3D Compact Rectenna for Anti-Counterfeiting Application

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***Abstract*— In this paper, a design of a 3D 2.45 GHz energy harvesting circuit also called rectenna is presented. The circuit is made on flexible polyester dielectric allowing 3D rectenna design. The realized circuit dedicated to anti-counterfeiting applications is stacked on wine bottles in order to test the product authenticity. Bending impact on antenna was tested in order to choose the best orientation. The recovered DC voltage for a received power of 0.16mW is 600 mV for a compact rectenna of 18.65 cm^3.**

Keywords—bending antenna, flexible printing, rectenna

I. INTRODUCTION

Communicating objects are spreading everywhere in our daily life. In other words, there is a need for innovative processes and materials for better adaptability and integration of 3D electronic circuits. Furthermore, it is generally interesting that these circuits could be able to communicate at RF frequencies.

For this reason, printed electronics [1, 2] has found a huge success over the past decade. In fact it is a technology allowing the printing on flexible substrates which enables the production of 3D circuits. In addition it is an environmentally friendly process and a low-cost technology. Roll to roll machines are used enabling also a mass production.

The rectenna [3] is an RF power receiver which converts RF to DC power. It is the key element of the free space wireless power transmission which supplies small and low power devices like biomedical implant, sensor networks.

In this paper, both technologies described above are grouped together for the design of a 3D harvesting circuit made on flexible substrate. The intended application is the protection against counterfeiting. The device is pasted directly on a wine bottle in order to check the product authenticity. A planar electrochromic display [4] is connected to the rectenna. When the display recovers enough voltage, its color changes and a code appears which identifies the product.

The first part of this paper describes how the rectenna recovers RF power and converts into a DC voltage. Next, a study of bending antenna is presented. Then, the rectifier is described. Finally, overall simulated and measured rectenna behavior is presented.

II. STATE ATR OF RECTENNA

A typical rectenna configuration is described in Fig. 1. The microwave energy is collected from one or more sources through a receiving antenna. The recovered power is converted into DC power through a rectifier consisting of one or more Schottky diodes, in order to supply low power electronic devices. Zero-bias Schottky diodes are selected thanks to their low threshold voltage, high switching speed and ability to operate at high frequencies. The diode, a non-linear device, generates high harmonic signals on either side of the circuit which affect the performances of the rectenna. For this reason, two low-pass filters on the RF and DC sides are designed. The interest of the low-pass RF filter is avoiding energy losses by eliminating harmonics of higher order modes which are reflected back to the antenna. The DC filter blocks all RF components including the fundamental component at 2.45 GHz. In that way, the remaining RF energy is reflected in the diode to enhance the mixing and consequently the RF to DC conversion of the input signal. An impedance matching network is added between the RF filter and the diode to ensure good matching between both of them for a maximum power transfer.

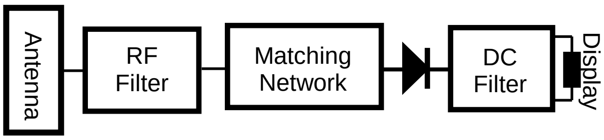

Fig. 1. Classic pattern of a rectenna.

III. IMPLEMENTED ANTENNA

A. Flat Antenna

The proposed antenna is a monopole radiating at Wi-Fi frequency band and folded for the purpose of miniaturization. The used substrate is 0.1-mm-thick Polyester with dielectric constant of 3.3 and dielectric loss tangent of 0.007. The substrate thickness is chosen very thin in order to achieve bended circuits and 3D applications. This property has to be taken into account for the choice of the antenna topology. The microstrip technology for instance is not suitable; the bandwidth of this kind of antennas on a thin substrate is too narrow to cover the Wi-Fi bandwidth. Monopole antenna is so chosen with a partial ground plane as described in Fig. 2. The length of the ground plane is optimized in order to act as a reflector and makes the antenna more directive. The antenna reflection coefficient S_{11} is depicted in Fig. 3. It shows that the antenna is well matched at the working frequency (S_{11} = -22 dB at 2.45 GHz), also the bandwidth of the antenna covers the entire frequency range of the Wi-Fi (2.4 GHz to 2.48 GHz). The antenna is directive. The simulated gain of the antenna is about 5.12 dB. It exhibits an efficiency of -0.64 dB corresponding to 86.2%.

