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Novel Techniques for the Integration of Antennas and Photovoltaic Cells

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***Abstract*-Various novel approaches to the integration of antenna and photovoltaic technologies are proposed. These include the use of polycrystalline solar cells as groundplane for microstrip patch antennas as well as for reflectors of half-wave dipole antennas. Transparent materials were also evaluated as antenna radiating elements, allowing greater solar efficiency. A novel technique illustrating how emitter-wrap-through rear contact solar cells can be used as a folded-dipole antenna, which is located in the focal line of a parabolic solar concentrator, to provide high solar efficiency as well as high antenna gain, is presented.**

I. INTRODUCTION

Solar energy is becoming an attractive alternative for powering modern communication systems. The integration of antennas and PV technology in a single multifunctional device reduces the marginal cost of renewable energy, improving its economic viability.

This paper summarizes the novel approaches taken by the authors for the integration of antennas and solar, providing greater efficiency and avoiding the need for laser cutting and RF-DC decoupling used in previously reported solar antennas [1, 2].

The use of high efficiency polycrystalline silicon (poly-Si) solar cells as ground plane for microstrip antennas as well as reflector for dipole antennas has been investigated. The radiation performance of a material that is both transparent and conductive such as AgHT-4, comprising a clear polyester film coated with nano-layers of metal oxides, was also evaluated on the glass cover of an amorphous silicon (a-Si) solar panel. And a unique approach was investigated for the integration of PV and antennas with the development of a photovoltaic dipole antenna made of emitter-wrap-through (EWT) rear contact solar cells, employing a solar concentrator. All the proposed designs were modelled and experimentally verified, and the advantages and drawbacks of each of the presented solutions are discussed.

The developed technology arises as a promising solution for the unification of building façade transceivers as well as for base stations in remote areas as part of an integrated autonomous system, so decreasing the use of grid-supplied electricity and hence contributing to the mitigation of climate change.

II. SOLAR ANTENNA DESIGNS

Fig. 1 shows the first prototype built using the polycrystalline silicon (poly-Si) solar cell as a ground plane for a 2.19 GHz square microstrip patch [3]. The poly-Si solar cell from *Solland* is 156 x 156 x 0.26 mm in dimension. On the upper surface, the Ag-lattice layer is 17.62 µm thick. It comprises 57 electrodes with a line width and separation of 0.1 mm and 2.64 mm respectively, and 2 orthogonally oriented bus bars that are 2 mm wide and separated by 74.18 mm. The n^+–p–p^+ doped poly-Si layer thickness is 210.23 µm and the lower Al contact layer thickness is 35.71 µm. The microstrip patch which is 33.62 mm square is printed on a single sided FR-4 substrate, of height = 1.52 mm and ϵ_r = 4.2, with a 50 Ω inset feed line in order to avoid piercing the brittle solar cell. The SMA port is grounded to the Al layer of the solar cell. Thus the solar cells acts as microwave ground plane for the antenna.

The main drawback of this configuration is clearly the shading obstruction of the light to the solar cell due to the microstrip patch. In order to reduce this shading a half-wave dipole was developed, as presented in Fig. 2, using this same type of solar cell as reflector. The dipole of length 47mm, width 5mm printed on FR-4 substrate and spaced 1.57mm from the solar cell though a printed balun [4]. A 3mm wide 50Ω microstrip line with solar cell as RF ground plane connects the dipole to the SMA connector.

In order to further reduce the solar cell shading, the radiation performance of AgHT-4, a material that is both transparent and conductive, was evaluated. The proposed structure, shown in Fig. 3, consists of a multilayer proximity-coupled feed configuration with an amorphous silicon (a-Si) glass panel of dimensions 85mm x 55mm x 2.3mm as ground plane and lower substrate. Directly placed on the glass of the solar module, a 1.4 mm width 50 Ω copper transmission line couples to a 19 mm square transparent patch located on top of a 3mm thick clear Perspex superstrate.

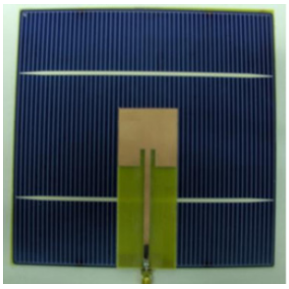

Figure 1. Poly-Si solar cell acting as the ground plane for a microstrip patch antenna.

