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A GSM-900 MHz and WiFi-2.45 GHz Dual-Polarized, Dual-Frequency Antenna Dedicated to RF Energy Harvesting Applications

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Abstract— A dual-polarized, dual-frequency and dual-access antenna for RF energy recycling applications is presented. The antenna shows good measured performances at 940 MHz and 2.45 GHz with a simulated broadside gain higher than 6 dBi and a return loss lower than -12 dB. It also exhibits harmonic rejection properties at 1.88 GHz and 4.9 GHz avoiding the use of RF filters when the antenna is connected to a non-linear device as the diode rectifier because no RF filter is required to suppress higher order harmonics.

Index Terms: Microstrip Antenna ; square patch antenna; ring antenna; dual linear polarization; dual frequency; harmonic rejection.

I. INTRODUCTION

The rectenna (rectifying antenna) is mainly used to collect and convert RF energy into dc power to supply low power actuators, sensors or sensors network [1]-[2].

Today, recycling ambient energy is particularly attractive. As an example, the equivalent isotropic radiated power EIRP for the GSM-900 (Frequency range in France 925-960 MHz) is about few hundreds of Watt, and the EIRP for the 2.45 GHz WiFi (in France 2.4-2.47 GHz) has a maximum level of 100 mW (European Norm [3]) and 4 W (US Norm [4]).

However, the available RF power is often very weak and to improve the amount of power converted, multi-band rectenna can be used [5]-[6].

In term of polarization characteristics, the field is generally linearly polarized at both the GSM band and the ISM 2.45 GHz band, but in indoor or outdoor environment, multipath effects can cause depolarization. Thus, the electromagnetic waves have an unknown angle of incidence when incoming toward the antenna which may decrease the efficiency of the rectenna.

The dual polarization reception can overcome this problem because it permits to collect the RF signal regardless the angle of polarization of the incident wave. In addition, dual polarization topology can avoid the traditionally 3 dB losses when using a circular polarization antenna.

Aiming to work at 940 MHz (Global System for Mobile Communications) and 2.45 GHz (unlicensed ISM Band), we propose in this article to design a dual frequency and dual polarization printed antenna with two separated accesses for rectenna applications.

II. ANTENNA DESIGN

The geometry of the proposed antenna is illustrated in Fig.1. It consists of a dual polarized inner 2.45 GHz square patch and outer 940 MHz square ring, printed on a 3.175-mm-thick Duroid 5880 top substrate, with relative permittivity of 2.2.

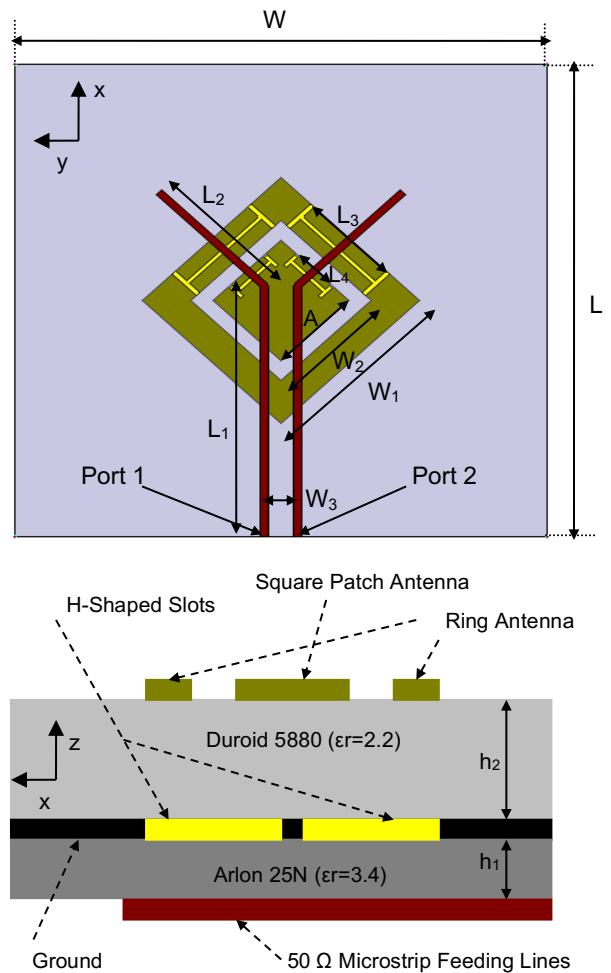


Fig.1. Antenna Geometry

$L_1=100.85$; $L_2=58$; $W_1=74.7$; $W_2=47.4$; $A=37.5$; $L_3=37.4$; $L_4=18$; $W=L=190$;
 $h_1=1.524$; $h_2=3.175$; $W_3=9.68$ (Dimensions in mm).

The two radiating elements are fed by electromagnetic coupling through an aperture on the ground plane.

Two orthogonally H-shaped slots etched on the ground plane are accurately localized below the edge of the inner square patch. Each slot has a center arm of 18 mm length and 1.5 mm width and two side arms of 6 mm length and 1.5 mm width.

