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Compact Implementation of an RFID Tag with Electromagnetic Wave Polarization Diversity

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Abstract. The paper presents a backscattering RFID system with reduced interference of incident and reflected electromagnetic waves. The tag system is designed for 5 GHz operating frequency and uses two microstrip patch antennas with linear polarization in perpendicular directions. Between the tag antennas a block including a Schottky diode is used for amplitude modulation of the received signal with tag information. The tag is fabricated on a FR–4 double clad substrate and the measurements results are presented for different reading ranges.

Key-words: Amplitude modulation, microstrip patch antenna, RFID, wave polarization diversity.

1. Introduction

The history of the *radio frequency identification* (RFID) technique started about 100 years ago [1] when the basic principle was defined. An RFID system has two main blocks: the tag and the reader and can be classified into different categories [2-4]. There are two main families of RFID systems: near field RFID and far field RFID. The first is based on Faradays magnetic induction and the second uses *electromagnetic* (EM) waves propagated through antennas in both the reader and tag (Fig. 1). The reader sends an interrogating RF signal to the tag and the tag responds with a signal that is processed by the reader.

Depending on how the tags get the required energy to respond to the readers, far field RFID systems can be classified in: active tags (need batteries to power their own chips and to generate the RF signal with the response to the reader); semi-passive (the batteries are used to power their own logic circuits, not the transmitter) and passive tags (the required power is harvested by itself).

The development of far field RFID technologies is connected to the development of the chips, antennas and information processing algorithms. Currently the upper frequency range of the common commercial RFID systems is in the UHF frequency band (up to 1 GHz - typical 866 MHz in Europe and 915 MHz in United States of America).

There is on-going research aimed at increasing the operating frequencies towards the microwave and millimeter wave ranges, where far-field communications are employed. Future developments of RFID will include the *Internet of Things* (IoT) and 5G (including beyond 5G) [3].

In these frequency ranges the propagation is limited to line of sight, the signals are attenuated by water and reflected by metallic objects. The communication between the reader and the tag is mainly based on backscattering of the electromagnetic field by the tag with the undesirable effect of the interference of the incident and the reflected waves by both the tag placed on different objects (including metallic ones) and the noisy environment. One possible solution to this problem is to change the polarity of the tag reflected wave with respect to the incident wave. This approach is illustrated in Fig. 2 for microstrip technology. The incident wave has a vertical polarization while the reflected wave has a horizontal polarization.

The concept of RFID tag with EM wave polarization diversity at 5 GHz was reported in [5] using circuit blocks (antennas, amplitude modulation block, measurement equipment etc.) interconnected with connectors and coaxial cables. The blocks were fabricated and tested independently and the measured results were in good agreement with the simulated ones.

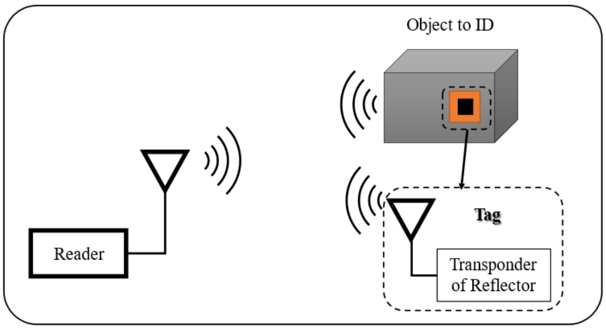


Fig. 1. Working principle of far field RFID systems.

This paper presents the design, fabrication and experimental characterization of an RFID tag with electromagnetic wave polarization diversity operating in the 5 GHz frequency range. The tag implementation is based on two microstrip patch antennas with inset for impedance matching placed with the linear polarization in perpendicular directions. Between the antennas, a circuit including a Schottky diode, as well as input and output matching networks is inserted and used for *amplitude modulation* (AM) of the received signal with the tag information. All the blocks are integrated on the same FR4 substrate with a thickness of 1.5 mm, 4.6 measured dielectric permittivity and 0.02 estimated loss tangent. The copper cladding thickness is 0.035 mm. The circuit layout was defined using thermal transfer technique and ferric chloride etching. The lumped Surface Mounted Devices (inductors, capacitors, diodes) were soldered on the *printed circuit board* (PCB). The tag is tested with the experimental setup shown in Fig. 2 and the experimental results are presented.

