APPLICATION OF PHOTOVOLTAIC SOLAR CELLS IN PLANAR ANTENNA STRUCTURES

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ABSTRACT

This paper describes the application of photovoltaic solar cells in planar antenna structures. The radiating patch element of a planar antenna is replaced by a solar cell. The original feature of a solar cell (DC current generation) remains, but additionally the cell is now able to receive and transmit electromagnetic waves. For a proper performance of these functions a RF-DC decoupling is necessary.

Besides a general technical description some selected realisations of solar cell antennas are presented. The comparison of measured and simulated antenna properties shows a good agreement. However, due to the non ideal patch material slightly higher losses are expected compared to copper patches.

Furthermore the application field of this new device in wireless communication systems is outlined.

1. INTRODUCTION

Wireless communication systems require electric energy for their operation and their use. Stand alone applications like environmental monitoring systems, vehicular communication systems or satellite systems need a net independent power supply which is preferably realisable by photovoltaics, an advanced technology distinguished by reliability, longevity and eco-friendliness. Besides that antennas are needed in order to receive or transmit electromagnetic waves.

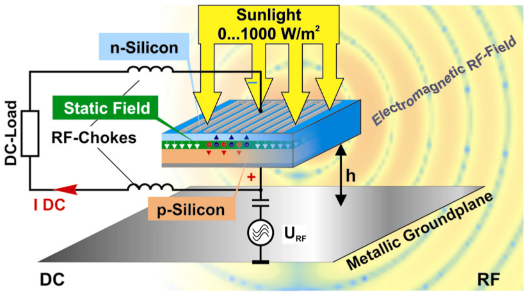

Fig. 1 Basic principle of planar solar cell antennas. The solar cell whose backside contact is excited with an RF signal is placed above a conducting ground plane. A decoupling network separates the RF from the DC current.

At present photovoltaic generator and antenna are two separate devices. They compete for the available space on mobile and stand alone systems which are generally limited in size. Furthermore they may be bulky and expensive and they limit the capabilities of product designs.

To overcome these restrictions a combination of antenna and solar cell in one device is desired. Thus, new product designs and cost reduction becomes possible [1], [2].

A new approach, the Solar Planar Antenna – SOLPLANT®, avoids these disadvantages. It consists of an appliance for the conversion of solar radiation energy into electric energy with at least one solar cell. The electrically conductive contacts of the solar cell are used simultaneously as antenna for radiation or to the reception of electromagnetic waves. In this case the backside contact of a solar cell is used as radiating element in terms of radio frequency.

Based on these considerations a product development concept was originated at the Institute for Solar Energy Supply Technology (ISET e.V.) whose basic idea has been registered as a patent in Germany, Europe, Japan and USA [3]. The invented appliance implies that the solar cell and antenna are combined as an integrated unit and that the conductive parts which are available anyhow for operational reasons in a solar cell (or a solar module) are used simultaneously as antenna elements.

2. DESIGN AND BASIC CONSIDERATIONS

The basic principle of a planar solar cell antenna is depicted in Fig. 1. In this exemplary case a galvanic coupling of the RF signal is shown. However other coupling methods (e.g. aperture coupling) are also possible. Since the solar cell has a DC circuit the direct current path must be decoupled from the RF signal path in such a way that the DC load has no influence on the RF properties of the antenna. The decoupling can be realised by means of concentrated reactive elements and distributed elements respectively.

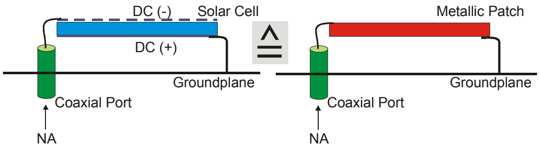

Fig. 2 The RF impedance between the DC contacts of a PV cell was measured with a network analyser and compared to metallic patch measurements. The measured impedance shows series and parallel resonances. Both impedance curves are nearly identical.

Numerous measurements have shown that from an RF point of view the solar cell acts like a homogenous metallic plate. For this purpose comparative measurements of different solar cells and metallic plates with identical dimensions were performed, see Fig. 2. These results encouraged the design of planar antennas with photovoltaic solar cells [1].