In the same way, two longer H-shaped slots are etched below the outer ring element. Each slot is centered relatively to the axis of the upper associated ring arm. The center arm is of 37.4 mm length and 1.65 mm width and the two perpendicular side arms are of 13.65 mm length and 2 mm width.

The H shape for the coupling slots has been chosen to improve the coupling effects [7], especially for the ring element. This also increases the resonant input impedance, whose real part was generally very low when using the rectangular shaped slots.

Two 50 Ω microstrip feeding lines, are printed on a 1.524-mm-thick Arlon 25 N substrate with a relative permittivity of 3.4 at the backside of the antenna.

For each feeding line, there is two specific electromagnetic coupling points : one with the top patch and a second with the top ring. This coupling is insured by one of the two H-shaped slots corresponding to each radiating element in order to provide a specific linear polarization. Indeed, the radiated electric field has an azimuthal orientation according to $\varphi = 45^\circ$ or $\varphi = -45^\circ$.

For each polarization, an inclined tuning stub (-45° or $+45^\circ$) at the end of the feeding line adjusts the reactance on the slot to correctly match the antenna.

The dimensions of the ground plane are 190 mm per 190 mm corresponding to a compact $0.6\lambda_0$ per $0.6\lambda_0$ at 940 MHz.

III. SIMULATION RESULTS

All simulated results have been obtained using HFSS software. From an excitation at port 1, the S_{11} is -15.2 dB at 940 MHz and -28.6 dB at 2.45 GHz.

The two ports are well isolated resulting in a transmission coefficient S_{21} of -26.2 dB at 940 MHz and -23.2 dB at 2.45 GHz.

The 1.88 GHz second harmonic and 2.82 GHz third harmonic are correctly rejected (S_{11} is of -1.4 dB and -1 dB respectively).

Considering the 2.45 GHz frequency of interest, the 4.9 GHz second harmonic is also correctly rejected ($S_{11} = -2.5$ dB). Therefore, in a rectenna application, no RF filter is required between the antenna and the non-linear rectifier, resulting in a more compact structure.

The normalized radiation patterns (E-plane and H-plane) at 940 MHz and 2.45 GHz are shown at Fig.2 and Fig.3.

The front-to-back ratio is 13.6 dB at 940 MHz and 19.3 dB at 2.45 GHz. The simulated radiation efficiency of the antenna is respectively 78.8 % at 940 MHz and 95.3 % at 2.45 GHz.

The simulated realized gain at broadside is 6.1 dBi at 940 MHz and 6.6 dBi at 2.45 GHz.

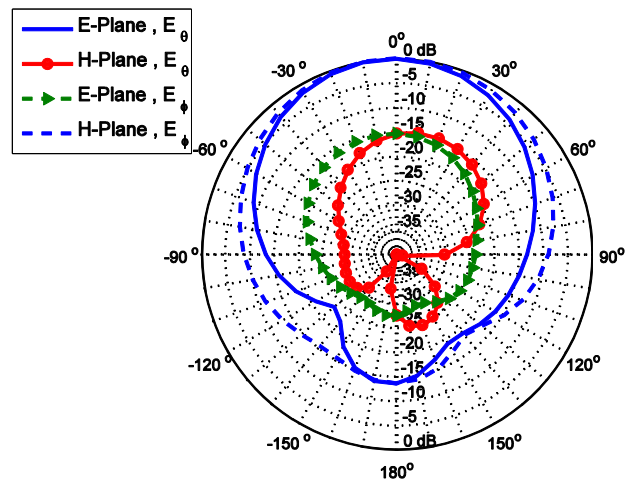


Fig.2. Normalized Simulated Radiation Patterns at 940 MHz (in dB)

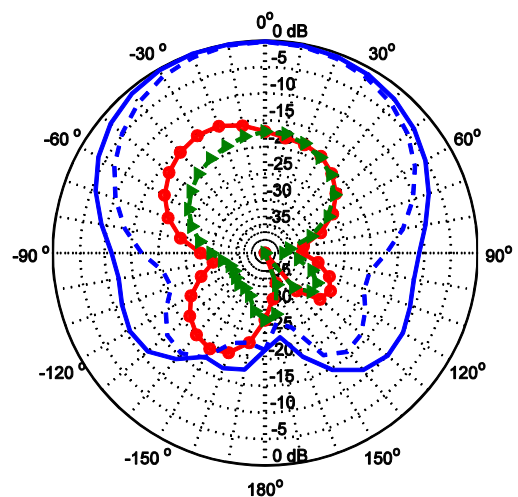


Fig.3. Normalized Simulated Radiation Patterns at 2.45 GHz (in dB)

IV. MEASUREMENT RESULTS

We have shown on Fig.4 and Fig.5 the measured S_{ij} parameters in a frequency band from 800 MHz up to 5.3 GHz.

All experimental curves are superimposed with the simulated ones.

The measured S_{11} is -12 dB at 940 MHz and -18 dB at 2.45 GHz (-15.2 dB and -28.6 dB in simulation).