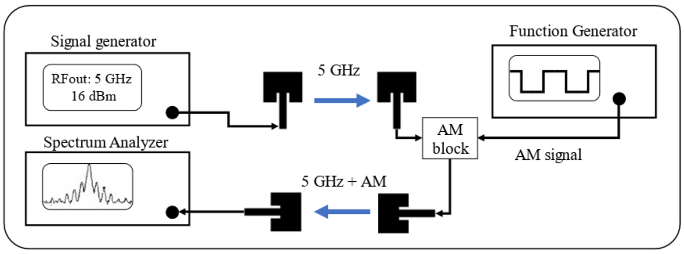


Fig. 2. The experimental setup used for tag testing.

2. Design and measurements of 5 GHz microstrip antennas

Microstrip patch antennas are planar antennas, easy to fabricate and design, with a moderate directivity of 7-8 dBi, low cost and can be easily matched for a wide range of characteristic impedances [6]-[9]. The main antenna layout parameters are shown in Fig. 3 (a). The design procedure has two steps. First, the layout parameters are evaluated using the following standard analytic equations:

$$f_c \approx \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{1}{2L\sqrt{\varepsilon_0 \varepsilon_r \mu_0}}, \tag{1}$$

$$Z_{in}(d) = \cos^2\left(\frac{\pi d}{L}\right) Z_{in}(0), \tag{2}$$

where f_c is the desired central operating frequency; c is the speed of light in free space; ε_r is the relative permittivity of the dielectric substrate; $\varepsilon_0 = 8.85 \times 10^{-12}$ Fm^{-1} is the vacuum permittivity; $\mu_0 = 4\pi \times 10^{-7}$ H/m is the vacuum permeability; L is the patch length; d is the inset length; $Z_{in}(0)$ is the input impedance if the patch was fed at the end; $Z(d)$ is the antenna input impedance when the patch is fed at the inset (d).

The thickness of the substrate is 1.5 mm which is about $1/40\lambda$ at 5 GHz, a practical lower limit before the antenna efficiency starts to degrade. The length L should be about 2-3% shorter than half of the freespace wavelength, in order to account for the fringing effects. Since the width, W, of the patch also influences the radiation pattern, this value is therefore optimized primarily for radiation. The inset (d) is added in order to offer an additional degree of freedom for antenna input impedance matching purposes.

Next, using the *electromagnetic* (EM) software package CST Microwave Studio the antenna layout is optimized through parametric simulation routines. One or more model parameters are varied and the user selects the best solution as a tradeoff between matching bandwidth and directivity. The final layout parameters are presented in Table 1. Fig. 3 (b) and (c) present the simulated 3D radiation pattern at 5 GHz and directivity as a function of frequency, respectively. The simulated directivity in the broadside direction has a maximum value of $\sim$ 8 dBi around 5 GHz, with an exceptionally large 3dB bandwidth of $\sim$ 46%. These values show the radiation potential of the device. The final radiation performance will be influenced by the relative narrow impedance matching bandwidth of 2-3% typical for the resonant patch antenna.

Fig. 3 (d) presents the simulated electric field intensity distribution at a distance of 60 mm above the antenna, confirming the linear polarization of the emitted EM waves.