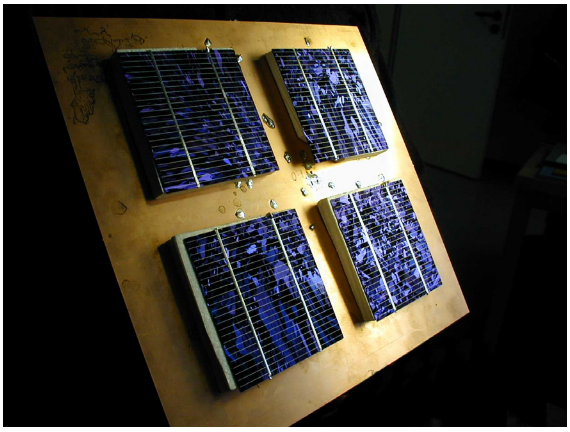

Fig. 3 Laboratory prototype of a 4 element antenna array with poly crystalline solar cells. The DC connection of the cells is in series. The output DC voltage is about 2V (Source: ISET).

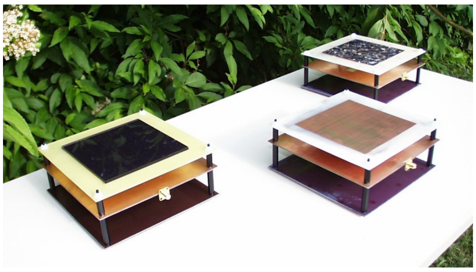

Fig. 4 Laboratory prototype of Aperture coupled patch antennas with linear polarisation. Thin film solar cell – copper – poly crystalline solar cell.

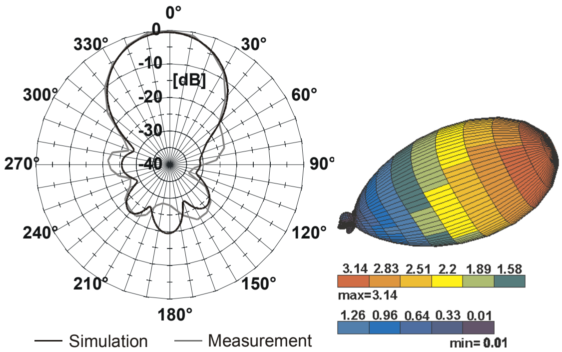

Fig. 5 Left: Simulated and measured normalized radiation pattern of a 4-element antenna array with solar cells. Right: Simulated 3D radiation pattern.

Independent of the RF circuit arrangement the solar cells can be operated in series or parallel connection and combinations of both as usual. By the use of multilayer printed circuit board technology very compact and flat antenna arrays are possible. By means of a purposeful layer construction specific networks for the isolation of RF and DC current can be implemented. In order to eliminate the influence of the DC current path on the RF antenna properties, networks consisting of discrete or distributed elements can be applied.

3. EXEMPLARY DESIGN STUDIES

First studies in the laboratory confirmed the technical feasibility of planar antennas with photovoltaic solar cells. Based on simulations two different antenna types were realised: a 4-element planar array with poly crystalline cells and an aperture coupled single antenna element with poly crystalline and thin film cells. The simulated results were verified by means of measurements in both cases.

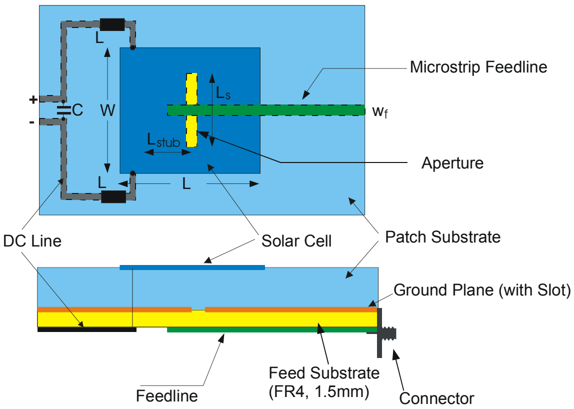

Fig. 6 Layout of an aperture coupled planar antenna with solar cells. The most important difference to conventional patch antennas is the DC current line. Since the DC lines are on the backside of the ground plane board, the influence on the antenna properties is minimized.

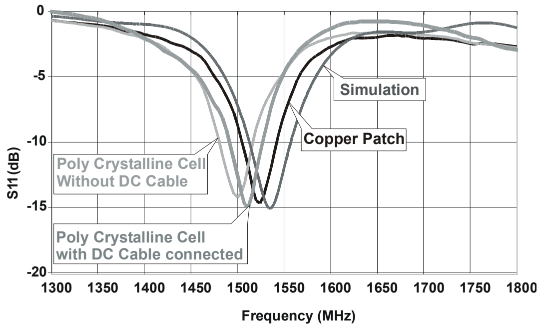

Fig. 7 Antenna reflection coefficient: Comparison of different antenna measurements with Microwave Studio simulations.

