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Connected Objects with Optical Rectenna for Wireless Information Systems

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Abstract—Harvesting and transport of optical and radiofrequency signals are a topical subject with multiple challenges. In this paper, we present a Optical RECTENNA system. We propose here a hybrid system solar cell antenna for 5G mobile communications networks. Thus, we propose rectifying circuit. A parametric study is done to follow the influence of load resistance and input power on Optical RECTENNA system performance. Thus, we propose a solar cell antenna structure in the frequency band of future 5G standard in 2.45 GHz bands.

Keywords—Antenna, Rectenna, solar cell, 5G, optical RECTENNA.

I. Introduction

In recent years, wireless communications systems are continuously growing, which leads to the use of large number of mobile equipment. So, we are facing the energy feeding problem. The RF and solar energy harvesting is one of the emerging technology allowing to solve the power problem feeding. Powering wireless communications systems from environmental energy sources is a very promising solution to improve their energy independence. Among the recoverable energy sources, electromagnetic and solar waves are considered to be the most promising due to their availability in our environment (Fig. 1). This vision gave birth to an RF/DC conversion system which is currently called ”Optical RECTENNA”. RECTENNA or a rectifier antenna is a system that to collects and to convert RF and solar signal to DC current.

The Rectenna is composed essentially by a receiver antenna that captures the RF and solar waves from free space and a rectifying circuit. The harvesting energy system is based mainly on the receiver antenna choice since it is a fundamental element that has the strong geometric controls in the Rectenna. In the context of RF energy harvesting, several designs have been proposed. The first design of Rectenna was started with W.C. Brown [1]. The obtained conversion efficiency was around 90.6% with an input power of 8 W. He had used an aluminum dipole antenna and a Schottky diode associated with a transmission line, the same research team have obtained Rectenna operating at 2.45 GHz [2]. The obtained rectifying efficiency reaches 85%. Another Rectenna system is developed using a patch antenna fed by an input power of 120 mW at 3.5 GHz. The efficiency is measured as a function of the input power for a fixed load resistance of 100 Ω [3].

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Fig. 1 Different radiating sources

II. Reserved Frequency Bands for 5G

The 5G is a telecommunications technology has been actively investigated all over the world. This technology is different from previous generations, 5G should not only outcome in the deployment of new frequency bands. The 4G goes through the use of three bands 800, 1800 or 2600 MHz bands. Indeed, the 5G will need spectrum in these three bands to satisfy needs of all users and for achieve optimal coverage. Also, frequency ranges are those below 1 GHz, between 1 GHz and 6 GHz and above 6 GHz [4]. Concerning the data distributed in the frequency range below 1 GHz, the European Union has been officially declared that 700 MHz band it will be among the reserved bands for 5G.

Concerning the frequencies distribution below 1 GHz, such as the 700 MHz band, it has been officially declared by the European Union that it will be among the reserved bands for 5G. This band is considered a gold one thanks to its best ability in buildings penetration more than its better coverage when compared to bands greater than 1 GHz [5].

The frequencies distribution in the spectrum range between 1 GHz and 6 GHz possesses a logical mix of both coverage and capacity for 5G services such as the band of 2.6 GHz and which 3.5 GHz well be appropriated and used for 5G [6]-[8]. Moreover, these two bands can be used for connected objects networks, mobile networks, connected objects networks or the provision of fixed internet in rural areas [9].

The use of frequencies bands above 6 GHz ensure global coverage of the territory. So, these high frequencies are well known around the world as the key of 5G's ultra-fast services since in their absence, 5G will not be able to provide much faster data speeds or support the expected growth of the marked increase in mobile traffic [4].

III. Rectenna Global Structure

The optical Rectenna system consists of the recovery of electromagnetic and solar energy. Its principle is to harvest energy from free space and convert it into DC voltage. It is composed of a antenna that captures microwave and solar energy and transmits it to the conversion circuit, as shown in Fig. 2. The rectifier circuit converts the energies into a DC voltage usable by the resistive load RL. The rectifier circuit is essentially composed of a HF low-pass filter, a DC filter and a DC load circuit. The HF low-pass filter fulfills two tasks: it blocks the harmonics generated by the schottky diodes and it realizes the impedance matching between the antenna and the rectifier. On the other side of the rectifying circuit, there is a DC filter, it is a low pass filter which ensures the impedance matching between the conversion circuit and the resistive load.

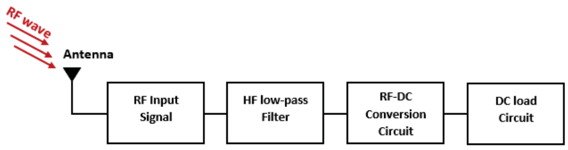

Fig. 2 Global structure of a Rectenna system

A. Rectifying Circuit

The Rectifying Circuit is a voltage doubler has been simulated. The measure of magnitude of voltages can be done using Harmonic Balance (HB) method (Fig. 3). This circuit consists of 4 diodes HSMS-285B, 4 capacitors 80 pF and load resistor with value of 10 KΩ. Obtained results are present in Fig. 4. The output voltage obtained is 1.9 V with the input of 0.126 V.

