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New optically transparent hybrid system for satellite and terrestrial communications

Chokri Baccouch[1,*], Hedi Sakli[1], Taoufik Aguili[1]
[1]*National Engineering School of Tunis, Tunis El Manar University, B.P. 37, Le Belvédère, 1002 SYS'COM Laboratory, Tunis, Tunisia.*
*corresponding author, E-mail: chokri.baccouch13@gmail.com
saklihedi12@gmail.com
taoufik.aguili@gmail.com

Abstract— **This work presents a rectangular optical solar cell antenna designed to operate for solar energy harvesting and RF transmission in ku band. A parametric study was realized to determine the optimum design parameters giving maximum values of the collected electric power and antenna parameters in the frequency range 10-20 GHz. It is not the first method to merge antenna and solar cell, but the advantage of our method is that it allows preserving good performances for both the antenna and the solar cell. A solar cell antenna designed for satellite communication is examined. Simulated results for this solar cell antenna, with a silicon material and using Advanced Design System (ADS) software, showed clearly resonance frequencies at 10.70 GHz, 12.02 GHz, 17.49 GHz and 19.70 GHz.**

***Index Terms*— Solar cell, Antenna, RF, Communication Systems**

I. INTRODUCTION

solar energy has been considered as one of the most renewable energy resources that could fill the shortage of energy needs. In fact, human beings used the solar energy to produce electricity. Although the photovoltaic (PV) cell was first employed to produce it, its efficiency remained limited [1]. Solar powered communication systems have received considerable attention due to their ability to operate without the necessity of being connected to an electricity grid. This has become a significant challenge when it comes to powering communication systems in remote places where the electricity grid is not available. In order to address this challenge, the use of photovoltaics in communication systems has recently been the subject of much research.

The concept of solar energy and its combination with microwave antennas in order to create low-profile compact and reliable autonomous communication systems for terrestrial and satellite communication links capable of generating DC power output has received much attention recently.

Before, antennas and solar cells do not mix. They must operate independently so as not to interfere. This constraint, for example, has repercussions on the weight and size of satellites: they must have a surface large enough to accommodate both an antenna system for transmitting and capturing data and both solar panels, for the supply of electricity [2].

In space applications for instance, both solar panels and communication system are major contributors to the overall size and weight of the satellites and combining these two systems could save real estate and cost. In urban areas, the integration of antennas and solar cell or solar panels can be essential for the transportability of emergency autonomous communication stations [3-5].

In the present work, new method to merge antenna and solar cell was studied. The hybrid system solar cell antenna proposed was dedicated at a time to the energy recovery and the RF transmission.

II. SOLAR CELL ANTENNA

A. Basic considerations

Optically transparent mesh antennas are antennas that have a certain level of optical transparency. These transparent antennas, for example, are potentially suitable for integration with solar cells for small satellites. Traditional patch antennas used on small satellites compete with solar cells for the surface. However, a meshed patch antenna can be placed directly on the solar cells and solve the problem of surface limitation. For such integration, a high optical transparency of the patch antenna is required from the point of view of solar cells, since solar cells require sufficient sunlight to generate adequate electrical power. On the other hand, the antenna must have at least acceptable electrical properties at the same time so that it can radiate correctly and efficiently [6-9].

The hybrid system discussed in this paper will be dedicated to both energy harvesting and RF transmission for terrestrial and satellite communications. This structure is made of a photovoltaic cell in which the front grid was designed to have a miniature antenna suited to the multi-band transmission and to minimize the power loss of the cell dedicated to energy conversion. The received electrical energy was used to operate the complete system; it can be used for the polarization of a diode or a low-noise amplifier in a receiver block.

B. Optimal design of solar cell antenna

We propose an optical solar cell antenna with meshed patch. Optimization of the maximum electrical power collected as a function of finger width was determined based on a mathematical model that we have already studied to minimize the power losses of the solar cell antenna and improve the conversion efficiency as a solar cell [10]. The optimal width W_f has been used for the design of the meshed patch or front face collection grid. We conclude that

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improving the performance of a solar cell depends not only on the materials and structure but also on the design of the metal grid front face.

With this mesh structure two types of waves can be exist. The optical waves that will be absorbed by the silicon (semiconductor) and the RF waves that will be collected by the meshed patch metal whose optimal finger width W_f [11-12].

The designed structure is a solar cell antenna printed on a multi-layered substrate figure 1.