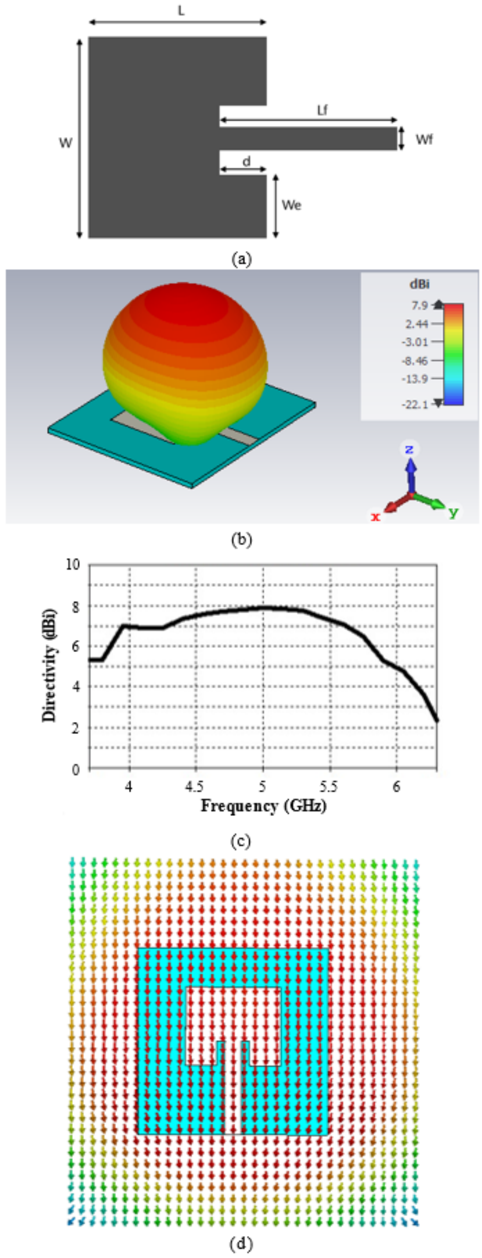


Fig. 3. The microstrip patch antenna: (a) The main antenna layout parameters; (b) simulated 3D radiation pattern at 5 GHz; (c) simulated antenna directivity as a function of frequency; (d) simulated electric field intensity distribution at a distance of 60 mm above the antenna (color online).

Table 1. The final layout parameters of microstrip patch antenna

Parameter	Value[mm]
L	13.38
W	17.38
Lf	16
Wf	3
d	1.47
We	4.2

Two microstrip patch antennas are placed in perpendicular directions. A photo of the fabricated antennas is shown in the inset of Fig. 4. The antennas were contacted with vertical SMA connectors (on the opposite side) and represent the front-end interface of the reader in the experimental setup. The reflection parameters were measured with a Vector Network Analyzer and are presented in Fig. 4. The matching around 5 GHz is excellent, with a –10 dB impedance matching bandwidth of ∼3.7%. The measured direct EM coupling at 5 GHz is about –30 dB (Fig. 4).

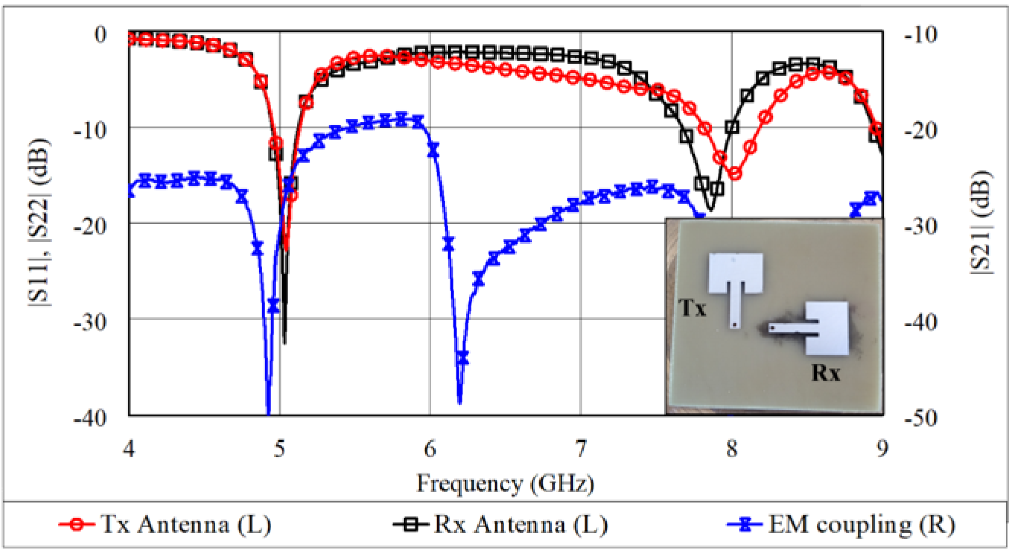


Fig. 4. Measured reflection parameters and direct EM coupling for the fabricated microstrip patch antennas (in inset) (color online).

3. Design of RFID tag with amplitude modulation and polarization diversity

The circuit used for the AM of the input signal is based on a Schottky diode (NSR201MXT5G) and an input and output matching network with the central operating frequency of 5 GHz. The matching networks have an open-stub line configuration. A similar circuit was tested in [5]. In the present paper the AM block is inserted directly between the receiving antenna and the transmitting antenna on the same PCB. A photo of the tag with a size of 62 × 67 mm^2 is presented in

Fig. 5 (a). The lumped *Surface Mounted Devices* (SMD) *Schottky diode* (SD), the 100 nH SMD RF choke inductor and a 2 kOhm bias resistor were soldered on the PCB.