The antenna array in Fig. 3 is excited by a microstrip feeding network on the backside of the ground plane. Each antenna element is fed in phase by means of direct coupling. The DC contacts of each solar cell are led through vias to the microstrip layer. In order to minimize the influence of the DC circuit on the antenna properties the DC lines are designed as $\lambda/4$ transformers which are shorted with capacities at the end. Thus the DC lines are high impedance at the input and therefore “invisible “ for the RF current. The radiation pattern of this antenna is shown in Fig. 5. The measurement agrees quite good with simulation results.

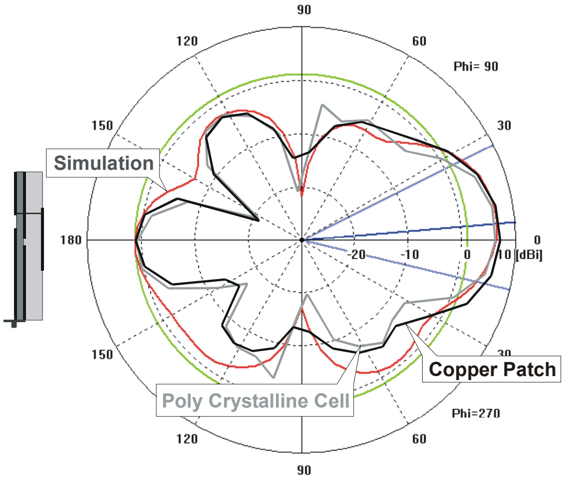

Fig. 8 Simulated and measured gain of antennas with copper patch and poly crystalline solar cell in the vertical plane.

Fig. 9 Laboratory prototype of a planar antenna with solar cells for GSM 900. It is used for radio transmission and DC power supply of a wireless monitoring system (Source: ISET).

The simulations for this antenna were performed with CONCEPT II software which is based on the method of moments.

Further investigations of the application of solar cells in planar antenna design were performed with aperture coupled patch antennas (Fig. 4). Based on the SSFIP principle [4] (Strip-Slot-Foam-Inverter Patch) several antennas were designed with patches made of standard solar cells. These cells are square with an edge length of 100mm and 105mm respectively. Due to the aperture coupling there is no galvanic contact between the RF and DC current. Thus the RF source needs not to be protected from the DC power.

The measured and simulated results are shown in Fig. 7 and Fig. 8 respectively. The bandwidth is about 3%. Further optimisation of the antenna geometry (slot dimensions, stub length etc.) may improve the bandwidth. But the aim of these investigations was to draw conclusions for the use of solar cells in planar antenna design. Thus a large bandwidth is secondary. The match between the different antenna measurements and the simulation is quite good. However a small frequency shift is to recognize.

The observation of the vertical radiation pattern also shows a good agreement between measurements and simulations (Fig. 8). The gain of a conventional antenna with copper patch is 7.5 dBi whereas the gain of an antenna with poly crystalline patch is 6.5 dBi due to the lossy material of the solar cell. Although this discrepancy is in the range of measurement uncertainty, numerous measurements have shown that the losses of solar cell antennas compared to copper patch antennas are about 1-2 dB. This result was confirmed by means of efficiency measurements in a GTEM cell. The general test procedure is outlined in [5].

4. FIRST PRODUCT DEVELOPEMENTS

One of the first SOLPLANT® developments was an antenna for a wireless monitoring system in the GSM 900 band (Fig. 9). The solar module consists of a series connection of many solar cell strips in order to increase the output voltage. (The solar cell strips are arranged one upon the other with partial overlap, like shingles.) This solar module generates a voltage of 8.4V and a current of 130mA. The size is 9.5cm in square. The power supply of the electrical equipment (RF unit, data logger) by means of batteries and a battery charge controller is possible.

This solar antenna is based on an E-antenna as described in [6]. The antenna is fed with a coaxial cable whereat the inner and outer conductor each are directly connected to one DC port of the solar module. With this construction RF and DC signals are available on the same lines. The RF-DC separation is carried out by means of a Bias-T at the end of the coaxial cable. Thus the RF source is protected from the DC power.

