Butterfly design mesh antenna of optical rectenna for S-band communication systems

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ABSTRACT

A novel optical rectenna design is presented in this paper to operate in S-band communication. We propose a new method of combining antennas and solar cells to collect and transmit optical and radio frequency signals respectively. In this work, we determined the electrical power collected, it can be used for the polarization of a diode or a low-noise amplifier in a receiver block thus simulation results provides a gain of 6.74 dBi at 2.9 GHz with an effective return loss of -33.62 dB and radiated power of 7.08 mW. These good results make it possible to use the antenna particularly in point-to-point communication systems. A three topologies of rectifying circuits are proposed in the present work. The parametric study has been shown that the efficiency RF/DC conversion can reach 66% for an input power of 10 dBm and a load resistance of 3 kΩ.

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1. INTRODUCTION

Recent years, the energy feeding problem for many communications systems can be solve by the RF energy harvesting and conversion into direct current. Rectenna, or a rectifying antenna as it is popularly known, is one such means of technology for recovering that energy. The antenna choice, an essential element, for rectenna system is very important. The development of space telecommunications controls and remote controls, have led to the growing need for inexpensive and space-saving antennas using simple and cost-effective technology [1]. It is therefore desirable to design devices that can harvest energy from their environment by reducing the load on the power grid and reducing operating costs [2].

Recently, integrated communication systems with photovoltaic technology for low cost and stand-alone applications have received a lot of attention. The integration of microwave antennas and solar cells offers a number of advantages for satellite and terrestrial applications [3]. A stand-alone remote base station is such an application where PV technology can be used. But these devices often involve the use of solar cells and separate antennas, which necessitates a compromise in using the limited available surface. The integration of the base station antennas with the photovoltaic cells can provide a compact and reliable solution [4]. Rigorous analysis is always desirable to design antennas in the energy harvesting environment to maintain the desired overall performance of the dual-function system of energy harvesting and RF transmission simultaneously [5].

2. SOLAR CELL ANTENNA
2.1. Basic considerations
Many methods to realize high-performance antennas integrated with solar cells have been studied, but the problem of surface limitation has not resolved with the method of integration [6-8]. These return to the solar cell placement above the antenna element or underneath the antenna element. The minimization of blocking of the solar radiation and the maximization of the solar efficiency are due to the location of the solar cells above the elements of the antenna. A complicated power supply structure to isolate the RF and DC outputs that may be difficult to produce at low pressure and costly is required.

Otherwise, the location of the solar cells under the antenna elements reduces solar efficiency, but can improve the RF performance of the antenna. In this case, where we focused our study between minimizing reduction in solar efficiency and improving RF performance. Therefore, in order to remedy the problem of surface limitation, here we propose a new type of solar cell antenna with a mesh patch printed on a silicon substrate with an SiO_2 insulating layer, it is an optically transparent hybrid system. A higher operating frequency, an ability to operate at low voltage and low power consumption and insensitivity to the effects of ionizing radiation can be obtained when we used the silicon on an insulating layer SiO_2.

It is not a integration of patch antenna with a solar cell. The method used here it is a hybridization of solar cell antenna utilize to combine both microwave and optical signals. This method solves the major problem of surface limitation, compared to a simple integration, with good performances DC and RF [9-11].

2.2. Optimal design
The main goal of optimal design for this solar cell antenna has been studied to minimize the power losses of the solar cell antenna and improve the conversion efficiency as a solar cell. We determine the maximum electrical power collected as a function of finger width and the optimal finger width W_f has been used for the design of the meshed patch [12]. Two types of waves can exist with this mesh structure. The optical waves that will be absorbed by the silicon (semiconductor) and the RF waves that will be collected by the mesh patch metal. Table 1 show the dimensions of the proposed design. The proposed structure of solar cell antenna printed on a multi-layered substrate show in Figure 1. While the proposed design of solar cell antenna is given in Figure 2. A microstrip line of characteristic impedance equal to 50 Ω is used to power the proposed solar cell antenna. The simulation complexity and the high computation time are due to the use of substrate with thin films.