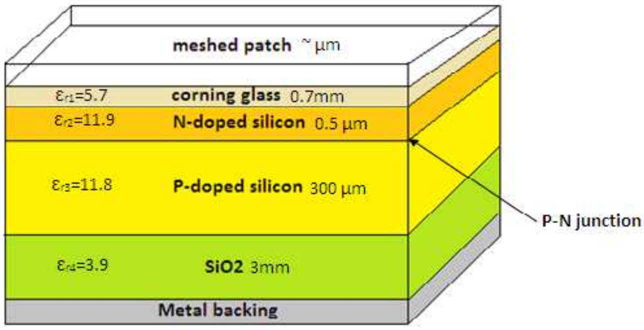

Figure1. Multi-layered substrate of optical solar cell antenna

Many investigations have shown that the silicon on an insulating layer SiO_2 confers to the components that are realized, a higher operating frequency, an ability to operate at low voltage and low power consumption and an insensitivity to the effects of ionizing radiation. So we found that when using a thin film substrate, we observe that the simulations are complex and time consuming.

The meshed patch of solar cell antenna proposed is given in figure 2.

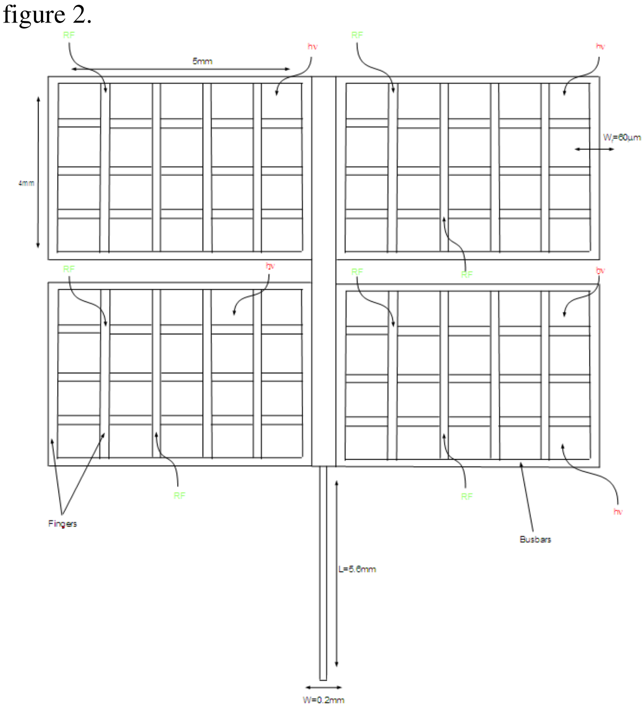

Figure2. Meshed patch of optical solar cell antenna proposed

This antenna was excited by a microstrip line of characteristic impedance equal to 50 Ω.

III. Simulations Results And Discussions

A. *Solar cell antenna parameters*

As a solar cell, the optical solar cell antenna has been studied in another work and its collected electrical power was determined according to the geometric parameters. The optimum values of these geometric parameters obtained such as the finger width, the metal height or the distance between the fingers are used for the design of the meshed patch or the front face collection grid of solar cell antenna.

As an antenna, the electromagnetic performances of the solar cell antenna were obtained by simulations using the ADS software. The return loss over at frequency band from 10 to 20 GHz show in Fig 3. We can note that we get a good impedance matching (|S11| < -10) dB over this band.

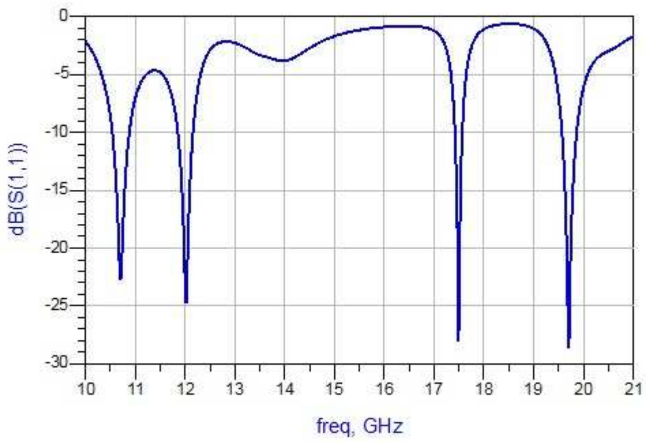

Figure3. Reflection coefficient S11

We note also the presence of 4 resonating frequencies at 10.70 GHz, 12.02 GHz, 17.49 GHz and 19.70 GHz, with return loss respectively -23.05 dB, -24.96 dB, -28.76 dB and -29,34dB.

When designing an antenna, the gain must be taken into consideration as it is an important metric. The good values of S11 and VSWR are not enough to confirm a good radiation. The radiation pattern in the horizontal plane and in the E plane of this solar cell antenna at frequency 12.02 GHz is show in Fig.4 and Fig. 5.

