Design of a Compact Solar Cell Meshed Antenna for WLAN/WIMAX Application

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ABSTRACT Patch antenna is a low-profile antenna that has a number of advantages, low cost, light weight, easy to feed and their attractive radiation characteristics. For a WiMAX communication system, a patch antenna which operates at 2.76 GHz frequency band was presented in this work. The hybrid system solar cell antenna allows energy recovery as well as RF Transmission. A simulation process, with MATLAB, is used to determine the electrical power collected by the studied system as a photovoltaic cell. As a antenna, parameters such as directivity, gain, radiation pattern and radiated power were studied. Simulation results, showed a resonance frequency of the antenna at 2.76 GHz with a reflection coefficient of -18.64 dB and a gain of 6.58 dBi. Thereafter, an optical rectenna with a solar cell antenna was proposed and studied.

INDEX TERMS Pactch antenna, Solar cell, RF, DC, WLAN/WiMAX

I. INTRODUCTION

THE advancement in the wireless communications is more improved in recent years compared to the past. Since antennas are key elements of wireless communication systems. Many microstrip antennas may be used in a variety of ways to improve the performance of communication systems. Due to their various advantages [1], patch antennas are popular in wireless communication. When combined with solar cells, can provide compact and reliable autonomous communication systems, which can be used for many applications. Autonomous solar energy communication systems have received considerable attention due to their ability to operate without the need to be connected to an electrical grid. A significant challenge especially for powered communication systems in remote places where the electricity grid is not available can be presented. The use of photovoltaic in communication systems has been recently the subject of much research [2]–[4], in order to reach this challenge.

Solar cell and microstrip antenna are two separate devices, when their first use in satellite communication. They compete for the available space on satellite which is generally limited in size. Thus, they can be bulky and expensive and limit the possibilities of product design. Integrating solar cells with patch antennas into a single multifunctional device has the potential to offer numerous volume, weight, intelligent appearance and electrical performance benefits for many applications [5-8].

II. APPROACH

We propose here a solar cell antenna with mesh patch. Based on a mathematical model that we have already studied [9-10] to minimize the power losses of the solar cell antenna and improve the conversion efficiency as a solar cell. Optimization of the electrical power collected maximum as a function of finger width was determined.

The optimal width W_f has been used for the design of the mesh patch or front face collection grid. Improving the performance of a solar cell depends not only on the materials and structure but also on the design of the grid metal front face. The solar cell antenna structure proposed is given in Fig. 1.

For this mesh structure, two types of waves can exist. Both optical waves, absorbed by the silicon (semiconductor), and the RF waves, collected by the mesh patch metal whose width of fingers W_f, will be optimized. The designed structure was a solar cell antenna printed on a multi-layered substrate as shown in Fig. 1.

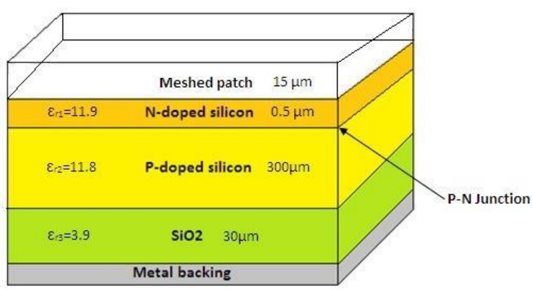


FIGURE 1: Multi-layered substrate of solar cell antenna.

The silicon of an insulating layer SiO_2 confers to the realized components, a higher operating frequency, an ability to work at both low voltage and power consumption with an insensitivity to the effects of ionizing radiation. When using a thin-film substrate we observe that the simulations become more complex and time consuming.

A. GEOMETRY OPTIMIZATION OF SOLAR CELL ANTENNA

Due to the contradiction between photovoltaic demands and antenna requirements, the integration of the solar cell and the antenna requires special approaches. For example, the size of the patch is important for determining the resonance frequency of the solar planar antenna. Therefore, the RF optimization criteria also affect the usable area for the conversion of solar energy [10]–[16].

