Solar Cell Antenna for IoT and Wearble Applications

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Abstract— In this paper a promising photovoltaic cell antenna solution for Internet of Things (IoT) and wearable applications is presented. In the proposed solution no physical modification of the photovoltaic cell is needed. The photovoltaic cell metallic components is used as an antenna part for a radio frequency (RF) transceiver. Prototyped antenna has been characterized in lab environment. The antenna is well matched at 1.5 GHz.

***Index Terms—PV cell antenna*, wearables, IoT.**

I. Introduction

Photovoltaic (PV) cells are now common place in home appliances and consumer devices, such as wearable electronics, as a primary or alternative energy source.

Modern solar or PV solar cells consist of photocells chain - semiconductor devices that convert solar energy directly into electricity. The solar cell is composed of individual solar cells and are connected in series or in parallel to increase the output parameters (current or voltage and thus increase the harvested power). All the solar cell elements further connected to a ground (reference) line and at least one positive DC output line.

A PV cell element can be found not only as an alternative building energy solution but also in consumer portable and wearable electronics.

Traditionally, the solar cells are used to power supply the electronic and not for RF signal transceivers. The transceiver antennas in its turn are either brought as a separate unit or integrated to the circuit board but not combined together. Combination of the two features (PV cell and antenna) in one opens new perspectives in telecommunication and photovoltaic industry.

Output power of the PV cell is well dependent from the cell surface area.The PV cell effective area starts from a few square cm to a few square meters. Current lab tests shows, that the PV cell can be used as RF energy transceiver or an antenna.

Available effective solar cell surface is large enough for efficient antenna systems realization. Novel flexible and free form PV cell makes this idea even more attractive. By the antenna system we mean any antenna solutions from a simple microstrip line to an antenna array with multiple antenna elements. Because of high system flexibility novel PV cell based antenna solution can cover multiple frequency bands from some MHz up to tens of GHz ranges.

II. Background and Antennas Overview

Aerospace and satellite in particular were the trigger of the idea to combine together the PV cell and radiation and/or receiving electromagnetic (EM) waves for telecommunication applications. First trials in this direction do not present much progress due to technological inflexibility of the PV cell from one side and massive antenna solutions from another side. Compactness, miniaturisation and lightweight are most valuable parameters for all low power transceiver systems. Integration of the PV cell and antenna is still challenging task. Many presented literature solutions are using perforated metallic structures (see [1], [2]) placed on top of the PV cell. Such solutions demonstrated low efficiency, high complexity in realisation and furthermore affect the PV cell efficiency (see [3]-[5]). In some papers the PV cell surface is used as a reflector or passive periodic structure. In this case the cell physical modification is necessary (see [6]-[8]).

More advanced combination solutions are based on transparent conductive materials (see [9]). Theoretical results and preliminary laboratory test demonstrated promising results. The drawbacks of this solution are realisation complexity and cost.

The combination of photovoltaic and antenna technology requires special approaches for the antenna port interconnection with an antenna element. There are two general interconnect ways described in literature: direct and EM coupling. In case of direct antenna connection to the feed line a VIAs or micro strip (MS) lines are used.

Another publication suggest to use additional RF lines for the antenna excitation (see [10]).

Unlike, to available (published or patented) solutions where an additional radiating element should be placed above the PV cell or be integrated in the PV cell structure. Our antenna solution is only based on a direct current (DC) lines available in any type or shape PV cells. The length and shape of the DC lines will influence the antenna resonance frequency.

Usually, the RF devices are designed with 50 ohm input circuit, while the proposed antenna solution might have arbitrary length and shape. Thus, the antenna port location and dedicated matching circuit fine tuning are desired and crucial. The DC lines can be seen as MS or coplanar waveguide (CPW) line. Attached to the DC lines PV cell elements will act as an antenna load or parasitic element.

One of possible drawback of proposed antenna solution is relatively narrowband operation bandwidth limited by the matching circuit and particular DC line topology.

Table 1 summarizes existing PV cell antenna solution compared to the solution described in the paper.

