

SOLAR CELL ANTENNAS IN WIRELESS COMMUNICATION AND RADIO BROADCAST SYSTEMS

Dr. C. Bendel¹, J. Kirchoff¹, N. Henze²

¹ Institute for Solar Energy Supply Technology
Koenigstor 59, D-34119, Kassel, Germany, cbendel@iset.uni-kassel.de

² University of Kassel
Wilhelmshoeher Allee 73, D-34121, Kassel, Germany, nhenze@uni-kassel.de

ABSTRACT: This paper describes the application of photovoltaic (PV) solar cells in planar antenna structures. The radiating patch element of a planar antenna is replaced by a solar cell. Furthermore radiating slots are built due to the cell spacing in a solar cell array. The original feature of a solar cell (DC current generation) remains, but additionally the solar cell is now able to receive and transmit electromagnetic waves. Both single solar cells as well as solar cell arrays can be used as antennas. Furthermore the application field of this new device in wireless communication systems is outlined.

Keywords - planar antenna, solar cells, simulation, mobile communication, vehicular application

1. INTRODUCTION

The growing demand for stand alone systems with wireless communication functions leads to the development of new products with a very high integration rate. In the case of environmental monitoring systems, vehicular communication systems or satellite systems a net-independent power supply is needed, which is preferably realisable by photovoltaic, an advanced technology distinguished by reliability, longevity and eco-friendliness. Besides that antennas are needed in order to receive or transmit electromagnetic waves. At present, photovoltaic generator and antenna compete for the available space on mobile and stand alone systems, which are generally limited in size.

communication devices or systems derive benefit from the simultaneous use of solar cell and antenna function with costs reduction at the same time.

2. APPROACH

The new approach 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 receipt of electromagnetic waves. The backside contact of solar cells is used as radiating element in terms of radio frequency. This new approach, the "Solar Planar Antenna – SOLPLANT[®]", avoids the disadvantages mentioned above. Based on these considerations, a product development concept was originated at whose basic idea has been registered as a patent in Germany, Europe, Japan and USA [3].

The basic principle of a planar solar cell antenna is pictured in Figure 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.

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. These results encouraged the design of planar antennas with photovoltaic solar cells.

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

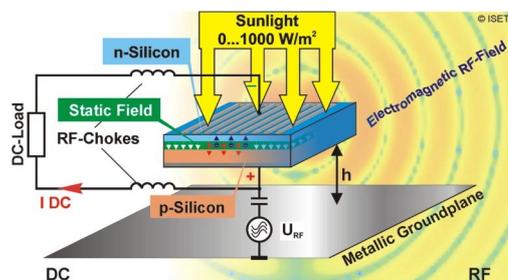


Figure 1 SOLPLANT[®], radiation of electromagnetic waves and DC current generation at the same time

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. The Institute for Solar Energy Supply Technology (ISET e.V.) invented an appliance which implies that the solar cell and antenna are combined as an integrated unit and that the electrical contacts which are available anyhow for operational reasons in a solar cell and a solar module are used simultaneously as antenna elements (see Figure 1). Previous investigations have shown that the "Solar Planar Antenna – SOLPLANT[®]" [1, 2] opens a very wide field of application. Especially mobile and wireless

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.

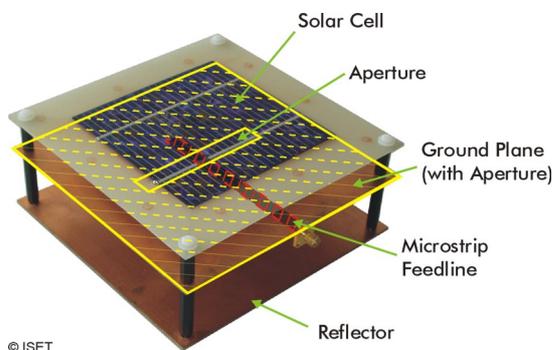


Figure 2 Laboratory prototype of an aperture coupled SOLPLANT[®] patch antenna.

The antenna includes three layers. A solar cell is laminated on the top layer. The middle layer has a metallic ground plane with slot (aperture) and on the backside a microstrip feedline. The bottom layer acts as reflector to reduce the radiation of the feed network. Slot and solar cell are two resonators which are responsible for the resonance and the radiation of the antenna

3. RESULTS

First studies in the accredited EMC laboratory of ISET/University of Kassel confirm the technical feasibility. Based on simulations, the radiation characteristics of different solar cell antennas (4-element array, coaxial and slot feed antennas, GPS antenna) were investigated. The results were verified by means of measurements.