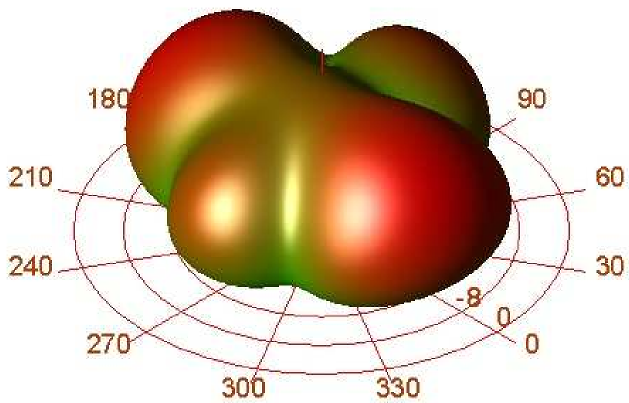

Figure4. Radiation pattern

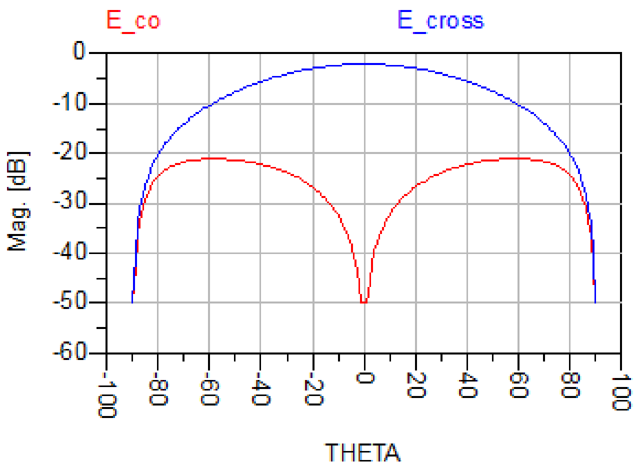

Figure5. Far field radiation pattern in E plane.

The simulation results obtained are given in the following table (Table I).

Table I. Electromagnetic performances of the optical solar cell antenna

Parameters	Values			
Frequency (GHz)	10.70	12.02	17.49	19.70
Gain (dBi)	1.83	3.68	1.12	0.82
Directivity (dB)	6.14	7.82	7.93	9.34
Power radiated (mW)	3.68	4.32	1.33	1.32

These values are important for solar cell antennas as patch antennas that are generally characterized by low gain. The simulation results show that the designed solar cell antenna can be used for terrestrial and satellite communications in ku band.

The obtained values of gain (Fig. 6) and that of radiated power (Fig.7) are respectively 3.68 dBi and 4.32 mW. In addition, antennas integrated on silicon substrate have very often negative gains (silicon low resistivity) or limited to the range 0-2 dBi on high resistivity silicon. The use of an insulating layer SiO_2 makes it possible to reduce the losses of the silicon substrate and to improve the gain of the solar cell antenna; this is why the gain obtained exceeded 2 dBi. These good results make it possible to use the antenna particularly in point-to-point transmission systems.

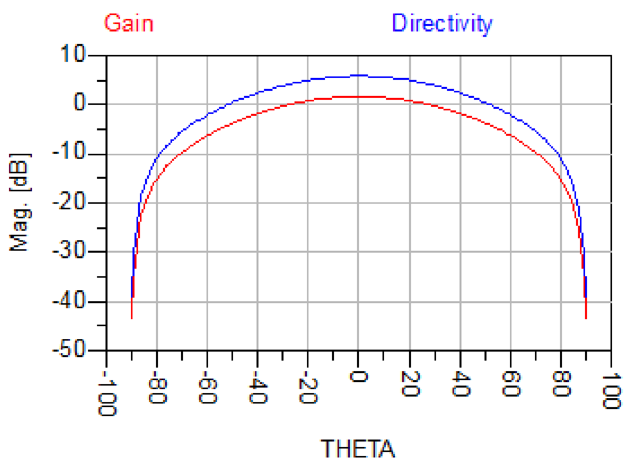

Figure6. Directivity and Gain

The efficiency of this solar cell antenna is given in Fig. 8. This efficiency is of the order of 40%, this amount to the silicon substrate which is less radiation than that of a conventional FR4 substrate.