TABLE 1 SOLAR CELL ANTENNA SOLUTION

Solution	Efficiency	Realization Complexity	Influence on PV cell efficiency
Perforated metallic structures	low	high	medium-high
Transparent conductive materials	medium-low	high	medium
External attached antennas	high-medium	medium	medium - low
Proposed solution	medium-low	low	low

III. CONCEPT

In the proposed solution no physical modification of the PV cell is needed.

The idea is to combine a photovoltaic (PV) cell or module and a radio-frequency (RF) antenna into a single design without physical PV cell modification. This would allow for tight and conformable packages, low cost, lower weight and volume, typically flat. The combined system will form a single unit performing the harvesting and the communication functions (transmission, reception or both). The concept aims at using the PV cell as usual (e.g. an energy harvester) and to reuse its internal metallic structure to create the necessary RF antenna structure.

It is often difficult to integrate the antenna close or above the cell, either because this degrades the energy harvested or the performance of this antenna, or both, by mutual interference.

The principle used in this antenna concept is to use a photovoltaic cell (or panel) internal metallic DC lines and/or the backplane element of an antenna (whichever is required in the design of the antenna), as the radiating while avoiding as much as possible the two basic functions of the system to interfere and degrade mutually their performance. This solution means that there is no physical modification of the PV cell and that the latter performs simultaneously or alternatively two distinct blocs (filter and balun in Fig. 1) that are the PV energy harvesting combined with the (RF) tranceiver. Note that the transceiver can be powered by the same way as the PV consumer.

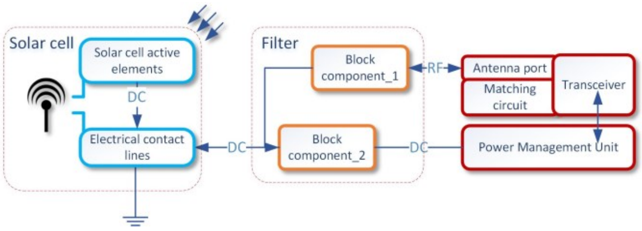


Fig.1. Block diagram of the proposed antenna system solution.

Based on the application and physical realization, the PV cell based antenna may have an omnidirectional and / or directive radiation performance. For most of the cases a balanced antenna is one where the elements are fed and are of equal length on both sides such as a dipole antenna or full wave loop. A balanced antennas excitation can be realized in different ways, such as open wire, microstrip lines or a simple coax with a balun (Fig. 2 b, c).

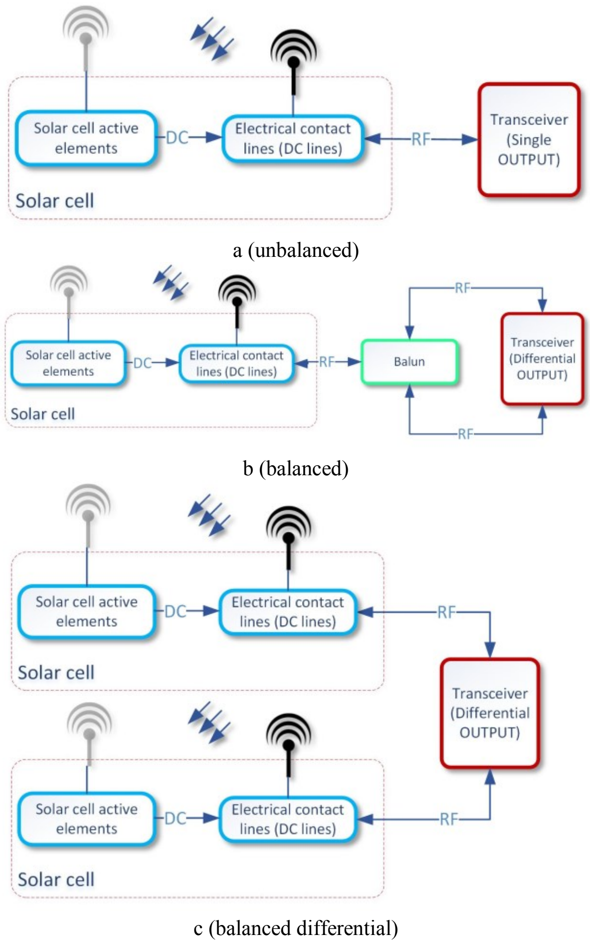


Fig. 2: General case block diagrams.