Table 1. The dimensions of the solar cell antenna

Parameters	Values
W_b	0.5mm
W_f	60µm
L	18.2mm
W	0.235mm

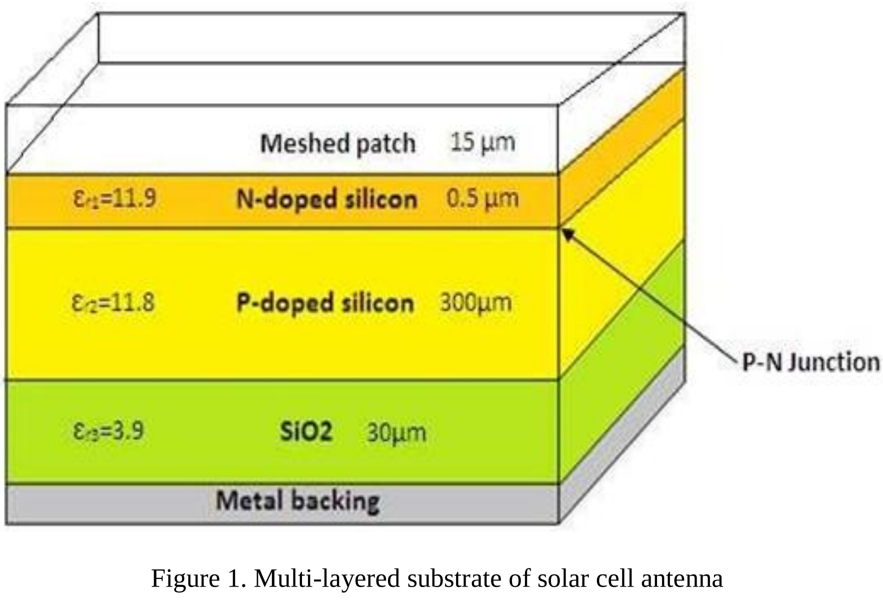

Figure 1. Multi-layered substrate of solar cell antenna

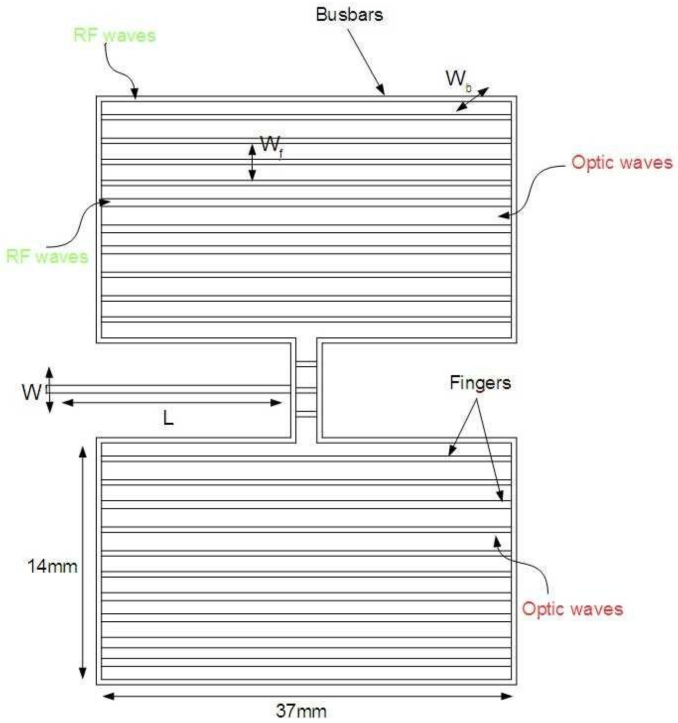

Figure 2. Solar cell antenna design

3. RESULTS AND DISCUSSIONS

The simulation results show that this designed solar cell antenna can be used at 2.9 GHz with an effective return loss of $S11 = -33.62\ dB$ as shown in Figure 3. To the normal scale, only 0.043% of the emitted power will be reflected as well as the impedance Z_a = 49.6 Ω which confirms the adaptation of the antenna. Thus to evaluate this adaptation, the VSWR is a important parameter of performance measurement at the input of the antenna must be studied. This is indicates the signal reflection due to a mismatch between the impedance of the antenna and that of the source. The reflected signal leads to the appearance of the standing wave voltage in the power supply line which, in turn, destroys the reliability of the antenna [13]. For this solar cell antenna, the obtained VSWR is equal to 1.008. The ideal value of VSWR is 1 which means that 100% of the delivered power is accepted (no reflection). But, practically speaking, it is tolerable up to 2.