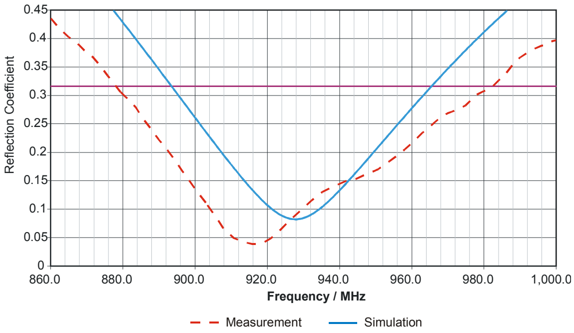

Fig. 10 Measured and simulated reflection coefficient of the SOLPLANT® system in Fig. 9.

Although this antenna was simulated with PEC (Perfect Electric Conductor) sheets the simulation matches nearly the measurement results (both, reflection coefficient (Fig. 10) and radiation pattern).

Another advantage of this antenna is the large patch surface which is important for an energy output as large as possible. Furthermore it has an omni directional horizontal radiation pattern which is advantageous for GSM applications.

Currently another SOLPLANT® development is in progress: an aperture coupled circular polarized patch antenna for GPS in mobile applications.

5. CONCLUSION

Previous investigations have shown that the Solar Planar Antenna – SOLPLANT® opens a very wide field of application. Especially mobile and wireless communication devices or systems derive benefit from the simultaneous use of solar cell and antenna function with costs reduction at the same time.

Fig. 11 Vision of the pv-powered flying wing aircraft “HELIOS”, suggested by the NASA. It is profitable to use this “atmospheric satellite” in combination with SOLPLANT® as integrated antenna to reduce weight (Source NASA, modified by ISET).

Fig. 12 SOLPLANT® in combination with a WorldSpace Satellite Receiver for grid independent use in villages of the third world. Left: principle of simultaneous reception and PV-generation. Right: WorldSpace Receiver with a Prototype of a SOLPLANT® Satellite Antenna (Source: ISET).

Applications of SOLPLANT® are in the fields of bureau and laboratory communication (Bluetooth), wireless environmental monitoring, online building observations and others, as well as in the extraterrestrial field of application (e.g. satellites).

Generally the RF properties of solar planar antennas can be designed using commercial EM software packages. However the DC current path should be taken into account in the simulation. It turned out during measurements that the solar cell itself behaves like a metal plate from a RF point of view. This is also approximately valid for the series connection of solar cell stripes (“shingle module”) mentioned above.

The combination of photovoltaic and antenna technology requires special approaches because the demands of photovoltaics are often in opposite to antenna requirements. For example, the resonance frequency of the solar planar antenna depends on the patch size. Therefore RF optimisation criteria also affect the useful surface for the solar energy conversion.

The previous investigations have shown that a combination is possible if all needs are considered sufficiently. This leads to new innovative product designs.

REFERENCES

[1] Bendel C., Henze N. and Kirchhof J.: “Die photovoltaische Planarantenne – High-Tec durch multifunktionale Nutzung der physikalischen Eigenschaften von Solarzellen“, 16. Symposium photovoltaische Solarenergie, Staffelstein 2001, pp.37-42.

[2] Bendel C., Henze N. and Kirchhof J.: “Solar Planar Antenna – SOLPLANT®”, *17th European Photovoltaic Energy Conference,* (Munich 22-26 Oct. 2001).

[3] Bendel C., Henze N. and Kirchhof J.: “Apparatus for converting solar energy into electrical energy and for radiating and/or receiving high frequency electromagnetic waves”, United States Patent 6,395,971, Aug. 2000 (US), Deutsches Patent- und Markenamt, Patentschrift DE 199 38 199 C1, Aug. 1999 (DE).

[4] Zürcher, J.-F. and Gardiol, F. E.: “Broadband Patch Antennas“, Artech House (Boston-London, 1995).

[5] Klinger, M., Rioult, J., Ghys, J-P. and Ficheux, S.: “Wideband Total Radiated Power Measurement of Electronic Equipment in TEM and GTEM Cells”, *Proceedings of the 13th International Zurich Symposium on EMC*, (Zurich, Switzerland, February 1999), pp. 665-670.

[6] Zaid L., Kossiavas G., Dauvignac J. Y., Cazajous J. and Papernik A.: “Dual-Frequency and Broad-Band Antennas with Stacked Quarter Wavelength Elements”, *IEEE Transactions on Antennas and Probagation*, Vol. **47**, No. 4. (April 1999), pp 654-659.