On the other hand the balanced antenna is the structure in which the induced current is the same, but opposite in each conductor. This does not mean, that each antenna part (e.g. leg, conductor) must have the same physical length, but do have equal electrical length and introduce 180 degrees in phase between the antenna conductors (e.g. between two dipole arms).

In real life application it's common, when one of the antenna side/arm is physically different from another one, and closer to a metallic parts or surfaces. Both cases (physical difference and close presents of metallic objects) cause antenna unbalancing. However, unbalanced part placed close to the metallic object can be capacitively or inductively loaded in order to create the balance.

In case of miniature devices, the PCB will play both the ground plane as well as an unbalanced antenna part role.

Example of an unbalanced and a balanced solutions are presented in Fig. 2.

The solar cell element is represented by two parts: the solar cell active element and electrical DC lines. The DC lines in all cases are an active antenna element, which is indicated by black antenna pictogram. The solar cell active element has also antenna pictogram, but slightly vanished. This means that the solar cell active element can act as passive antenna element, or be a part of the radiative structure.

IV. PV CELL THEORETICAL MODEL

The antenna design and optimization was performed with commercially available EM software. Computational accuracy of the HFSS solver is fairly good and provides close results between theoretical estimation and prototyped and characterized antennas.

The PV cell antenna theoretical model is presented in Fig. 3. The model consists of three principal elements: DC lines, the PV cell element and a FR4 substrate with a thickness of 0.8 mm. The antenna overall dimension is 26.6mm x 11.6m x 0.9mm. The DC lines width is 0.6mm and 10mm for the side lines and the central line respectively. A lumped port is used for the antenna excitation.

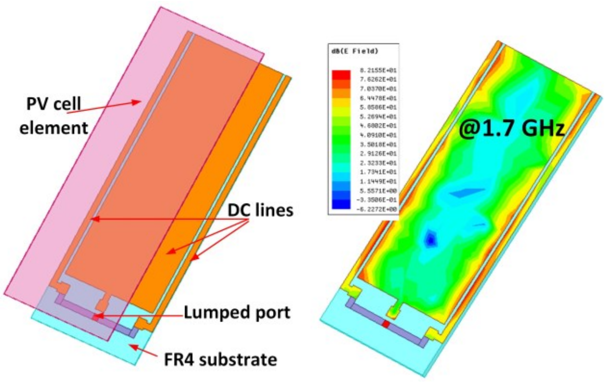
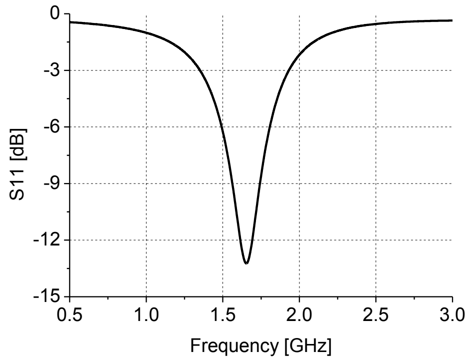


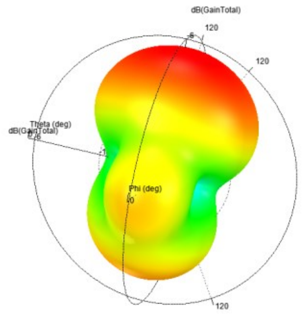
Fig. 3. PV cell antenna theoretical model and current distribution at resonance frequency.

The PV cell element in the theoretical model is a 0.1mm thick dielectric substrate (ε=5, tgδ=0.002), which is located on top of the PV cell DC lines (see Fig. 3).