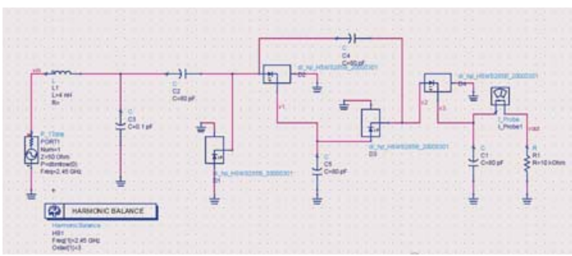

Fig. 3 Schema of the rectifier Circuit

The main target of optical rectenna is to improve the conversion efficiency. The circuit rectenna efficiency can be investigated as:

$$\eta = \frac{P_{DC}}{P_{RF}} = \frac{V_{DC}^2}{P_{RF}.R_L} \quad (1)$$

where P_{RF} is the input RF power received by the receiver antenna, P_{DC} is output DC power, R_L is the resistive load and V_{DC} VDC is the output DC voltage.

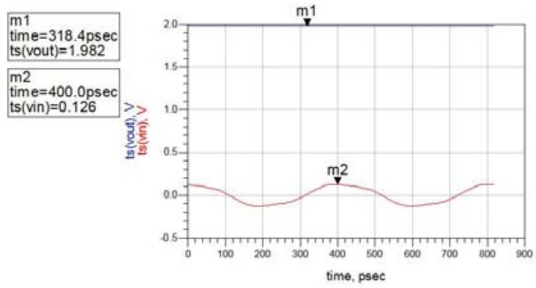

Fig. 4 Two stage voltage multiplier output

Fig. 5 shows the dual stage voltage multiplier topology gives an optimum conversion efficiency in order of 39.2% for a load resistance of 10 kΩ and an RF input power of 0 dBm. In the other hand, we present in Fig. 6 the conversion efficiency as a function of RF input power in the range of -20 dBm to 20 dBm. The load resistance is fixed to be 10 kΩ. This efficiency reaches the maximum value of 56.03% for a load resistance of 10 kΩ and an RF input power of 5 dBm.

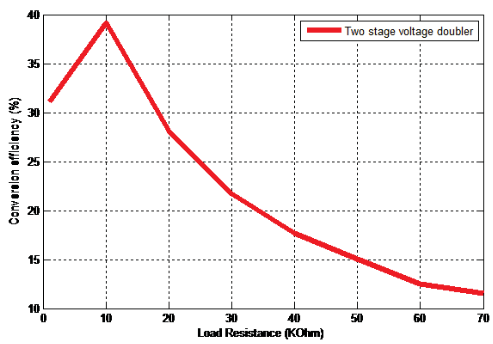

Fig. 5 Conversion efficiency as function of load resistance

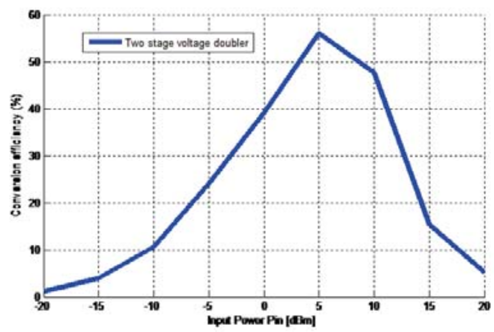

Fig. 6 Conversion efficiency as function of input RF power

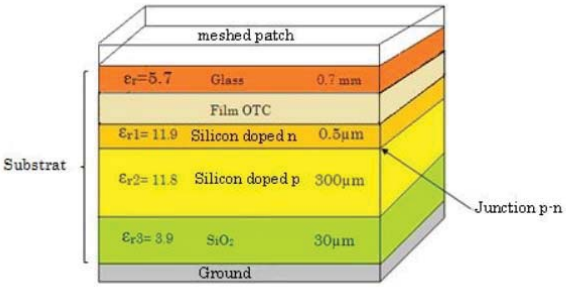

Fig. 7 Multi-layered substrate of solar cell antenna

B. Meshed Solar Cell Antenna Structure

We propose in this paper a solar cell antenna for 5G standard, future generation of mobile network. We propose an optically transparent mesh antennas [10]-[15]. The designed structure used here is a printed solar cell antenna with a substrate containing different layers of three major components: an insulating layer SiO_2 which realized a low power consumption and insensitivity, an ability to operate at low voltage, a higher operating frequency. The cathode and anode layers are respectively aluminum and silver (Fig. 7).