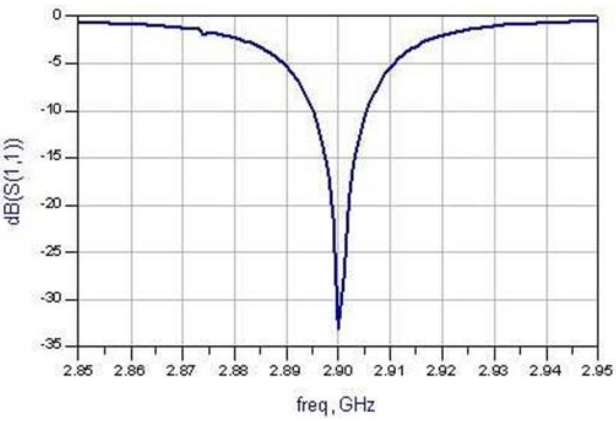

Figure 3. Reflection coefficient S11

To have a good radiation, the correct values of S11 and VSWR are not sufficient. An important metric must be taken into account when designing an antenna, and that is gain. The radiation pattern in the horizontal plane and the radiation pattern in the E and H plane are given in Figures 4, 5(a) and 5(b), respectively. Since it is a symmetrical structure, the radiation of our antenna is collected in two main lobes whose amplitude is much higher than that of the lateral lobes which are practically nil, and which have a wide beam width at -3 dB. The total directivity of this highly directional radiation at 2.9 GHz is 8.12 dB, and the antenna gain describes the energy transmitted to that of an isotropic source along the direction of the radiation peak. The values obtained of the radiated power and of the gain are 7.08 mW and 6.74 dBi respectively is shown in Figure 6. These good results make it possible to use the antenna in particular in point-to-point transmission systems.

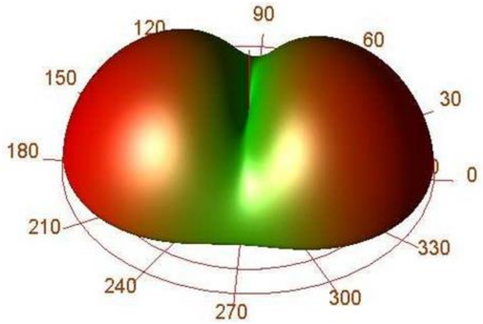

Figure 4. Radiation pattern

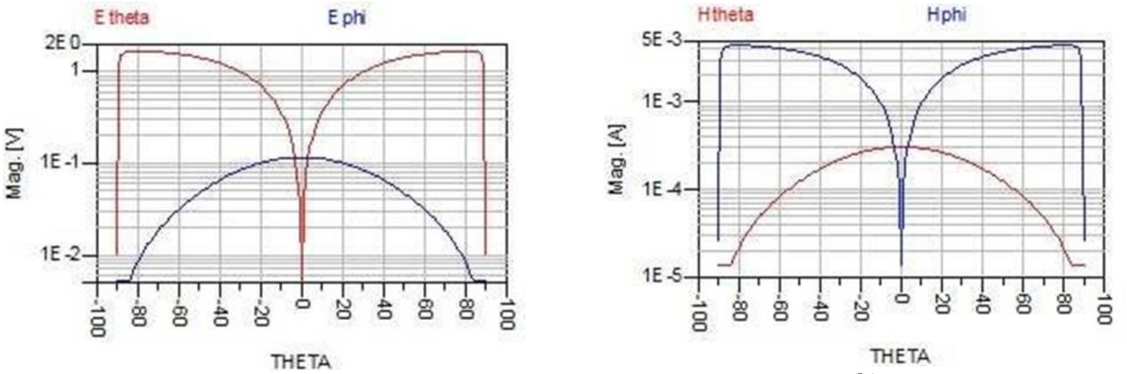

Figure 5. Far field radiation pattern, (a) in E plane, (b) in H plane

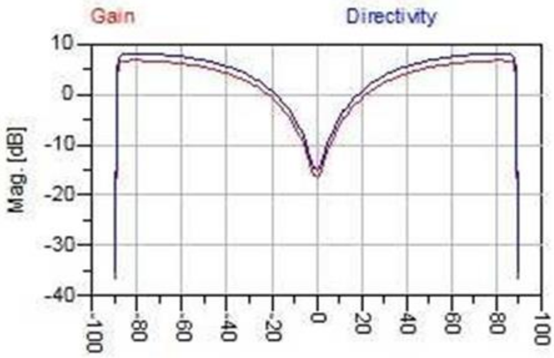

Figure 6. Directivity and gain

We propose an RF/DC decoupling circuit for solar cell antenna illustrated in Figure 7. The RF signals must be decoupled from the DC signal, they must not be interfered. Figure 8 shows the obtained result.