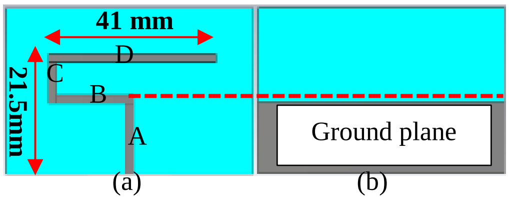

Fig. 2. Antenna structure simulated under CST a) Top view b) Bottom view. A, B, C and D allows the identification of each section of the antenna.

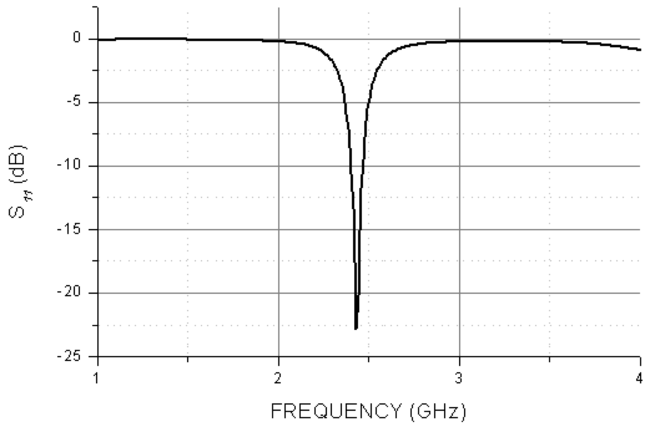

Fig. 3. Reflection coefficient of the monopole antenna simulated under CST.

B. Impact of bending on the antenna performances

In this paragraph, the bending effect of the monopole antenna is investigated for two different geometrical configurations: bending around z-axis (Fig. 4.a) and around y-axis (Fig. 4.b). This is achieved with CST microwave studio.

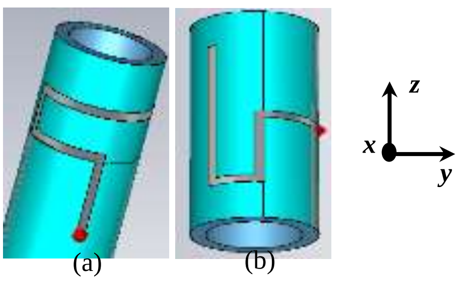

Fig. 4. Bended antennas a) around z-axis b) around y-axis.

The S-parameter plot of the flat and bending antenna in Fig. 5 shows a small decrease of the resonant frequency for both configurations in comparison with the flat antenna. T. Kashiwa already observed this phenomenon in [5]. This shift could be explained as follows: when curving a line, a capacitance is generated between the sections of this line which induces a small shift to lower frequencies. The bandwidth for the three cases remains the same.

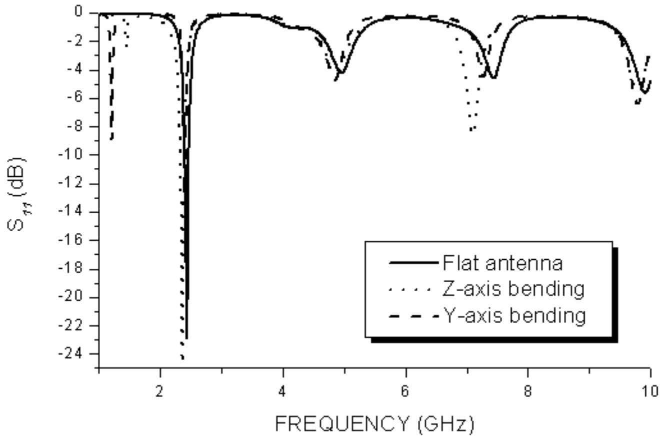

Fig. 5. S_{11} parameters of flat and bended antennas.

Fig. 6 shows the radiation patterns for the three antennas at their resonant frequencies; 2.45 GHz for the flat antenna, 2.41 GHz for the y-axis bended antenna and 2.39 GHz for the z-axis bended antenna. The radiation pattern changes for both bended antennas. The z-axis bended antenna becomes omni-directional. The performed gain is equal to 2.9 dB. This drastic change is a consequence of the curvature of the "D" section of the antenna which is mainly responsible for the radiation pattern of the antenna. Y-axis bended antenna shows a gain level equal to the flat antenna one. Section “D” being flat, the radiation pattern doesn’t change a lot. A shift from 90° to 60° of the main radiation direction has to be noticed, probably due to the influence of the “C” and “A” sections curvature. The bending around y-axis configuration is so chosen for the antenna.

