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INSET-FED MICROSTRIP PATCH ANTENNA WITH INTEGRATED POLYCRYSTALLINE PHOTOVOLTAIC SOLAR CELL

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Abstract

A novel method of integrating microstrip patch antennas and polycrystalline silicon solar cells for application in autonomous communication systems is presented. The DC and RF functions are intimately linked, by using the silver DC bus bars of the solar cell as the ground plane of the microstrip patch. The performance of the solar antenna is compared with standard microstrip patch. Detailed studies of the effect of the solar cell on the microstrip antenna are then carried out. The effects of solar cell integration, DC loading and variation in incident photon intensity of the silicon layer on the performance of the solar antenna are discussed. The optimum orientation of the silver DC bus bars on the solar cell in order to achieve better antenna gain and radiation performance is also studied in detail.

1 Introduction

Autonomous communication systems often involve the use of separate solar cells and antennas, which demand a compromise in the utilisation of the limited space available. The precious space available for antennas for communication and solar cells for power generation can be saved by suitably integrating the solar cells with microwave antennas. Stand alone applications such as environmental monitoring systems, vehicular communication systems and satellite systems need a net independent power supply which is preferably realisable by photovoltaic techniques [1]. However, very few studies were carried out in this type of integration of solar cells with microwave antennas. The technique first used was placing solar cells directly on the microstrip patch antennas without covering the radiating edges of the patch [2]. Other combinations such as putting the solar cells behind the reflectarray antennas have also been studied. A higher level of integration was then made possible by integrating amorphous silicon solar cells with slot antennas [3]. Here the slot antennas were selected in order to minimize the effect of solar cells on the RF performance of the antenna. But this choice of slot antennas introduced drawbacks such as narrow bandwidth and poor circular polarisation performance. Complex laser cutting of the solar cells is required to achieve desired shapes of slots.

Most of these solar antenna designs use the amorphous silicon based solar cell technology which are less efficient with complex feeding mechanism. No work has been carried out to investigate the use of commonly available inexpensive high efficiency polycrystalline silicon solar cells in the design of solar antennas. The reasons behind this are mainly due to the brittle nature of these types of solar cells which are impossible to modify with different shapes for patch and slot antennas. Here we put forward a novel design of full integration of high efficiency polycrystalline silicon solar cells with planar microstrip patch antennas. The silver DC bus bars in the polycrystalline-silicon-solar cell are used as RF grounds of the inset microstrip line fed square patch antenna. An inset microstrip feeding technique enables the non-destructive integration of the crystalline silicon solar cell with the patch. Rigorous studies on antenna parameters were carried out to compare the proposed designs with standard microstrip patch antennas.

2 Solar antenna design

Figure 1. Exploded view of the proposed inset fed square patch solar antenna with different layer thickness

Polycrystalline silicon solar cells of dimension 15.6 x 15.6 x 0.026cm developed by SolLard have been selected for integration. The cell consist of an aluminium back contact
layer of thickness 35.71µm and silicon n'-p-p' layer with a thickness of 210.23µm. The 17.62µm thick Silver bus bars for DC collection forms the top layer. The initial electrical conductivity of the cell in dark state is 380.85mS/m which will vary with incident photon flux density. Standard conductivity values are used for Al and Ag for the simulation purpose. The overall dimension of 15.6 x 15.6 x 0.026cm makes this solar cell a perfect candidate for use in lower microwave frequencies as ground plane.

An inset fed square microstrip patch antenna is designed and optimised using the full wave integral equation based CST Microwave Studio. The basic structure of the inset fed square patch solar antenna is shown in Figure 1. The solar cell is modelled as a three layer structure of Al-Si-Ag, with all material and electrical properties defined. Silver bus bars are modelled as thin grids of 0.8mm width with 2.8mm spacing. An FR-4 (ε_r = 4.3) layer of thickness 1.52mm is used to place the solar cell and its DC circuitry. Total integration of the solar cell and the antenna is provided by using the densely placed DC silver bus bars over the silicon layer as an RF ground. As the skin depth of silver at 2GHz is 1.4330µm, an Ag-layer thickness of 17.62µm can act as perfect ground for the RF fields. Thus the DC and RF functions of the proposed solar antenna are intimately linked together and neither can perform without this common layer. Two RF blocking inductors are used at the DC load of the solar cell for good isolation between DC and RF functions of the device. The inset microstrip line fed patch is best suited for the integration since coaxial feeding is impossible through the polycrystalline-Si solar cell. The microstrip patch at 2GHz covers only an area of 11.49cm^2 which is only 4.7% of the total available illumination area of the solar cell.