The radiating patch is the main element of a microstrip antenna. In addition, an antenna consists of a dielectric substrate (in this case it is amorphous silicon a-Si) on which is deposited this patch and a fully metalized ground plane. The patch is usually made of a conductive material such as copper or gold and can take any shape possible. In this work, it is a hybrid structure will be dedicated to both energy harvesting and RF transmission. In this structure, the substrate consists of a silicon PN junction under which a SiO_2 silicon dioxide layer, the radiating element is a mesh patch as well as its feed line, and the ground plane is completely metalized. The mesh patch form allows both the absorption of photons by the silicon semiconductor and subsequently the collection of a photo-generated current and an adequate electrical power as a solar cell and the radiation. Electromagnetic as an antenna. This is our new hybridation method of a solar cell and a patch antenna in a single compact system.

The problem consists of two main parts. The first one concerns the choice of the grid structure. However, there is no general mathematical method for forecasting better shape [1]. The second step is the chosen structure optimization. This optimization is focused on the determination of electrical power collected as a function of the width of the metallic lines constituting the radiating patch. This width is the most important parameter in our study. Theoretically, it must not be wider in order not to decrease the transparency of the patch as well as the decrease in photon absorption and the photo-generated current collection and electrical power, and on the other hand this width must not be thinner to allow good radiation as an antenna [17]–[23].

We propose, in this case, a model whose design is shown in Fig. 2. The unit consists of two fingers and n collectors for Ox axis of symmetry (Fig. 3). The radii r_1, r_2, r_3, n is an arithmetic progression of first term r_1 and r_1 reason.

The power that should be provided without loss in a pattern is given by:

$$P_f = V_m J_m n^2 r_1^2 \tag{1}$$

with :

J_m : Surface current density.

V_m : Voltage supplied by the cell.

n : Number of collectors.

r_1 : Radius (mm).

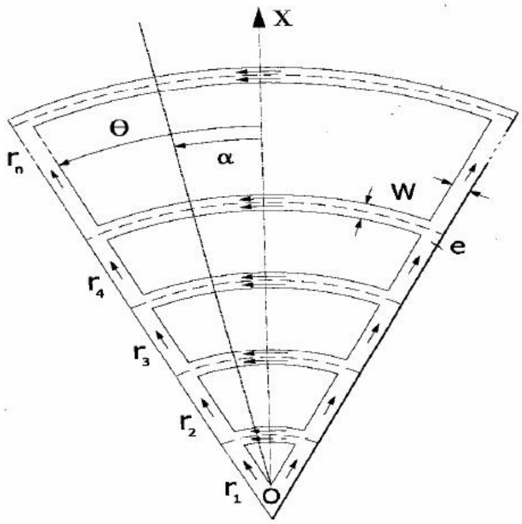


FIGURE 2: Design a circular grid.

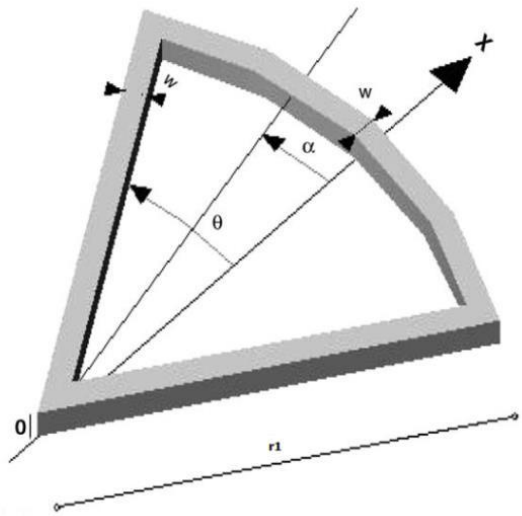


FIGURE 3: Design a circular grid.

An optimal design of proposed mesh patch structure is based on the determination of different power losses that they generate. Power losses caused by each mechanism of the studied structure are given by the following equations. In this section, we calculate the fractional loss of power contributing to power loss; this is defined as the power loss in a given area, divided by the power input cell.

P-junction of substrate (base) caused a loss of power as follows:

$$P_b = J^2 R_b L^4 \tag{2}$$

with

$$R_b = \frac{\rho_b W_b}{L^2} \tag{3}$$

R_b: Resistance of the base (Ω).