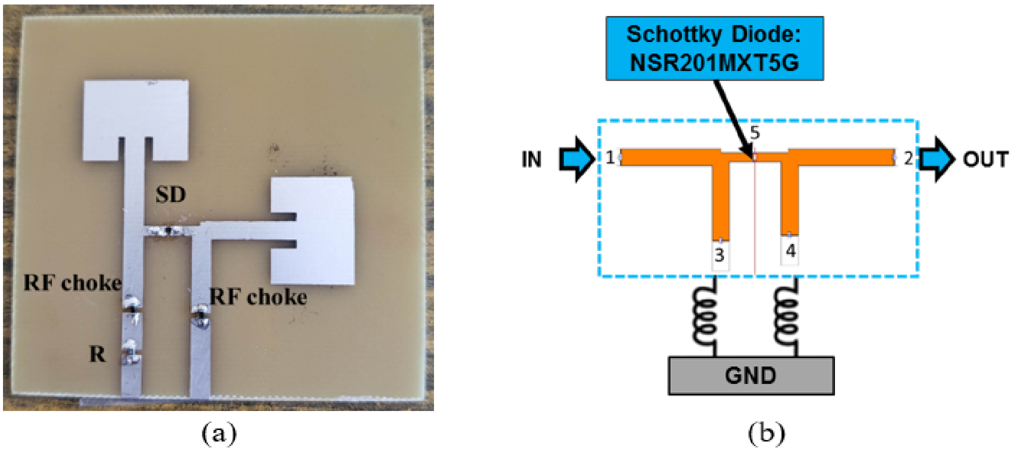


Fig. 5. RFID tag: (a) Photo of the RFID tag with soldered lumped SMD components (62 × 67 mm2); (b) Circuit and EM model (inset) for the AM block (color online).

The AM circuit block was modeled with the EM software package Mentor Graphics SSD (IE3D). The model has five ports and has the topology presented in Fig. 5 (b). Two EM ports are connected at the external ports of the circuit, one internal port is connected at the diode model and the last two ports at two RF choke inductors of 100 nH. The diode was modeled using the one-port Touchstone measurement file sets provided by the manufacturer for different DC biases. The block was simulated using NI AWR Microwave Studio software and the design goal was the best matching condition between the external ports and the antennas input impedances for a SD bias current of 0.5 mA.

4. Measurement results for the RFID tag

The experimental setup used for the RFID tag evaluation is presented in Fig. 6. Two antennas with vertical and horizontal polarization were connected with coaxial cables to a microwave generator (5.03 GHz, 16 dBm) and a spectrum analyzer. The two ports after the RF chokes were connected to a signal function generator (Fig. 2) with a coaxial connector. The test signals had sinusoidal and rectangular waveforms with 200 kHz modulation frequency and 1 V amplitude with 0 V bias offset. This amplitude assures the 0.5 mA bias current used in the design for the SD in ON state. The recorded results using the spectrum analyzer (in frequency and time domain) are presented in Fig. 7 and Fig.8, for 100 mm and 300 mm distance between reader and the tag. It can be noted that even at a distance of 300 mm, the received signal amplitude is large enough for future signal processing by a dedicated reader.

