Circularly Polarized Shorted Ring Slot Rectenna with a Mesh Design for Optimized Inkjet Printing on Paper Substrate

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***Abstract* — The design of a 2.45 GHz circularly polarized rectenna inkjet printed on paper is presented. The proposed antenna structure is a shorted ring slot with a modified ground plane where a mesh design is employed in order to reduce the required amount of silver nanoparticle ink that needs to be inkjet-printed. A meshed ground plane with 29 % conducting surface relative to a solid ground was demonstrated with a simulated gain of 2.2 dB, axial ratio of 0.6 dB at 2.45 GHz and a peak rectifier efficiency of 45 % for -15 dBm input received power at the antenna terminals.**

***Index Terms* — Inkjet printing, paper substrate, circularly polarized rectenna, slot antenna.**

I. INTRODUCTION

Energy harvesting is experiencing a great development towards providing autonomy to the sensors and devices that will form the so called Internet of Things (IoT). Among the different types of energy harvesting EM energy harvesting takes the available EM signals in the environment and convert them to DC power by using rectenna elements [1,2].

In order to achieve a higher integration of the EM harvesters with the corresponding sensors and devices, conformal and flexible implementations for the rectenna elements have been proposed [3,4]. In [3] flexible implementations of RF structures on paper substrate are presented where inkjet printing technologies are used. Inkjet printing is an additive process where conductive nanoparticles are deposited on a selected substrate, such as paper. In order to reduce the cost of inkjet printed circuits, it is desirable to minimize the amount of required conductive nanoparticles.

In this work, a 2.45 GHz rectenna with a meshed ground plane is designed aiming at reducing the amount of required surface to be inkjet printed. The proposed rectenna is a circularly polarized (CP) shorted ring slot structure together with a rectifier element [5]. The obtained results show that it is possible to reduce the amount of conductive material in this type of antennas and still maintain a good performance.

II. CIRCULARLY POLARIZED ANTENNA DESIGN

The proposed antenna at 2.45 GHz has a double layer structure. On one side of the substrate there is the feeding line and on the other side a shorted ring slot [5]. The width of the ring slot (w_{slot}) , the angle of the shorting slit (θ_{gap}) and its position (θ_{slit}), and the feed line dimensions (w_{feed1}, w_{feed2}) are used to optimize the input matching, the gain of the antenna element and the axial ratio (AR) (Fig. 1). The final dimensions of the designed antenna are shown in Table I.

The selected material for the design is a low-cost paper substrate (290 g/m2 smooth gloss paper by Ilford) with 290 um thickness, dielectric constant 3.28 and 0.06 loss tangent.

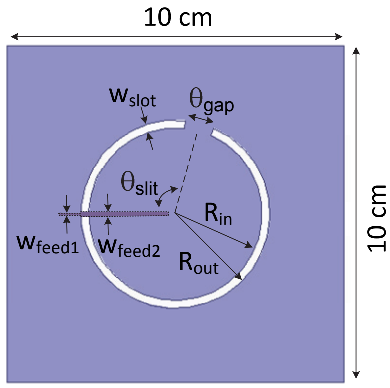

Fig. 1. Shorted ring slot CP antenna (original design).

TABLE I
DIMENSIONS VALUES FOR THE CIRCULARLY POLARIZED ANTENNA DESIGN

Dimension	Value	Dimension	Value
w_{slot}	1.5 mm	R_{in}	25.5 mm
θ_{gap}	7.1º	R_{out}	27 mm
θ_{slit}	101 º	w_{feed1}	0.68 mm
		w_{feed2}	1.4 mm

The simulated results in terms of input S-parameters, gain and axial ratio (AR) are shown in Fig. 2.