ρ_b: Resistivity of the transmitter(Ω/cm).
W_b: Thickness of the base (cm).
L: Length of the square cell (cm).
Power loss of the resistance of the front layer:

$$P_1 = \rho_s(\frac{J^2 m a^2 (1+b)\theta^3}{24}) \tag{4}$$

$$a = 2n^2 r_1^2 + Wn(1-n)r_1 + \frac{W^2}{4} \tag{5}$$

$$b = \frac{n(n-1)r_1 - W(n-1)}{2(r_1 - W)} \tag{6}$$

ρ_s: Resistivity of the transmitter (Ωcm).
W: Finger width (μm)
θ: Angle (°)
Power losses caused by the metallization of the grid:

$$P_2 = \rho_m r_1^2 \frac{J^2 m \theta^2 n^5}{5We} \tag{7}$$

ρ_m: Metal resistivity (Ωcm) .
e: Finger thickness (μm).
• Bus bars

$$P_3 = \frac{2}{3}\rho_m \frac{J^2 m \theta^3}{We} \sum_1^n (r_K^5) \tag{8}$$

Power loss due to contact metal/semiconductor:

$$P_4 = \rho_c \frac{J^2 m r_1^2 n^3 \theta^2}{2Wr_1 + W\theta(n+1)} \tag{9}$$

ρ_c: Resistivity contact front face(Ωcm^2).
The metallization surface is:

$$S_m = 2nr_1 W + W\theta(n+1)nr_1 \tag{10}$$

Hence the optical loss due to this surface metallization:

$$P_5 = J_m(2nr_1 W + W\theta(n+1)nr_1)V_m \tag{11}$$

$$P_t = P_1 + P_2 + P_3 + P_4 + P_5 \tag{12}$$

The power collected by the cell is therefore written:

$$P_{col} = P_{ecl} - P_t \tag{13}$$

with:
P_{ecl}: Cell lighting power.
P_t: Total power dissipated.

TABLE 1: Parameters used for the simulation of the calculation of the total losses of the photovoltaic cell on the front face.

Symbol	Description	Values
L	side of the square cell	15mm
J_m	surface density of the current	$0.03A.cm^{-2}$
ρ_b	base resistivity	$0.6\Omega/cm$
W_b	thickness of the base	$2.10^{-2}cm$
ρ_m	metal resistivity	$1.6710^{-8}\Omega.cm$
e	metal thickness	4 μm
W_{bus}	width of busbar	0.2 cm
n	number of fingers	10
ρ_c	contact resistivity front side	$10^{-5}\Omega/cm^2$
V_m	the voltage supplied by the cell	0.5 V

B. SIMULATION RESULTS AND DISCUSSIONS

The mathematical model previously proposed for the solar cell antenna structure geometry optimization study in this work led us to a compromise between maximizing energy harvesting as a solar cell as well as maximizing electromagnetic radiation as an antenna.
The maximization of recovered power, that is to say maximization of photon absorption by the substrate that is silicon requires less metal deposited on the latter is that which amounts to a high optical transparency of patch (width of metallic lines which constitute it thinner). On the other hand, the maximization of electromagnetic radiation as an antenna requires more conductive metal deposited on the substrate. A solid patch more efficient for an antenna than a mesh patch.
The parameters useful for the simulation when optimizing solar cell antenna structure geometry are given in Table 1.
Fig. 4 below shows the power variation according to the width w of a finger.

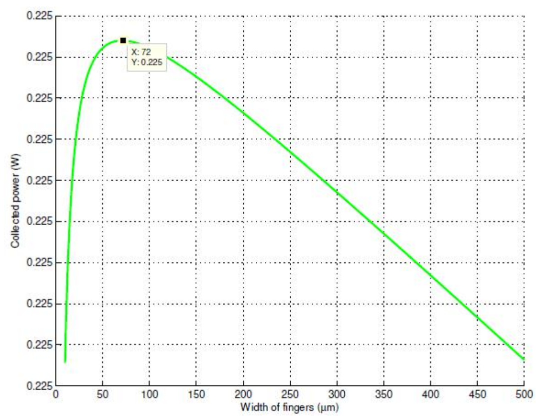


FIGURE 4: Collected power according to finger width.

