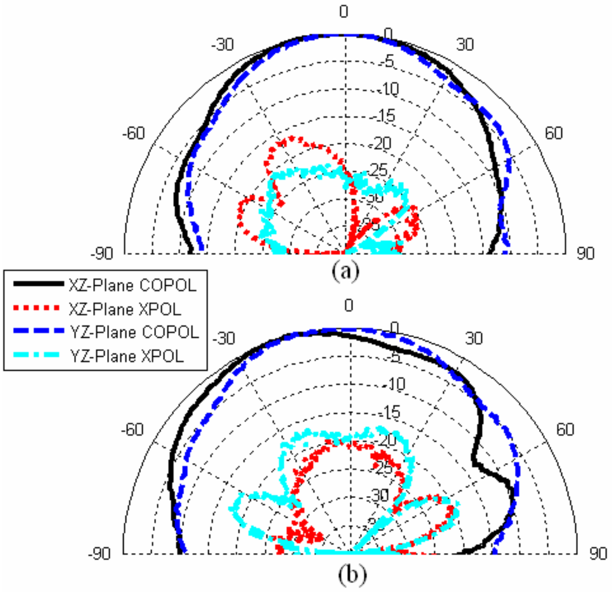


Fig. 7. Measured radiation patterns of the manufactured prototype. (a) Transmitter and (b) receiver frequency.

The radiation patterns at the two working frequencies are shown in Fig. 7. Both frequencies present a patch-like radiation pattern, as expected. The crosspolar components at the main direction are -25 dB at the first frequency and -20 dB at the second one. There are some undesired modes which will be filtered out in the next Section to avoid interferences and improve the isolation: two modes ([0,+1] and a higher-order mode) at port 1 near the working frequency of the second port (2.45 GHz) and a mode ([0,-1]) at port 2 near the working frequency of port 1 (1.45 GHz).

3. Filters Design

The filters are based on metamaterial particles coupled or connected to the feeding microstrip lines. Two types of filtering strategies have been investigated: notch filters and band-pass filters.

The proposed particles for the notch filters are Square Split Ring Resonators (SSRR) and Square Spiral Ring Resonators (SSR2), which were studied in circular geometry in [12]. These structures are coupled to the transmission lines and provide a stop-band in the vicinity of their self-resonant frequencies. The main difference between both types of particles is the size, because the self-resonant frequency of a SSR2 is half the self-resonant frequency of the SSRR with similar dimensions. This implies a larger degree miniaturization for SSR2.

Fig. 8 shows the sketches and the parameters of the metamaterials particles proposed for the notch-filters. Fig. 9 provides an example on how these particles are coupled to the feeding TLs. This example corresponds to the case of port 1 in which two resonances must be filtered. The filters have been designed for both ports and using the two types of particles. The sides of the squares (l_L) designed for port 1 are 8.05 mm and 8.95 mm for the SSRR. The spacing between both stages (S) is 15 mm. On the other hand, the dimensions (l_L) for the SSR2 are 4.95 mm and 4.53 mm with an 8 mm separation. At port 2 the side of the square (l_L) is 12.2 mm for the SSRR and 6.45 mm for the SSR2. All the gaps between the rings and the lines are 0.20 mm. The gaps inside the rings (d) are 0.40 mm and the copper width (c) of each line is 0.20 mm. The substrate is polypropylene (PP) with $h = 2$ mm and $\varepsilon_r = 2.2$.

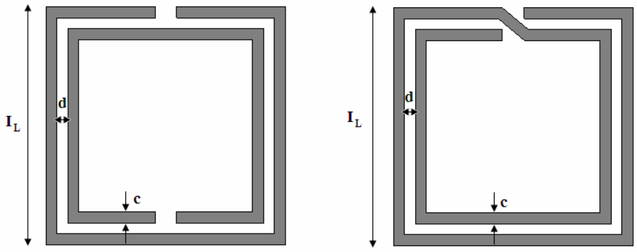


Fig. 8. Proposed metamaterial particles and their parameters for the notch-filters. (a) SSRR. (b) SSR2.

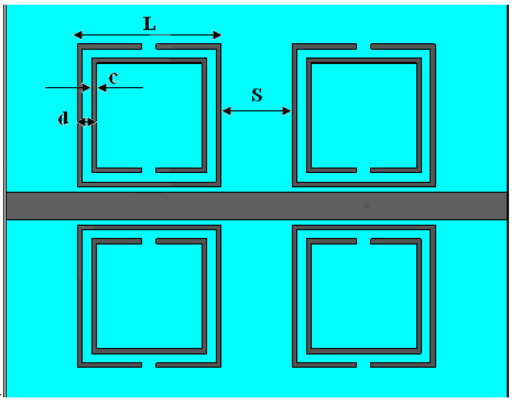


Fig. 9. Example of two notch filters based on SSRR coupled to a feeding transmission line. This example corresponds to the port 1 case in which two resonances are filtered.