The antenna theoretical results are presented in Fig. 4. Proposed antenna exhibits almost omnidirectional radiation and has an operational bandwidth of about 150 MHz with the resonance frequency at 1.7 GHz. Theoretical antenna gain is -7dBi.



S-parameter



3D radiation pattern

Fig.4. PV cell antenna theoretical results.

V. ANTENA CHARACTERIZATION.

A small flexible PV cell has been used to test resonance performance of the PV cell and evaluate the potential of using the cell as an antenna for wireless communication or as an additional source of energy harvesting. The PV cell under test is presented in Fig. 5.

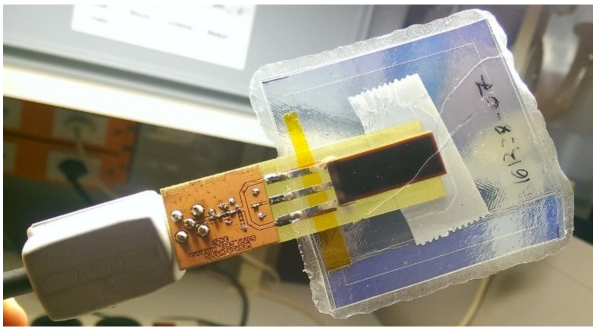


Fig. 5. Solar cell element antenna prototype.

Current lab tests shows, that the PV cell can be used as an RF antenna together with a transceiver. The PV cell antenna under test is well matched at 1.5 GHz (BW=150 MHz). The measured antenna resonance frequency is slightly (200 MHz) shifted towards the lower frequency. This can be explained by not precise theoretical PV cell antenna model.

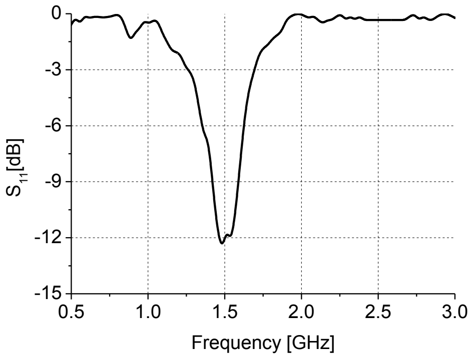
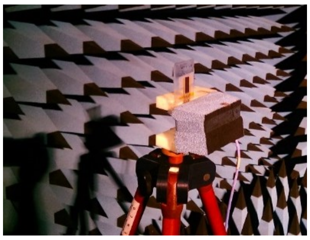


Fig. 6 Measured antenna S-parameter.

During the antenna radiation pattern measurements test, the antenna PCB and connector were protected by absorbers. As a result, only the solar cell panel and the metal electrodes radiation pattern were measured (Fig. 7).



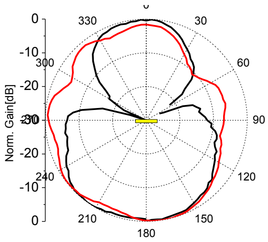


Fig. 7. Antenna under test: radiation pattern measurements @ 1.5GHz (CSEM anechoic chamber).

Antenna demonstrated omnidirectional radiation performance with the antenna gain of about -10 dBi. Measured antenna gain is a bit (3dB) lower in comparison with theoretical. This can be explained by not exactly described model including PV cell material properties and additional loses in the measurement setup.

VI. CONCLUSION

In this paper the PV cell antenna is presented. The antenna was characterized in lab environment and demonstrated promising performance. The realized PV cell antenna is matched at 1.5 GHz, and can be easily matched to the ISM 2.45GHz frequency.

The potential applications are numerous, such as the PV cell business for providing an integrated connection to the remote management, the internet of things that would be powered by the PV cell or using it as sensor, the autonomous connected watches, connected cars, smart home, security systems, IOT, etc.

Further, it is possible to design combined energy module harvesting PV and RF, point to point communication based on PV cell used as an antenna reflector ("dish"), satellite communication (for e.g. drones), smart strap, location estimation systems, in particular for anchors, etc.

The limitations of the proposed solution can be narrowband bandwidth and antenna efficiency dependence from the PV cell design and the production technology.

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