As a solar cell, we note that the maximum of the collected power for the solar cell antenna is 0.225 W, for a lighting power of P_{ecl}=1300 W/m^2 and which corresponds to a width of a finger equal to 72 μm. The meshed patch of solar cell antenna proposed is given in Fig. 5. This antenna was excited by a micro strip line of impedance characteristic of 50 Ω.

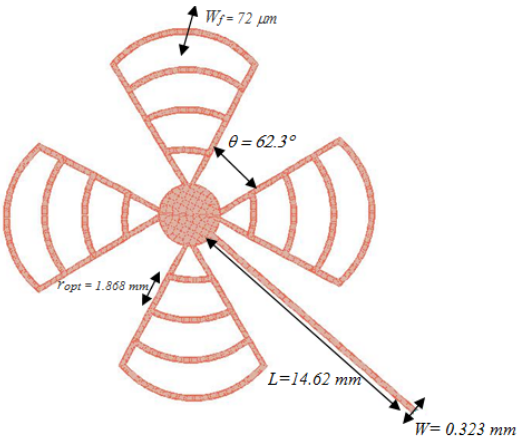


FIGURE 5: Proposed Solar Cell Antenna.

Solar cell antenna was simulated and the reflection coefficient S11 is presented in Fig. 6. The antenna should be a perfect radiator, not a perfect absorber. The radiated power returned from the port can be calculated to find the reflection coefficient at the resonant frequency. This reflection coefficient should be less than 10 dB i.e. S11 $\leq$ 10 dB at that resonating frequencies. Simulation results show that the designed antenna can be used as a frequency antenna with an effective reflection coefficient of -18.64 dB at 2.76 GHz.

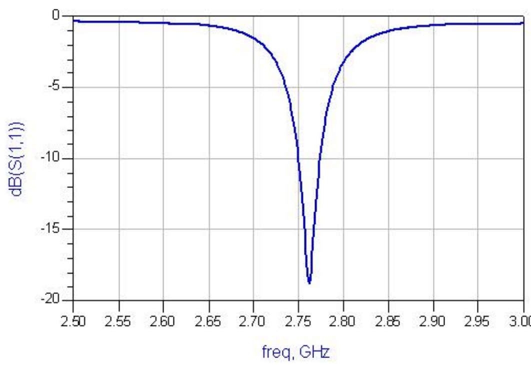


FIGURE 6: Reflection coefficient S11.

The current wireless applications require the antennas with larger bandwidths to handle higher data rates. The bandwidth of this solar cell antenna at -10 dB is of the order of 70 MHz. The radiation pattern of this Solar Cell Antenna at a frequency of 2.76 GHz is shown in Fig. 7. The polarization of the radiated field was linear. Antenna gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. The gain of antenna is 6.58 dBi and directivity of 7.33dB at 2.76 GHz.

The RF/DC decoupling circuit of the solar cell antenna is shown in Fig. 8. The circuit is simulated and values are compared. The plot of S11 is shown in Fig.9.

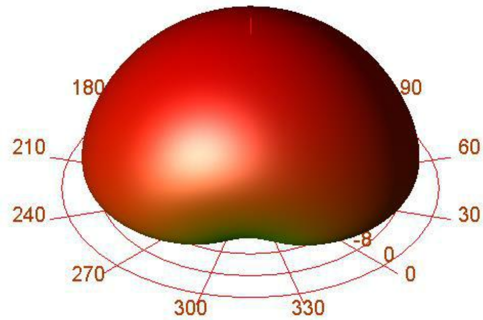


FIGURE 7: Radiation pattern.

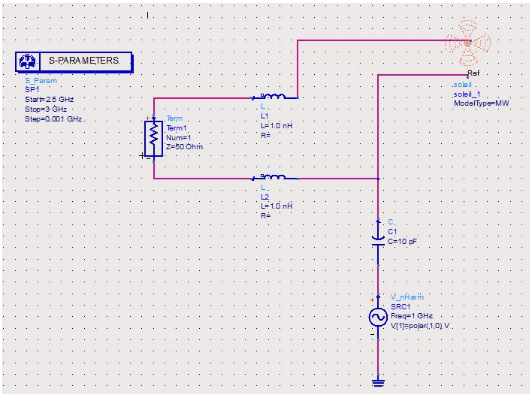


FIGURE 8: RF / DC decoupling circuit for Solar Cell Antenna proposed.