The square patch with length, L = 3.39cm is fabricated in an FR-4 substrate of ε_r = 4.3 and height, h = 1.52cm. Conductive glue is used to connect the SMA outer conductor to the solar cell. Since the DC collection parallel silver bus bars have been used as RF ground, their orientation with respect to the 50Ω microstrip transmission line and the patch is crucial. The desired orientation of these Ag-bus bars is along the direction of the resultant electric field vector of the square patch, so that these parallel Ag lines can act as perfect electric surface for the RF fields. Thus the proposed solar antenna gain greatly depends on the orientation of the Ag-bus bars of the solar cell. Two models were built with Ag-bus bars orienting along the resultant electric field vector of the patch and across it, as shown in Figure 2. The performances of these models are then compared with a similar standard patch antenna with PEC as ground plane.

3 Results and discussion

Figure 3 shows the measured $S_{11}$ and received power values for the two solar antenna models compared to normal PEC ground plane. A summary of the measured and simulated results are tabulated and given in Table 1. A reasonable agreement of measured and simulated return loss and bandwidth can be observed for both models.

![Figure 3. Comparison of measured $S_{11}$ and $S_{12}$ for the two solar antenna models and the ideal PEC ground patch antenna](image)

The Ag-bus bars parallel to the feed line orientation shows better matching of resonant frequency and return loss agreement with the ideal patch antenna with copper ground plane. The received power curve shows that the Ag-lines parallel orientation of the solar cell is almost similar to that of the normal PEC ground plane.
Antenna type & Resonant frequency (GHz) & % Bandwidth & Gain (dBi) \\
& Measured & Simulated & Measured & Simulated & Measured & Simulated \\
Solar antenna (Ag-parallel) & 2.224 & 2.170 & 2.98 & 4.29 & 2.75 & 2.39 \\
Solar antenna (Ag-perpendicular) & 2.096 & 2.332 & 2.8 & 5.3 & 0.46 & 1.83 \\
Ideal patch & 2.256 & 2.230 & 2.29 & 3.41 & 3.10 & 3.60 \\

Table 1: Summary of measured and simulated solar antenna parameters

A good agreement between the simulated and measured results is obtained because of the fact that in simulation, the characteristic of the solar cell is respected with its layered structure by suitably defined material and electrical properties.

Nevertheless, prolonged exposure to radiation will heat up the solar cell which in turn cause slight variations in the relative permittivity and increase in the loss tangent of the patch antenna substrate. Variation of antenna return loss and received power is studied with different light intensity values for the solar antenna with parallel Ag-bus bars and plotted in Figure 6. Only minor change in resonant frequency and corresponding received power is observed with illumination.

Figure 4. Comparison of measured radiation patterns for the two Ag-bus bar orientations of the solar antenna and ideal PEC ground plane patch

A gain of 2.75dBi is achieved when Ag-lines of the solar cell is oriented along the electric filed direction of the patch compared to 3.1dB of the ideal PEC ground plane patch. Meanwhile, when the solar cell is oriented with Ag-lines perpendicular to the resultant electric field, the gain drops to 0.46dBi. Thus the concept that the parallel orientation of the Ag-bus bars can provide an ideal match for the usual PEC ground plane is validated from the measured gain values.

A comparison of measured radiation patterns for the two Ag-bus bar orientations of the solar antenna and with ideal PEC ground plane is given in Figure 4, for the E and H principal planes.

Figure 5 shows the co-polar radiation pattern for the solar antenna when it is connected to a DC load resistance. Only minor changes in radiation pattern are observed when the cell is connected to the DC load. In the proposed solar antenna design, the portion of the solar cell beneath the square patch and the microstrip line is not illuminated, and hence we cannot expect any variation in antenna properties with this change in silicon conductivity with light intensities.

Figure 5. Measured co-polar radiation pattern for the solar antenna with and without the DC load

Figure 6. Variations of solar antenna return loss and received power for different incident light intensity values
4 Conclusion

A new concept of integration between polycrystalline-silicon solar cells and microstrip patch antennas has been presented and demonstrated for applications in autonomous communication systems. The DC and RF functions are intimately linked, by using the Silver bus bars of the solar cell as the ground plane of the microstrip patch. Rigorous experiments and simulations on antenna parameters were carried out to compare the proposed design with standard microstrip antennas.

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