The measured transmission coefficient S_{21} is of -23.1 dB at 940 MHz and -20.7 dB at 2.45 GHz (-26.2 and -23.2 dB in simulation).

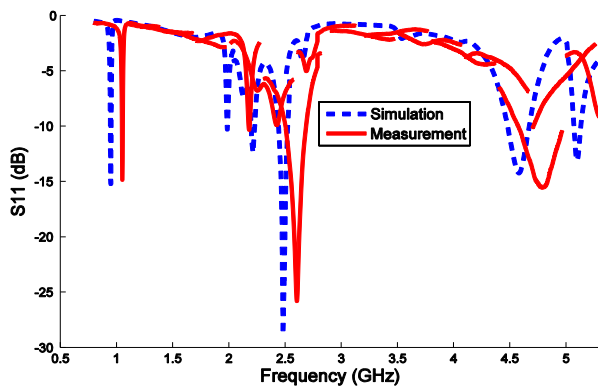


Fig.4. Measured and Simulated S_{11} (in dB)

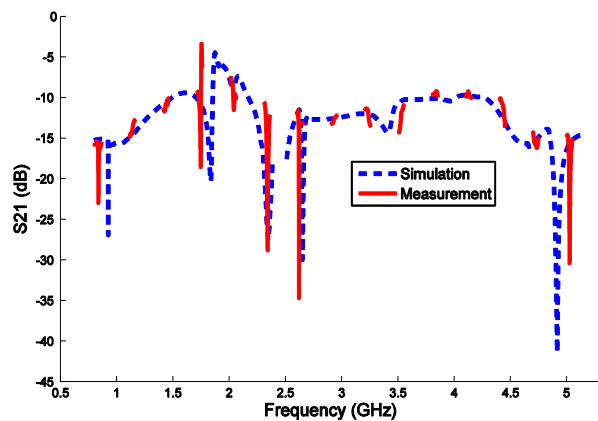


Fig.5. Measured and Simulated S_{21} (in dB)

The measured S_{11} at 1.88 GHz second harmonic and 2.82 GHz third harmonic is of -1.9 dB and -1.4 dB respectively. The measured S_{11} at 4.9 GHz second harmonic is of -5.2 dB. As we can see in these results, the measured and simulated S-parameters are very close.

The antenna has been measured on a dedicated anechoic chamber using an emitter horn antenna. The power received by the antenna under test is measured on port 1 while a matched load is connected on port 2. Due to the symmetry of the structure, the same radiating characteristics are obtained when the conditions on the excitations ports are inverted.

The normalized measured radiation patterns (E-plane and H-plane) at 2.45 GHz is shown in Fig.6. The radiation patterns show a broadside behavior.

The cross-polarization component is 18 dB lower than the co-polarization component at $\theta=0^\circ$. The simulated results show a difference between cross-polarization and co-polarisation of 17 dB at $\theta=0^\circ$.

Therefore, these results are very close to those obtained by HFSS simulations.

We can notice that the measures at 940 MHz are in progress due to the specific low frequency band localized outside the frequency bandwidth of interest of our anechoic chamber.

V. CONCLUSION

A dual frequency band and dual linearly polarized antenna with two dedicated accesses for rectenna applications is

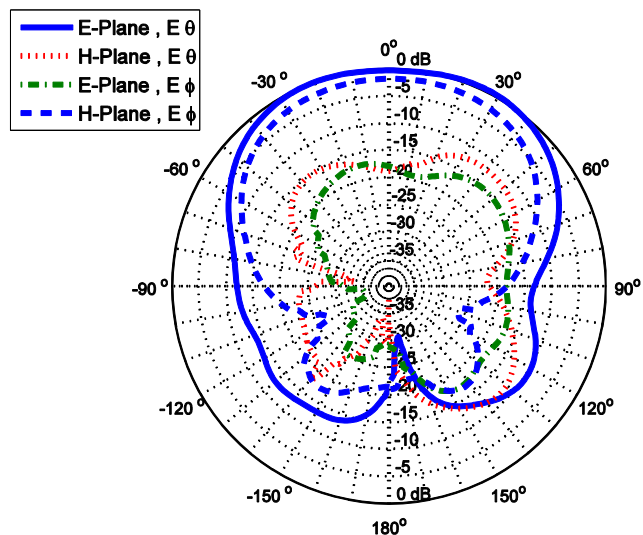


Fig.6. Normalized Measured Radiation Patterns at 2.45 GHz (in dB)

presented. The simulations show a good broadside gain and a correct matching level at 940 MHz and 2.45 GHz. It also exhibits a second harmonic rejection properties at both frequency bands then avoiding the use of an RF filter in a rectenna device. This results in a more compact structure. Measurements of the antenna have been done.

The measured input return losses of -12 dB at 940 MHz and -18 dB at 2.45 GHz have been achieved (-15.2 dB and -26.8 dB in simulations). These results are shown to be comparable to the simulations.

In the other hand, the radiation patterns at 2.45 GHz were measured at both E-plane and H-plane. They exhibit the same behavior that those obtained from the simulations.

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