At the University of Kassel, the development of a DVB-T (Digital Video Broadcasting Terrestrial) antenna laboratory prototype with beam forming is in progress and the development of a prototype of a GPS antenna for automotive use was finished successfully. An other product development uses a SOLPLANT[®] Antenna in combination with a digital WORLDSPACE satellite radio receiver.

Since photovoltaic solar cells are lossy materials in terms of radio frequency the effect on the antenna efficiency has been investigated by the wheeler cap method and measurements in a GTEM cell respectively. Compared to antennas with copper plates as radiating elements, the losses are about 1.5 dB [2].

Among others the resonance frequency of the solar planar antenna depends on the radiator area. Therefore RF optimisation criteria also affect the useful area for the solar energy conversion.

4. PRODUCT DEVELOPEMENTS

4.1. GSM Monitoring System

One of the first SOLPLANT[®] developments was an antenna for a wireless monitoring system in the GSM 900 band (Figure 3). 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.

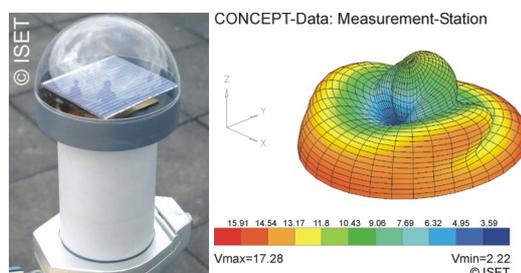


Figure 3 Prototype (left) and radiation diagram (right) of a stand alone monitoring system with SOLPLANT[®] GSM antenna

This solar antenna is based on an E-antenna. 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.

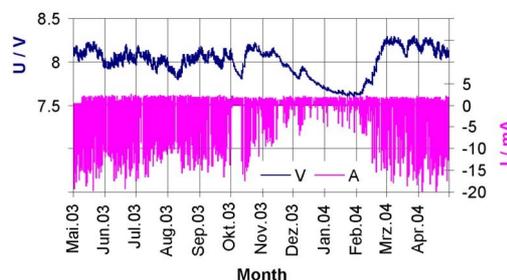


Figure 4 Battery voltage (upper trace) and charge / discharge current (lower trace) of the monitoring system between May 2003 and April 2004. The displayed curves are 2 hour average values. Positive current values are discharge values. Charge values are negative

The monitoring system was tested on the ISET test field in a time interval of one year. During this time the system was queried via GSM once every day. Battery charge- and discharge current and the battery voltage was measured every 15 seconds. A 10 minute average of these data was generated and saved by the ISET test field recording system.

In Figure 4 the 2 hour average of these data is pictured. During the whole test phase, the battery voltage varied only between 7.5V and 8.25V. The deepest break in of the battery voltage was measured between January and February. In this interval the irradiation was quite low, but temperature has also an influence on the battery voltage.

4.2. GPS Antenna for Automotive Applications

The main demand on GPS (Global Positioning System) antennas is a wide reception angle, because the GPS receiver needs at least the reception of four satellites at the same time to calculate the position (see Figure 5). The GPS antenna should consist of a solar cell array where several cells are used as radiating elements.

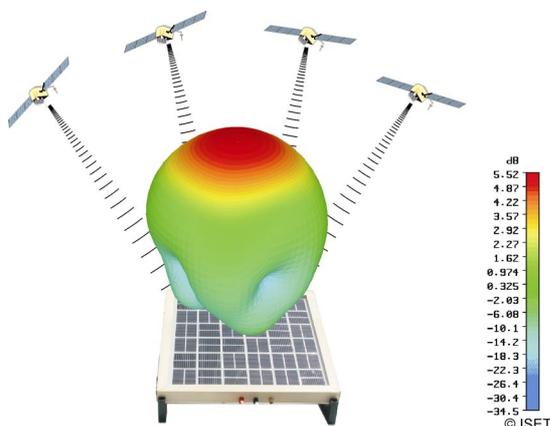


Figure 5 SOLPLANT[®] GPS-antenna pictured with the simulated reception antenna coil and with four GPS satellites

The basic principle is displayed in Figure 6. The aim of this study, realised by the University of Kassel [4], was to investigate the feasibility of using a solar cell array as GPS antenna. In a later stage of this project an integration of a SOLPLANT[®] GPS antenna in vehicular glass roofs is considered. Due to considerations concerning production the PV antenna module should be manufactured with usual manufacturing techniques. This involves a layered construction of the module as shown in Figure 6.