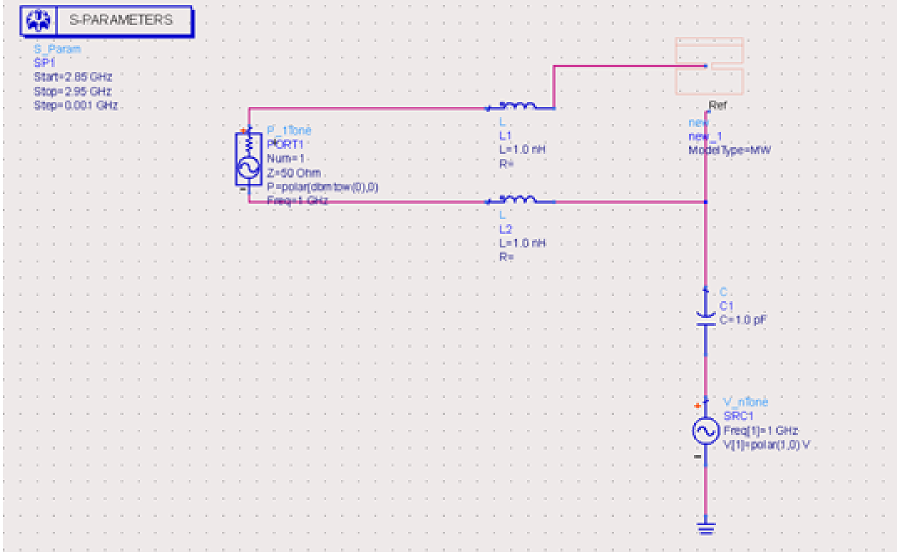

Figure 7. RF/DC decoupling circuit proposed

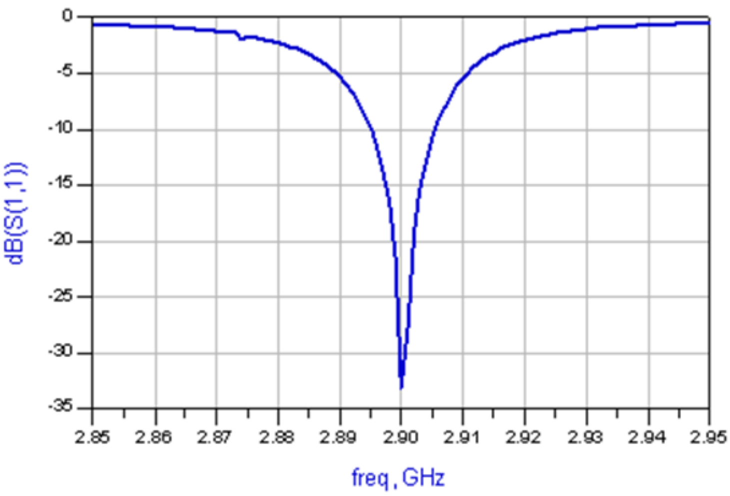

Figure 8. Simulation result of parameter reflection S11

4. RECTENNA GLOBAL STRUCTURE

The main role of a rectifying antenna, or rectenna as it is popularly known, is to recolt, from free space, RF waves and convert it into direct current [14-18]. In this work, we studied a optical rectenna based on a solar cell antenna dedicated to energy harvesting and RF transmission at the same time. The optical waves will be transmitted in the form of DC signals and the electromagnetic waves will be divided into two parts, one part contains the transmitted data and the other non-usable will be filtered, by a bandpass filter allowing only one band to pass or frequency interval between [2.895 GHz-2.905 GHz], and converted by the rectifier circuit into DC signals, as shown in Figure 9. The conversion circuit converts the part not usable from RF waves into a DC signal. A HF low-pass filter, a RF-DC conversion circuit and a DC load circuit composed the chained of rectifier circuit. The function of the high frequency low pass filter is: on the one hand, it avoids the harmonics generated by the Schottky diode; on the other hand, it performs the impedance matching between the antenna of the solar cell and the rectifier. On the other side of the conversion circuit, there is a DC filter whose principle is to ensure the impedance matching between the rectifier circuit and the resistive load, it is a low pass filter [19-25]. Single stage voltage multiplier, two stage voltage multiplier topologies and series topology, shown in Figure 10, are three different rectifier topologies proposed in this work.