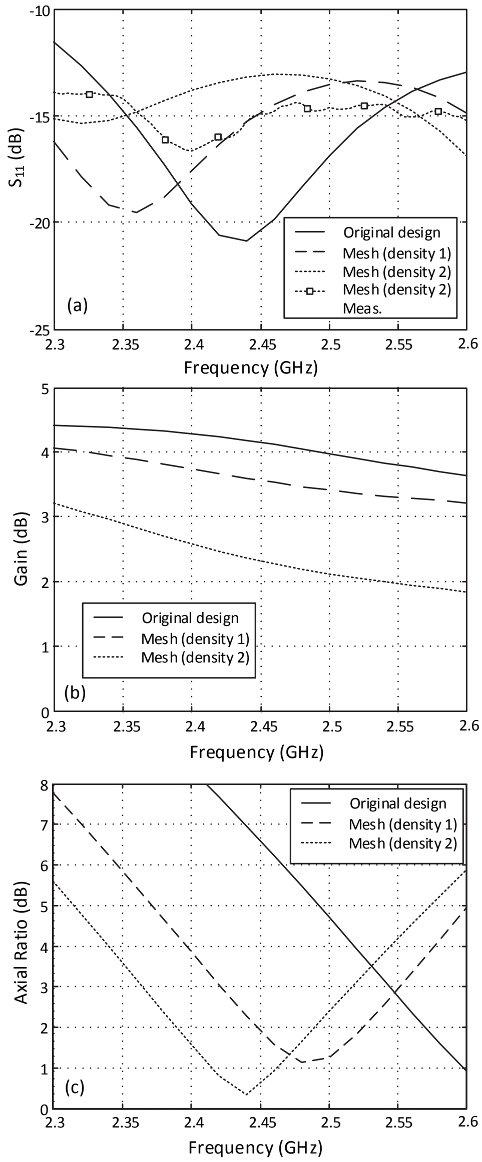

Fig. 2. Performance of the circularly polarized shorted ring slot antenna. (a) Input S-parameters (b) Gain (c) Axial Ratio.

III. Mesh Antenna Structure Optimized for Inkjet Printing

In order to reduce the amount of silver nanoparticles that are needed to print the antenna, a second design is proposed where the ground layer of the antenna is meshed by eliminating certain conductive areas.

Two different designs are presented, which present different densities in the mesh namely mesh density 1 (Fig.3a) and mesh density 2 (Fig.3b). The mesh line width was 2 mm. The design with mesh density 1 covers 41.6 % of the solid ground area, whereas mesh design 2 covers only 29 % of the solid ground area.

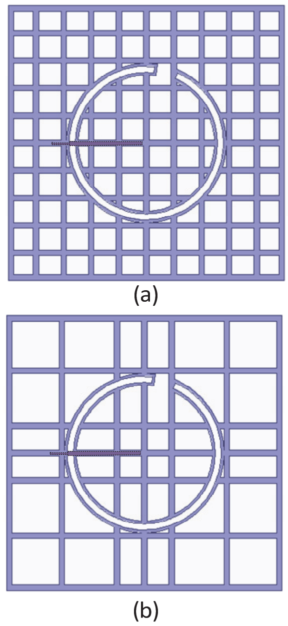

Fig. 3. Shorted ring slot circularly polarized antenna. (a) mesh design with density 1 (b) mesh design with density 2 .

The performance of the meshed designs in terms of input matching, gain and axial ratio are presented in Fig.2. The simulated input S-parameters remain below -13 dB within the 2.4 GHz ISM frequency band. Fig.2b shows that the gain decreases as the density of the mesh reduces. Finally, the axial ratio for the mesh (density 2) antenna was optimized to obtain a minimum value around 2.44 GHz. The mesh structure has a strong effect in the axial ratio frequency performance of the antenna.

The simulated gain radiation patterns in the xy-plane and yz-plane for the two meshed designs are shown in Fig. 4. It should be noted that the feed line is along the y axis.

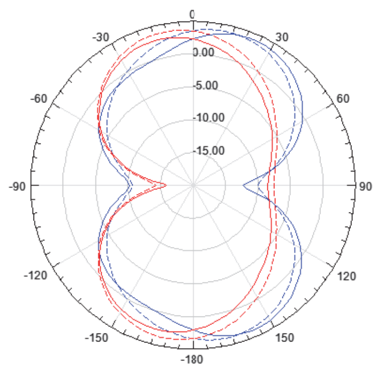

Fig. 4. Simulated gain radiation patterns of the antenna: zy-plane (red), zy-plane (blue), mesh (density 1) dashed line, mesh (density 2) solid line. The antenna feed is along the y-axis.