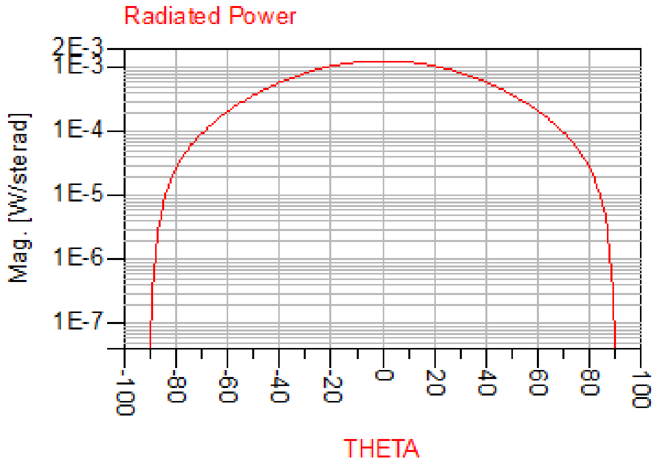

Figure7. Radiated power

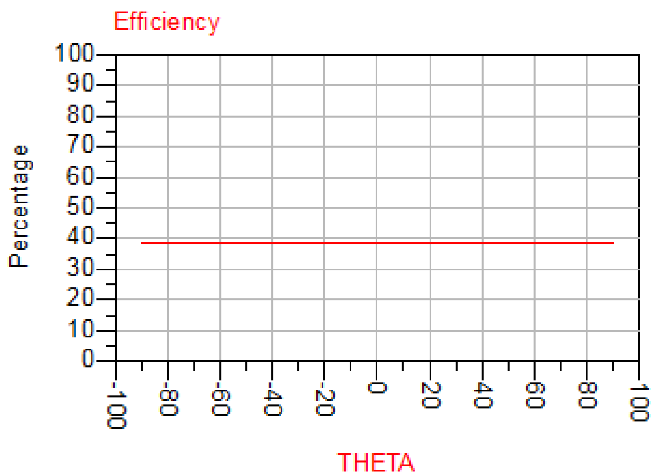

Figure8. Efficiency of solar cell antenna

B. Decoupling RF/DC in solar cell antenna proposed

Since the solar cell has a DC circuit, the direct current path and the RF signal path must be decoupled in such a way that the DC load has no influence on the RF properties of the antenna. The decoupling can be realized by means of concentrated reactive elements and distributed elements, respectively. In this case, we propose an inductive and capacitive RF/DC decoupling circuit shows in Fig 9.

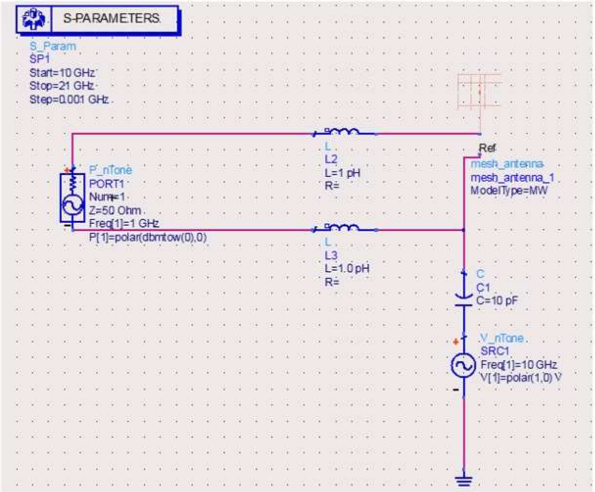

Figure9. RF / DC decoupling circuit

The decoupling circuit was simulated and obtained results are compared to the S11 parameter shown in Fig 3. The simulation of the parameter S11 of decoupling circuit (Fig 10) provides the same results of resonating frequencies of the proposed solar cell antenna in Layout with a slight decrease of return loss.

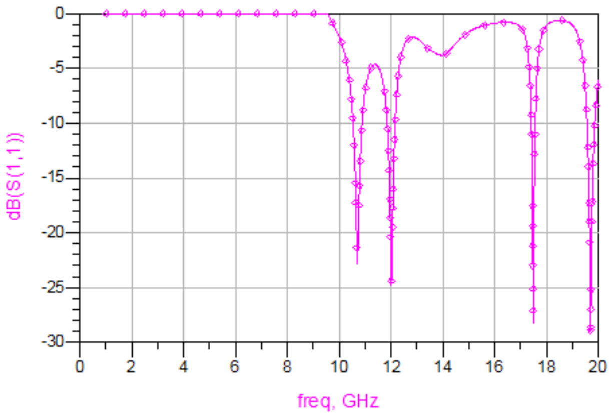

Figure10. Parameter S11 of RF / DC decoupling circuit

IV. Conclusion

In this work, we proposed an optical solar cell antenna well adapted for energy harvesting and for the RF transmission in terrestrial and satellite communications. We obtained good performances for this solar cell antenna such as the electric power collected equal to1.37 W/cm^2 as a solar cell, a maximal gain equal to 3.68 dBi at 12.02 GHz, a directivity of the order of 9.34 dB at 19.70 GHz and maximal radiated power equal to 4.32 mW at 12.02 GHz as an antenna. The efficiency of this hybrid system is very important compared to a simple integration of a patch antenna and solar cell. This system is also advantageous for other future communication applications.

The realization of this optical solar cell antenna and the measures of their different parameters such as the return loss S11, gain, directivity and the radiated power will be studied in another work. The measurement results obtained will be compared with those of the simulations that we studied in this work.

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