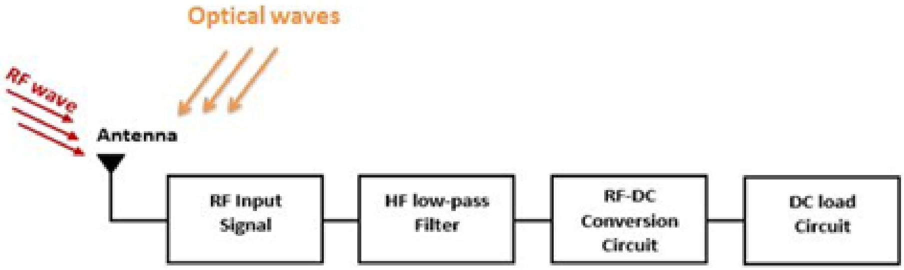

Figure 9. Global structure of optical rectenna system

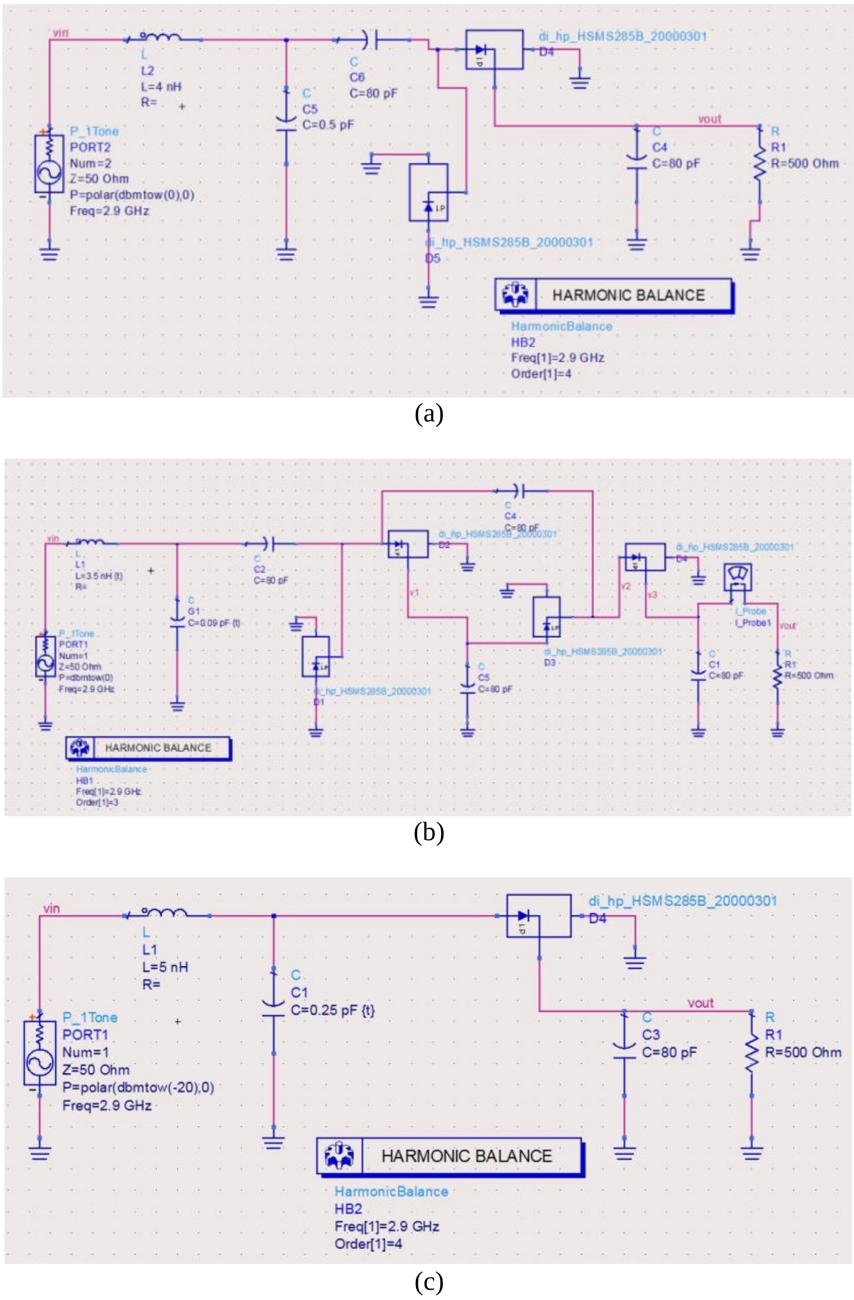

Figure 10. Rectifier circuit topology, (a) single stage voltage multiplier topology, (b) two stage voltage multiplier topology, (c) series topology