A prototype was fabricated using a silver nanoparticle ink and a Dimatix DMP-2800 materials inkjet printer. Five layers of silver nanoparticle ink were deposited and the circuit was sintered at 120 deg for 30 m in following fabrication. A photo of the prototype is shown in Fig. 5. The input s-parameters of the antenna were measured and are presented in Fig. 2a, where one can see that the S_{11} magnitude remains below -14 dB within the 2.4 GHz ISM band.

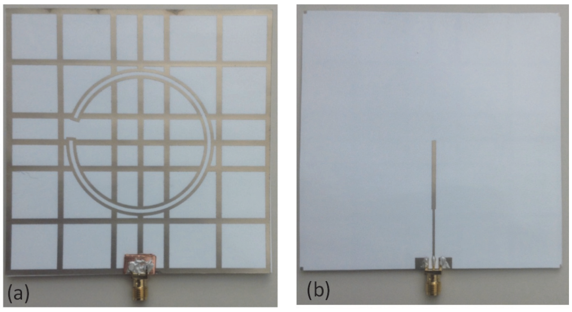

Fig. 5. Antenna prototype, a) top side (meshed ground plane and slot), b) bottom side (microstrip feed line).

IV. Rectenna Design

The proposed mesh (density 2) antenna is selected to design a rectenna element. The selected rectifying element is a low threshold voltage Schottky diode from Skyworks (SMS7630-02LF). The rectenna design is done introducing an L-type matching network between the antenna and the rectifier and placing an output RC filter (Fig. 6). The rectifier is optimized using harmonic balance (HB) simulations in combination with optimization goals on the RF-DC conversion efficiency [4]. The final selected value for the load is 3.3 KOhm.

The input matching of the designed rectifier is shown in Fig. 7a. The RF-DC conversion efficiency of the complete rectenna when the rectifier is receiving -15 dBm is shown in Fig. 7b reaching approximately 45 % at 2.45 GHz.

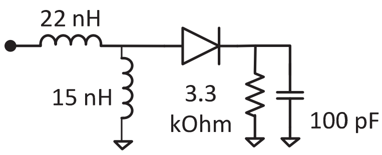

Fig. 6. Rectifier circuit schematic.

V. Conclusion

In this paper a mesh design of a circularly polarized shorted ring slot antenna is presented. The antenna is combined with a rectifier circuit to create a rectenna that can be inkjet printed by using a reduced amount of silver nanoparticles thanks to the mesh topology proposed.

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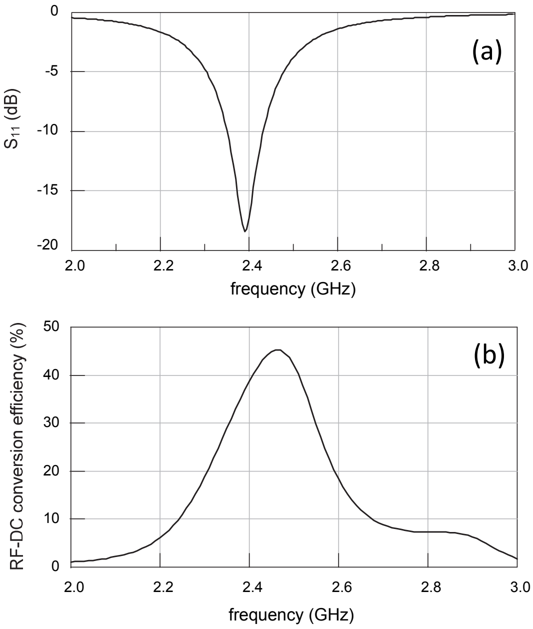

Fig. 7. Rectenna performance (a) S-parameters, (b) RF-DC conversion efficiency.

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