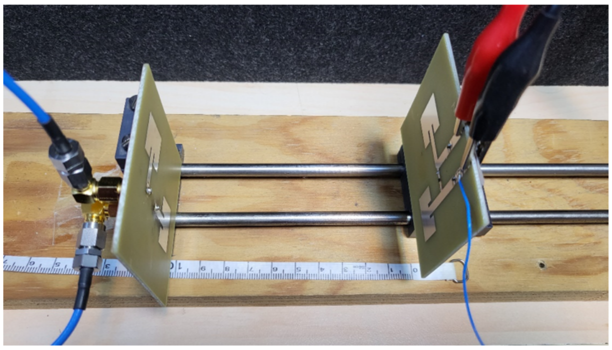
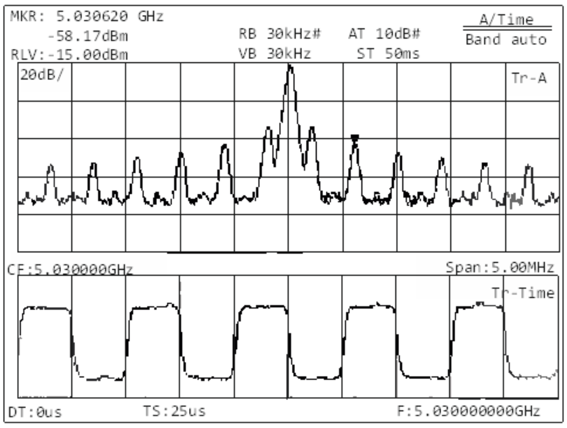
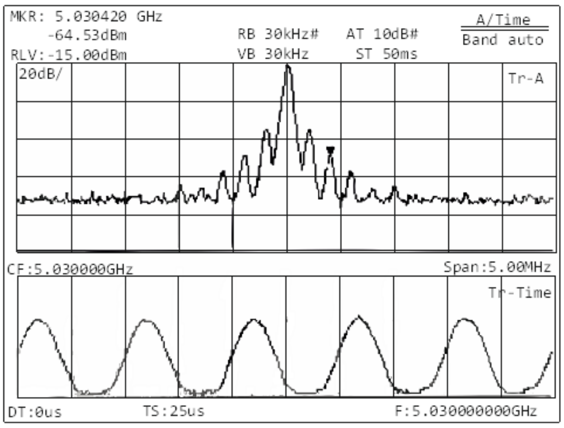


Fig. 6. Experimental setup for RFID tag evaluation (color online).

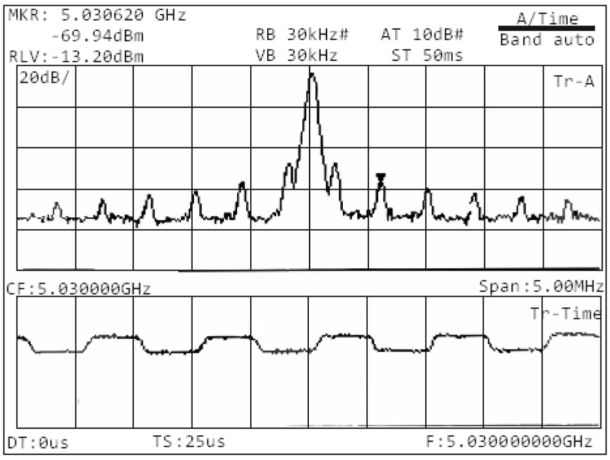


(a)

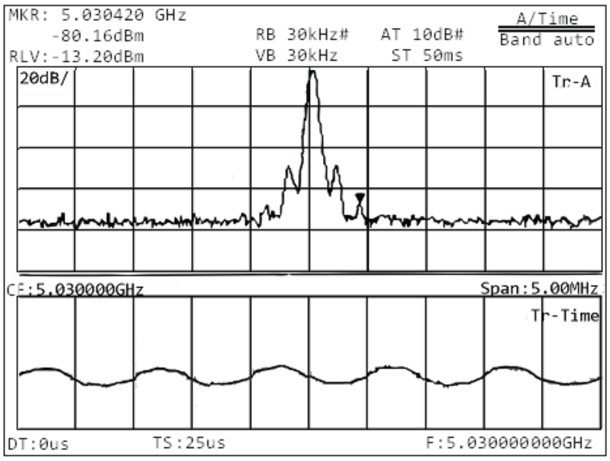


(b)

Fig. 7. The recorded signal in frequency and time domain for a distance of 100 mm for (a) sinusoidal and (b) rectangular waveform of the modulating signal.



(a)



(b)

Fig. 8. The recorded signal in frequency and time domain for a distance of 300 mm for (a) sinusoidal and (b) rectangular waveform of the modulating signal.

5. Conclusions

A RFID tag operating at 5 GHz was designed, fabricated and measured. The proposed technology can take advantage of existing 5 GHz WiFi infrastructure for IoT implementation. The tag design uses the orthogonal linear polarizations of two rectangular microstrip patch antennas to cancel the interference of the incident and reflected waves. A circuit with a Schottky diode and two matching networks inserted between the antennas is used for inserting the information using amplitude modulation. All the circuit blocks were fabricated using microstrip technology on the same FR-4 double clad substrate with a total area of 62×67 mm^2 and a thickness of 1.57 mm, making it viable for integration in handheld devices and systems. The tag system was tested using rectangular and sinusoidal amplitude modulations and the experimental results validated the proposed concept in far-field conditions. The reported approach has the potential to be scaled up to millimeter wave frequencies for high density RFID systems.

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