The main objective of the rectenna optical system is to improve the efficiency of converting RF waves into direct current. The performance of the rectenna can be studied as:

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

With
P_{RF} : Input RF power
P_{DC} : Output DC power
R_L : The resistive load
V_{DC} : Output DC

For a fixed RF input power in the order of 0 dBm, we investigated the influence of the resistance load value on the conversion efficiency. For a load resistance of 500, the series topology can provide the best conversion efficiency of about 49.8%, as shown in Figure 11. Under the smallest load resistance of 1 kΩ, the best efficiency of the single-stage voltage doubler topology is 28.27%. However, the existing two-stage voltage multiplier topology can achieve a higher DC output voltage of up to 1.158 V.

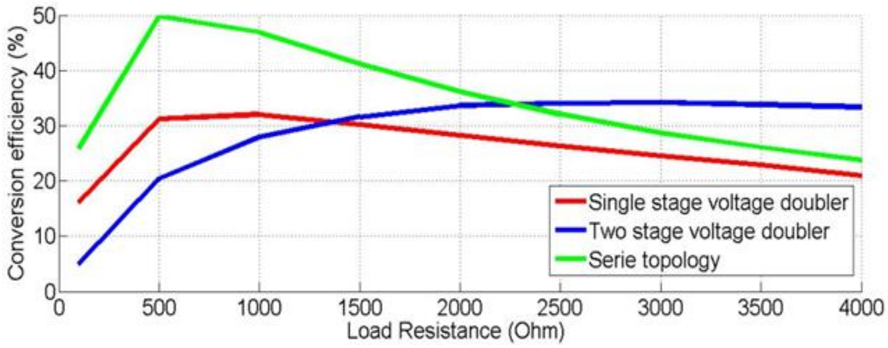

Figure 11. The relationship between the conversion efficiency of different rectifier topologies and the load resistance

Figure 12 shows the relationship between the conversion efficiency of different rectifier topologies and the RF input power. We have fixed the value of the load resistance at 500 Ω. We have noticed that the best conversion efficiency that can be obtained with a two-stage voltage multiplier topology is -20 dBm to 20 dBm. For an RF input power of 5 dBm and a load resistance of 500 Ω, this efficiency reaches a maximum of 90%.

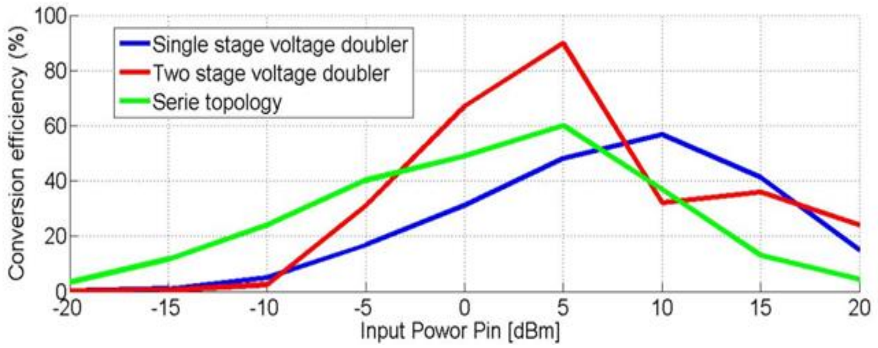

Figure 12. The relationship between the conversion efficiency of different rectifier topologies and the input RF power

5. CONCLUSION

In this work, we presented a optical rectenna with a solar cell antenna dedicated at a time to energy harvesting and RF transmission. This method allowed us to evaluate the performance of a new model of combination solar cell and antenna which is very advantageous and practical. We conclude that a solar cell antenna of linear structure is more efficient, as a solar cell (maximum electric power collected) or as an antenna (gain, directivity, radiated power...), compared to that of a crossed structure which we have already studied in another work. On the other hand, three topologies of rectifier circuits for rectenna optical systems have been proposed. The results show that the best conversion efficiency can be obtained using the two-stage voltage doubler rectification topology, which is 66%.

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