These four filters have been simulated (CST®). Simulation results for the filters based on SRR2 are shown in Fig. 10. The stop-bands of the proposed filters match with the undesired frequencies of the antenna. The results are similar for the case of the filters based on SSRR, but the bandwidth of the SSR2 based filters is slightly narrower. Although these filters work properly, as showed before, some drawbacks can be enumerated: the bandwidth of these notch-filters is narrower than the undesired resonances of the antenna. Thus, more stages should be added to eliminate completely the undesired resonances. Moreover, one filter must be designed for each undesired resonances. For these reasons, we propose the second type of filters (band-pass filters) which overcome all these drawbacks.

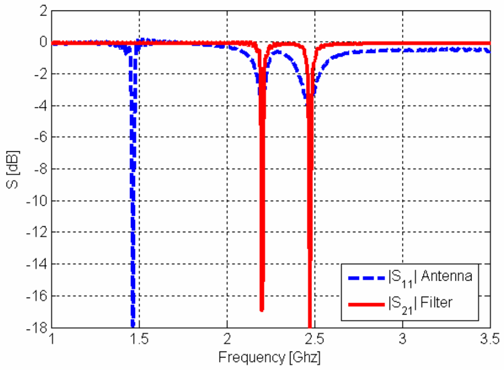


Fig.10.a Simulation results of the notch filters based on SSR2 at port 1, antenna $|s_{11}|$ and $|s_{22}|$ are also plotted.

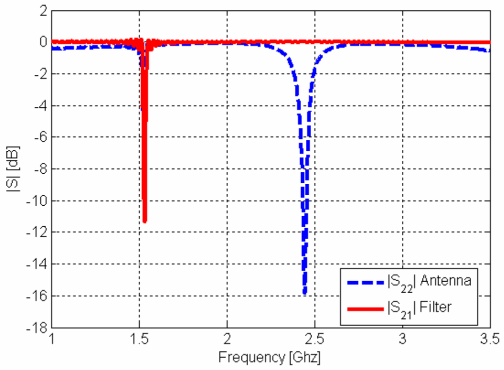


Fig.10.b Simulation results of the notch filters based on SSR2 at port 2, antenna $|s_{11}|$ and $|s_{22}|$ are also plotted. a) at port 1,

The passband filters are implemented by connecting metamaterial particles in series with the feeding line. These particles are Double Square Open Split Ring Resonators (DSOSRR), which are based on the Open Split Ring Resonator (OSRR) presented in [11], but our particles do not have a window in the ground plane and each of them are mirrored with respect to the feeding line. Fig. 11 shows the sketch of the proposed filters and their dependence parameters.

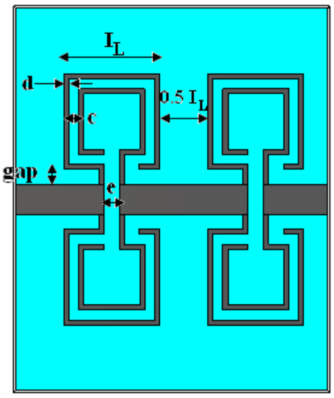
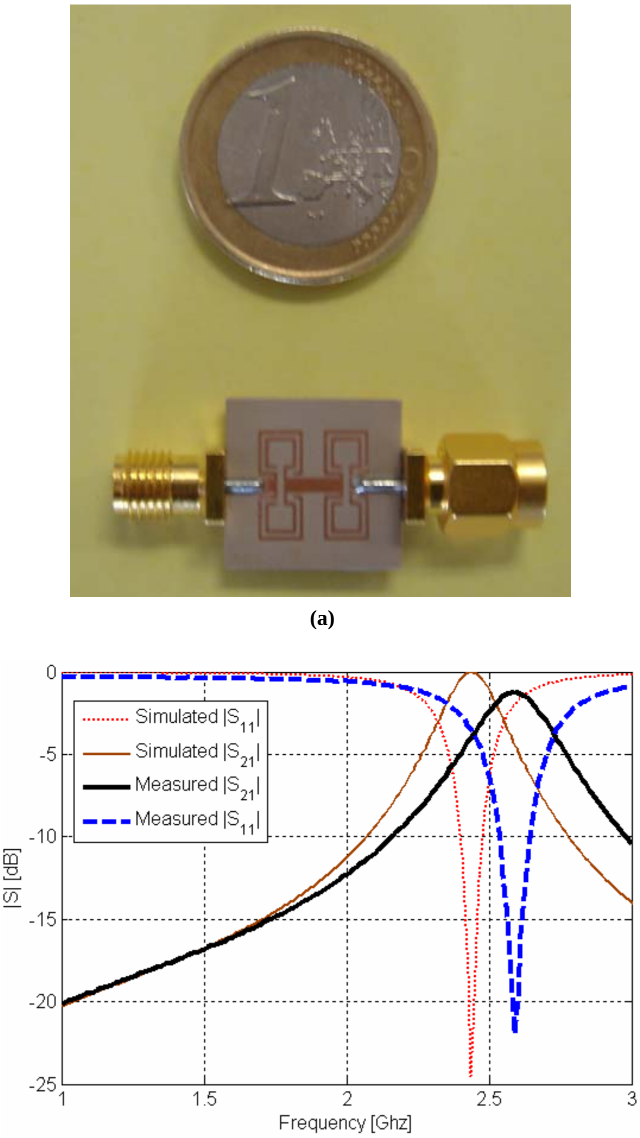