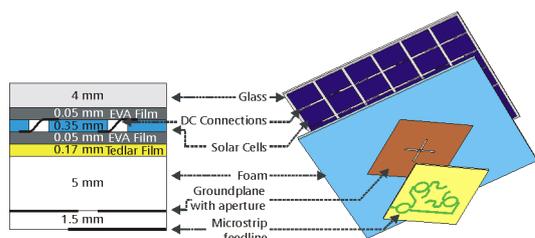


Figure 6 GPS antenna with 36 solar cells. Four cells are excited by means of apertures in a ground plane

The solar cells are embedded in EVA films (Ethylen-Vinyl-Acetat) which glues the solar cells on the glass substrate. The backside of the solar cell-EVA layer is covered with robust Tedlar[®] film which serves as a protective coating. The RF parts of the antenna are located underneath the photovoltaic layer. At first there is an antenna substrate (air or Rohacell foam). The aperture and the microstrip feedlines are etched on a FR-4 substrate. The overall thickness of this structure is less than 12mm. In Figure 7 the complete module is shown. For tests with several commercial GPS receivers a low noise amplifier was in the feeding network on the backside of the antenna. However a reception of the GPS signal is also possible with the passive solar cell antenna. The solar cells type used in this module is RWE TE 16 SFTTAP. The material is

mono crystalline silicon. In order to get the desired cell size of 49mm in square the cells with an original edge length of 100mm were cut in quarters. The cell voltage in the maximum power point of $V_{MPP} = 0.49$ V remains the same since only the current depends on the cell size. Thus the voltage of the whole module is 17.6 V. The short circuit current is 0.87 A. A detailed discussion of this antenna can be found in [5].

The generated DC current will feed an interior cooling fan which runs even when the car motor is switched off for a longer time.



Figure 7 GPS receiver and SOLPLANT[®] GPS antenna for automotive use. The PV energy runs an interior cooling fan

4.3. GSM Antenna for Automotive Applications

Similar to the GPS antenna in the previous section this antenna is also designed for the integration into vehicular glass roofs in order to provide a “dual use” of the solar cells as electric power generator and antenna respectively. The aim was to design antennas both for the GSM 900 and GSM 1800 band. The fixed size of the solar cells complicates the construction of a dual mode antenna therefore a single band antenna for the GSM 1800 band is presented here. This integrated planar antenna device should substitute conventional rod antennas on the car roof. Thus the requirements of the antenna are vertical polarisation in the horizontal plane and a monopole-like gain and radiation characteristic.

4.4. Antenna for a Worldspace Digital Satellite Receiver

The Worldspace digital satellite system was invented to deliver broadcast and education in digital quality to people of the third world. The satellites cover Africa, Asia the main part of America and parts of Europe including Germany. Worldspace uses the frequency range between 1453,384 and 1490,644 MHz with circular polarisation. Because of this low transmitting frequency, small antennas with moderate gain can be used to receive the Worldspace program, in contrast to conventional broadcast satellites with transponder frequencies between 12 and 14 GHz.

Unfortunately the available receivers consume a lot of power which is delivered by batteries. To extend the operating time of the receiver, ISET created a SOLPLANT[®] antenna which charges the battery during standby and supports the energy supply during the operation time of the radio. The antenna consists of two solar cells which are connected in series to deliver a voltage of about 1 volt. An integrated DC-DC

converter transforms this voltage into 9V to charge the battery of the radio.



Figure 8 Worldspace digital satellite receiver with SOLPLANT[®] satellite antenna. The solar energy recharges the battery during standby



Figure 9 Vision: Communication with remotely flying photovoltaic powered flying wing aircraft

5. CONCLUSIONS

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.

Applications of SOLPLANT[®] are in the fields of bureau and laboratory communication (Bluetooth), wireless environmental monitoring, online buildings observation 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.

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