We propose an optically transparent mesh antennas (Fig. 8). The antenna dedicated to the frequency band of 2.45 GHz are studied to test the parameters of the proposed solar cell antenna, such as the reflection coefficient S11, gain, directivity and radiated power.

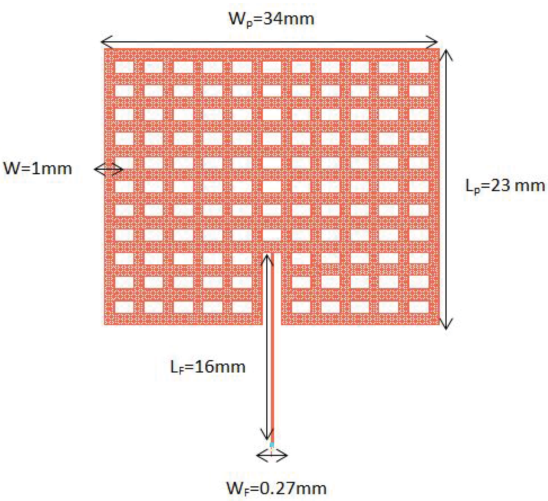

Fig. 8 Solar cell antenna for 2.45 GHz

The solar cell antenna was simulated and the result obtained of reflection coefficient S11 is presented in Fig. 9. In antenna theory, such as patch antennas, an antenna should be a perfect radiator rather than a perfect absorber. The result of the simulation show that the solar cell antenna designed at 2.45 GHz with S11 = -46.4 dB can be used for digital satellite communication systems.

When designing solar cell antenna, the gain must be taken into consideration since it is a very important metric. The good values of VSWR and S11 are not enough to confirm a good radiation. Fig. 10 shows the gain radiation diagram for 2.45 GHz. In other words, a gain of 4.9 dBi is obtained at 2.45 GHz.

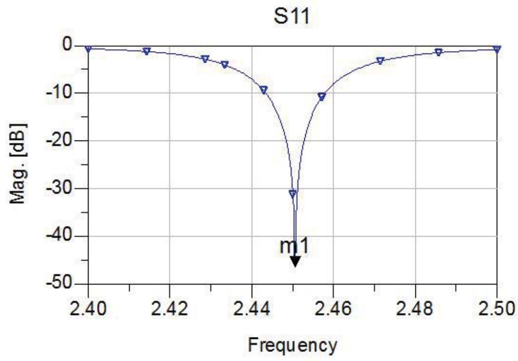

Fig. 9 Parameter S11 for 2.45 GHz

Fig. 11 shows the radiation diagram in the plane E and H for 2.45 GHz frequency. This reflects a very directive radiation by offering a total directivity of 6 dB at 2.45 GHz. This allows the antenna to be used especially in point to point transmission systems.

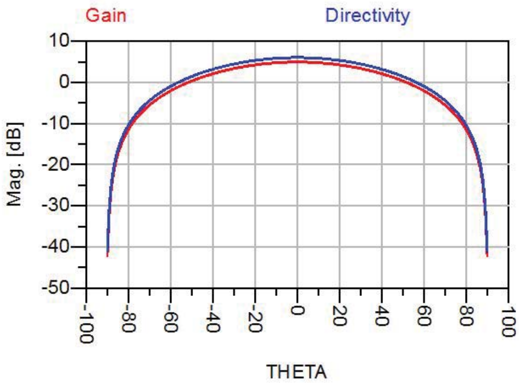

Fig. 10 Gain and directivity for 2.45 GHz

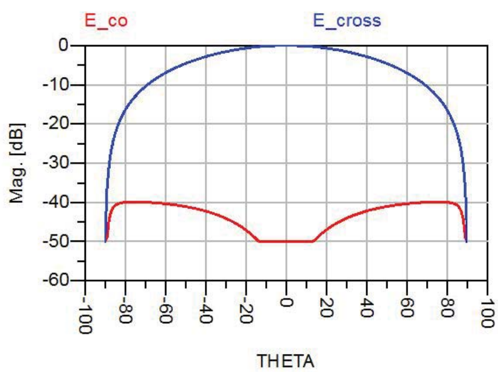

Fig. 11 Far field radiation pattern in E plane for 2.45 GHz

IV. Conclusion

In this work, we have presented a Optical RECTENNA system for energy harvesting and RF transmission for the future standard 5G. We have proposed antenna design and rectifying circuit for a rectenna system. This is optically transparent meshed solar cell antenna printed on a multilayer substrate such as glass which is a totally transparent layer, an OTC film with conductive and transparent properties and semi-transparent silicon layers. Good results of simulation are obtained, such as the gain, the electric power collect, the directivity and the reflection parameter.

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