Fig. 11. Band-pass filter based on DSOSRR and its parameters.

The passband filters for the port 1 (1.45 GHz) and port 2 (2.45 GHz) have been designed, manufactured and measured, showing good results in both cases. As an example the results for the port 2 filter are provided. The parameters of this filter are: I_L = 3.83 mm, *gap* = 0.60 mm, *c* = 0.20 mm, *d* = 0.40 mm, *e* = 0.60 mm. The substrate is Arlon® 1000 (h = 1.27 mm and ε_r = 10). Fig. 12 shows the picture of the manufactured photograph and the simulated (CST®) and measured [S] parameters of this filter. There is a small frequency shift between the simulated and measured results due to the tolerances of our manufacturing process. The measured insertion losses of this filter are 1.2 dB. As it has been demonstrated, these passband filters have a bandwidth broader than the one presented by the antennas and only one filter per port is needed in order to allow the transmission of the desired frequency and reject all the undesired frequencies.

4. Conclusion

A novel self-diplexed antenna for RFID application has been presented. First, it has been shown that it is possible to obtain an antenna with two dipolar modes ($n = \pm 1$) by filling a microstrip patch with LH structures. Then, an antenna working at $f_{[-1,0]}$ = 1.45 GHz and $f_{[0,+1]}$ = 2.45 GHz has been designed. These two orthogonal modes have been excited through two orthogonal coupled microstrip lines. The isolation between the ports is 40 dB at the first frequency and 20 dB at the second one. Finally, metamaterial particles have been coupled or connected to the feeding lines in order to filter the undesired frequencies which are near the working frequencies. Two types of filters have been investigated: notch filters and band-pass filters. For the first type of filters SSRR and SRR2 particles have been considered, while the band-pass filters are based on the particle DSOSRR. The passband filters are more suitable for this application, because their frequency response allows transmitting the desired signal and rejects all the undesired frequencies of the antenna with only one filter per port.



(a)

(b)

Fig. 12. (a) Picture of the filter prototype. **(b)** Simulated and measured results.

Acknowledgements

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About Authors...

Eduardo UGARTE-MUÑOZ was born in Caracas, Venezuela on April 23, 1983. Currently he is about to get his degree in telecommunications from Carlos III University in Madrid, Spain. At the moment he is working on CRLH antennas.

Francisco Javier HERRAIZ-MARTÍNEZ was born in Cuenca, Spain, on May 3, 1983. He received the Engineer degree in telecommunications from Carlos III University in Madrid, Spain, in 2006 (awarded with the first prize). He is currently working towards the Ph.D. in communications at Carlos III University in Madrid. His research interests include active antennas and metamaterial applications for antenna and microwave circuits. Mr. Herraiz-Martínez received the Spanish Best Master Thesis Dissertation Award from the COIT/AEIT. He was finalist of the IEEE AP-S Student Paper Contest.

Vicente GONZÁLEZ-POSADAS was born in Madrid (Spain) in 1968. He received the Ing. Técnico in radiocommunication engeneering degree from the Polytechnic University of Madrid (UPM) in 1992, M.S. degree in physics in 1995, from the UNED and Ph.D degree in telecommunication engeneering in 2001 from the Carlos III University of Madrid. He is working now as an Assistant Professor at the Technical Telecommunication School in the Polytechnic University of Madrid. His interest are related to active antennas, microstrip antennas, CRLH lines and metamaterials and microwave technology. He has authored or coauthored over 60 technical conference, letters and journal papers.

Daniel SEGOVIA-VARGAS (M'98) was born in Madrid in 1968. He received the Telecommunication Engineering Degree and the Ph.D. from the Polytechnic University of Madrid in 1993 and in 1998. From 1993 to 1998 he was an Assistant Professor at Valladolid University. From 1998 he is an Associate Professor at Carlos III University in Madrid where he is in charge of the Microwaves and Antenna courses. He has authored and co-authored over 80 technical conference, letters and journal papers. His research areas are printed antennas and active radiators and arrays and smart antennas, LH metamaterials and passive circuits. He has also been member of the European Projects Cost260, Cost284 and COST IC0603.