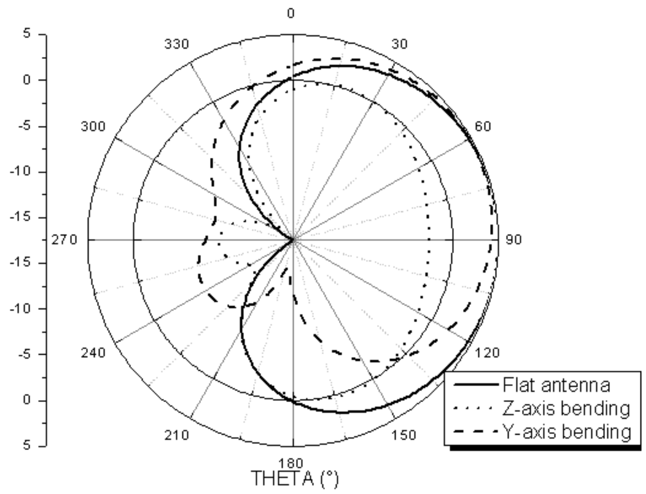

Fig. 6. Far-field radiation pattern of flat and bended antennas.

Reflection coefficient of the bended antenna presents a good matching at 2.45 GHz ensuring a high level of filtering for the three high harmonics. This result allows to eliminate the

RF filter bloc described in the previous paragraph (Fig. 1) as the filter is integrated in the antenna.

IV. MINIATURIZED RF-DC RECTIFIER

The rectifier was designed and optimized under Advanced Design System (ADS) software. The rectifier is composed of two SMS7630 [6] diodes and a display whose impedance is equal to 30 kΩ. SMS7630 is a zero bias Schottky diode, presenting an extremely low barrier height. Two diodes are used in order to maximize the output voltage of the circuit. The two diodes are connected in an opposite way for a full-wave rectifying effect. In order to connect the display to the circuit, two pads are connected to the end of the circuit. Each pad corresponds in high frequencies to a capacitance. Associated to the transmission line that connects the diode to the pads, this forms a low-pass filter (inductance + capacitance). The DC filter can therefore be removed. The lines connecting the diodes to the electrochromic display and to the input enable the matching between each part of the circuit. Fig. 7 shows the rectifier pattern. The dimensions of the circuit are 14.5 mm x 38.5 mm. Simulation results of the rectifier is described in Fig. 8. A voltage of 0.5 V is recovered with an input power of -10 dBm or 100 µW. The rectifier was also bended and simulated thanks to CST software version 2013. No bending effect was observed on the characteristics of the circuits.

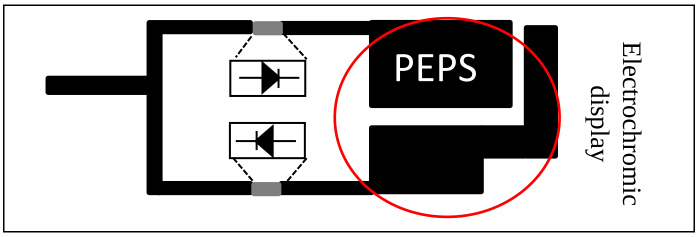

Fig. 7. Layout of the rectifier.

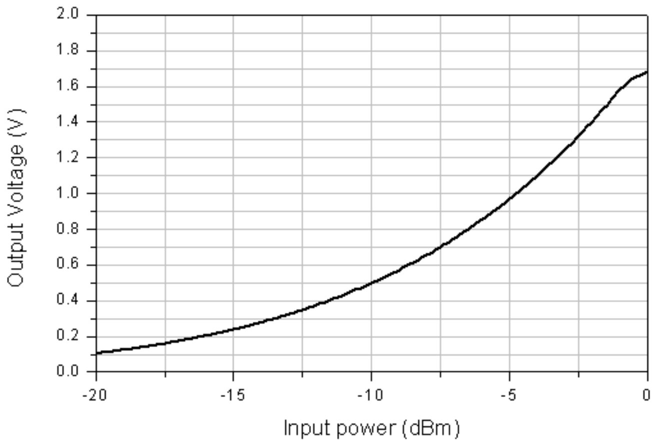

Fig. 8. DC voltage of the rectifier circuit depending on input power.