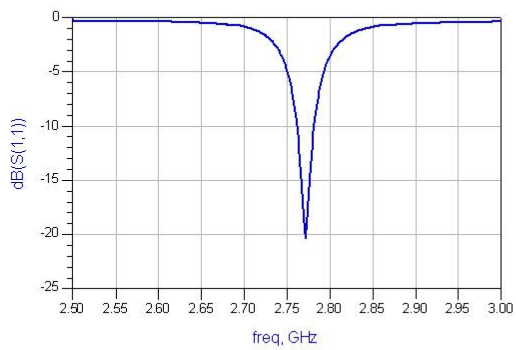


FIGURE 9: Simulation of RF / DC decoupling circuit.

The simulated reflection coefficient confirms well the values obtained previously, the resonance frequency at 2.76 GHz with a reflection coefficient of -20.78 dB.

III. SOLAR CELL ANTENNA FOR OPTICAL RECTENNA

In recent years, the RF energy harvesting and conversion into direct current is one of the solution allowing to solve the energy feeding problem. This technology is called RECTENNA. This system is based mainly on the antenna choice since it is a essential element that has the strong geometric controls in the system.

The main role of Rectenna is to harvest and convert RF waves from free space it into DC voltage. In the present work, Optical Rectenna based on a solar cell antenna that captures microwave and solar energies at the same time. The optical waves will be transmitted as DC signals and the electromagnetic waves will be split into two parts, one part contains the transmitted data and the other usable part will be converted by the rectification circuit,as shown in Fig. 10. The conversion circuit converts the RF and solar energies into a DC voltage usable by the resistive load RL. The rectifier circuit is composed of a HF low-pass filter, a DC filter and a DC load circuit. The HF low-pass filter fulfills two tasks: On the one hand, it blocks the harmonics generated by the schottky diodes and on the other hand, it realizes the impedance matching between the solar cell antenna and the rectifier. On the other side of the conversion circuit, there is a DC filter, it is a low pass filter its principle is to ensure the impedance matching between the rectifier circuit and the resistive load.

The proposed optical rectenna system architecture for a wireless communication system is shown in Fig. 11.

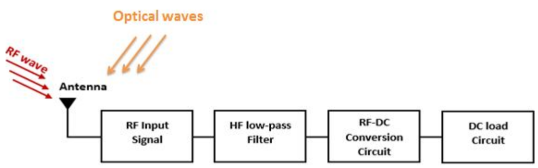


FIGURE 10: Global structure of Optical Rectenna system.

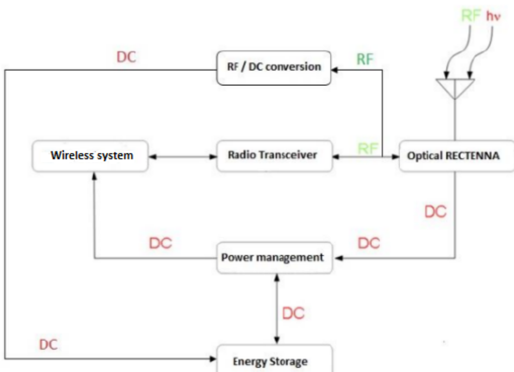
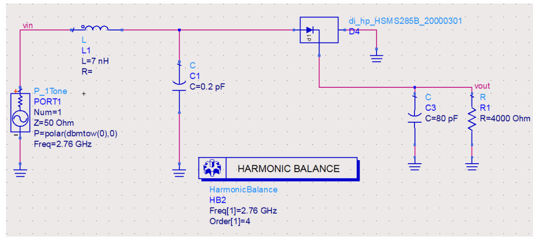


FIGURE 11: Autonomous wireless system using the Optical Rectenna.