V. 3D RECTENNA PERFORMANCES

The rectenna was fabricated and pasted on the upper side of a wine bottle. The diameter of the bottle is 25 mm there. As the ground plane of the rectenna doesn't cover the entire circuit, the bottle characteristics were taken into account into simulations. A cylinder glass with a dielectric constant of 4.82 was used. The measurement process is shown in Fig. 9. A 2.5dB gain dipole antenna was used as the transmitting antenna which is connected to a signal generator at 2.45 GHz. A distance of 10 cm is fixed between the transmitting antenna and the rectenna. Fig. 10 shows the measured voltage as a function of the power delivered from the signal generator. The difference between simulation results at the rectifier input and the measurements of the rectenna comes from the losses in the free space between the transmitting and receiving antenna.

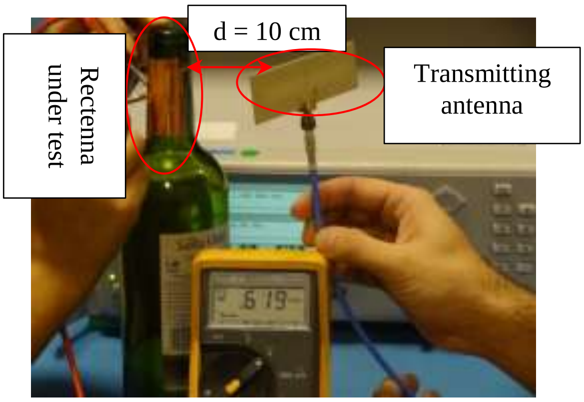

Fig. 9. Photograph of measurement process.

For an incident power of 5 dBm, the recovered voltage is equal to 619 mV. When measuring the rectifier alone, it recovers the same voltage at -8 dBm. This difference of 13 dB has its origins in the propagation losses. Friis equation (1) is used to calculate the power level at the output of the receiving antenna.

$$P_R = P_T + G_T + G_R + 20 \times \mathrm{Log}\left(\frac{c}{4\pi \times d \times f}\right) \qquad (1)$$

Where P_R (-8 dBm) is the power at the input of the rectifier, P_T (5 dBm) is the power generated by the signal generator; G_T (2.5 dB) is the transmitting antenna gain; G_R (4 dB) is the receiving antenna gain and d (10 cm) is the distance between the transmitting antenna and the rectenna. The calculated power from Friis equation is equal to -8.7 dBm. Theoretical and measurement results fit well.

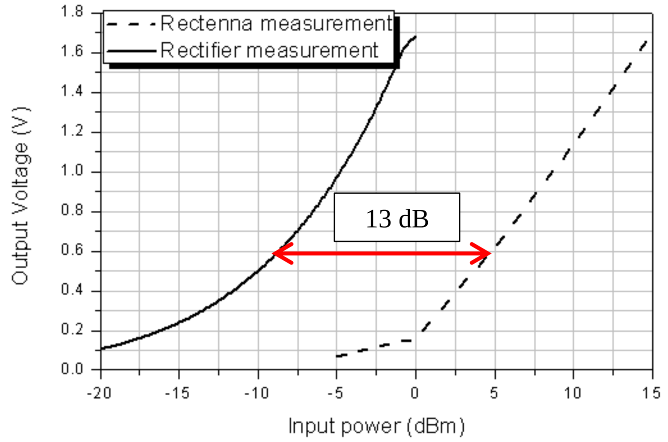

Fig. 10. Measured DC voltage of the rectenna.

To highlight the application and the interest of this circuit concerning the fight against fraud, a smartphone, operating on Wi-Fi mode and configured to send at high-baud rate, is used to send RF power to the receiving antenna. The rectenna, thanks to the two diodes, converts RF power to DC power. To perform the measurement, the device under test is placed in front of the Smartphone at a distance of 2 cm and is connected to a voltmeter to measure the output voltage across the display. Fig. 11 describes the measurement process. The voltmeter measures 1.9 V.

Fig. 11. Photograph of measurement process

VI. Conclusion

A design of a 3D compact flexible rectenna is presented in this paper. The realized circuit is bended on wine bottle for anti-counterfeiting application. The best orientation of the antenna was chosen taking into account the effect of the bending on its characteristics. The recovered DC voltage for a received power of 0.16 mW is 600 mV for a compact rectenna of 18.65 cm^3 at the state of the art of this type of RF structures.

Future work will focus on the use of conductive ink instead of copper with trying to keep the same performances.

Acknowledgment

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