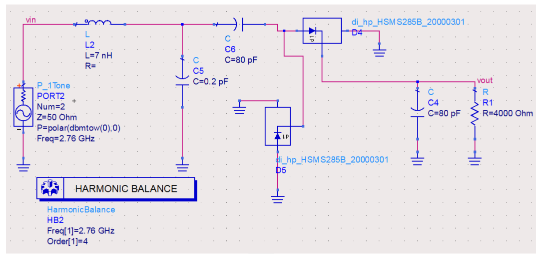
In this paper, we propose three different rectifier topologies, series topology, single stage voltage multiplier and two stage voltage multiplier topologies, as shown in Fig. 12.

The main target of Rectenna Optical system is to improve the conversion efficiency of RF waves into DC current. The rectenna efficiency can be investigated as:

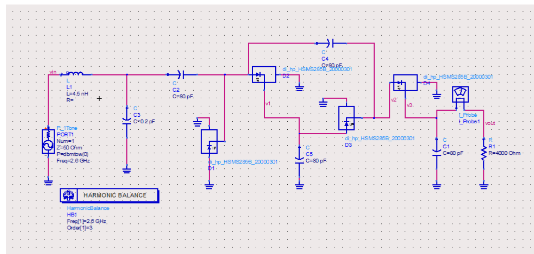
$$\eta = \frac{P_{DC}}{P_{RF}} = \frac{V_{DC}^2}{P_{RF}.R_L} \tag{14}$$



(a)



(b)



(c)

FIGURE 12: Different rectifier circuit topology: (a) Series topology, (b) Single stage voltage multiplier topology, (c) Two stage voltage multiplier topology

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.

We are studied to the resistive load value effect on the conversion efficiency for a fixed input RF power in order of 0dBm. As shown in Fig. 13, the series topology gives optimum conversion efficiency in order of 57.7% for a load resistance of 1kΩ . The optimum efficiency of single stage voltage multiplier topology is 31.6% for a load resistance of 2.5k , which is the lowest one. Nevertheless, the dual stage voltage multiplier topology presents the higher output DC voltage which reaches 1.135V.

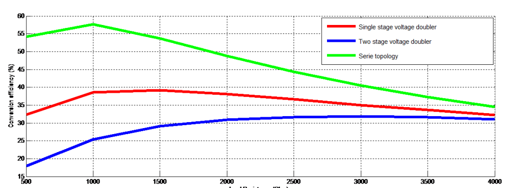


FIGURE 13: Conversion efficiency as function of load resistance for different rectifier topologies.

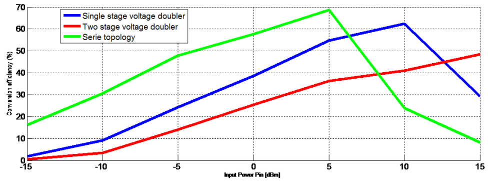


FIGURE 14: Conversion efficiency as function of load resistance for different rectifier topologies.

Fig. 14 present the conversion efficiency as a function of RF input power for different rectifiers' topologies. We have fixed the value of the load resistance at $1k\Omega$. We notice that, the dual stage voltage multiplier topology gives the best conversion efficiency in the range of -15 dBm to 15 dBm. This efficiency reaches the maximum value of 68.6% for an RF input power of 5 dBm and a load resistance of $1k\Omega$.

IV. CONCLUSION

In this work, we presented a Solar cell antenna dedicated to both Direct Current (DC) generation and RF transmission for WLAN/WiMAX application for the frequency of 2.76 GHz. This frequency is good agreement with the frequency band of WiMAX applications. In this paper, we have increased the performance of the antenna by improving certain essential parameters of the antenna such as radiation pattern, gain and reflection coefficient.

In this work, we presented a optical RECTENNA with a solar cell antenna dedicated at a time to Direct Current (DC) generation and RF transmission. This work allowed us to evaluate the performance of a new model of combination solar cell and antenna which is very advantageous and practical. Another advantage of this solar cell antenna is the large surface which is important for the largest possible energy output.

Both realization and design of the Solar cell antenna and the measures of their parameters such as the reflection coefficient S11, gain, directivity and the radiated power will be studied in another work. Faraway, measurement results obtained will be compared with those of the simulations studied in this work.

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