Figure 2. Poly-Si solar cell acting as reflector for a dipole antenna.

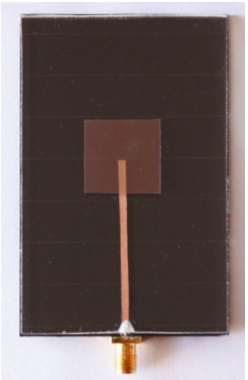

Figure 3. A-Si panel acting as the substrate for transparent proximity-coupled patch antenna

A 50 Ω SMA port is connected to the copper transmission line and grounded to the metallic rear electrode of the solar panel, so the solar cell serves also as ground plane for the microstrip antenna as well as DC generator.

A unique approach was investigated for the integration of PV and antennas with the development of a photovoltaic dipole antenna employing a solar concentrator, as seen in Fig. 4. For this structure, four identical 40mm x 3mm emitter-wrap-through rear contact solar cells were connected in series as a folded [5]. A split coaxial balun is implemented on a 50 Ω semi rigid coaxial line and positions the dipole antenna along the focal line of a parabolic solar concentrator made of a conducting reflector surface, with the active side of the cells facing the reflector. The dipole-to-reflector distance is a quarter-wavelength. The DC connection and the feed line pass through a 9mm radius hole to the back of the reflector.

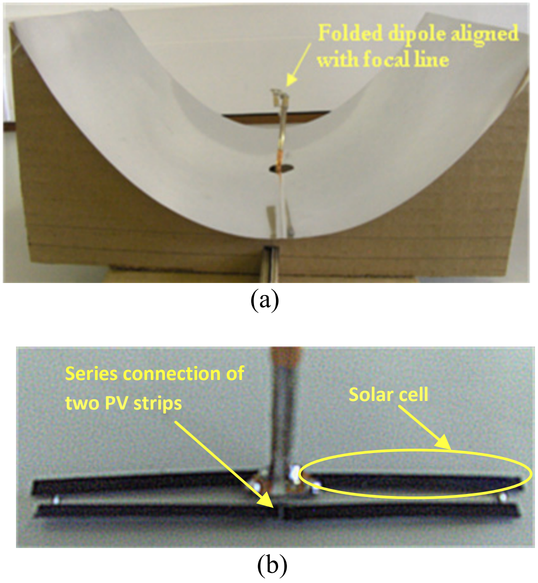

Figure 4. (a) Solar folded-dipole antenna with parabolic reflector/solar concentrator (b) detailed picture of the four series connected EWT solar cells forming the folded-dipole.

III. Results and Discussion

The field flux lines from radiating edges of a half-wave microstrip patch are typically parallel to the microstrip feed, which is used as an orientation reference. To interpret the impact of the inhomogeneous conducting groundplane below the truncated FR-4 substrate; the feed line for the antenna shown in Fig. 1 was aligned (1) parallel with the Ag electrode lines, (2) perpendicular with the Ag electrode lines, and (3) contrasted with a homogenous copper (Cu) groundplane. The S_{11} results are presented in Fig. 5, and the E-and H-plane radiation patterns for each of these Ag-lattice orientations are shown in Fig. 6. While the parallel and perpendicular orientated Si groundplanes loose small amounts in peak gain values, the radiation patterns are similar to the homogeneous copper case. Cross-polarization isolation values exceeding 20 dB on boresight are observed for both orientations of the Ag-lattice

The same three orientations were also investigated for the prototype of Fig. 2 where the solar cell acts as reflector for the dipole antenna. A summary of the radiation properties of

TABLE I
Summary of Radiation Properties for Microstrip Patch and Dipole with the Poly-Si Solar Cell as Ground Plane and Reflector Respectively.

Ground plane configuration	Frequency (GHz)		Bandwidth (%)		Gain (dBi)	
	Patch	Dipole	Patch	Dipole	Patch	Dipole
Parallel Ag-Lattice	2.190	2.339	3.11	15.8	1.23	8.60
Perpendicular Ag-Lattice	2.168	2.348	3.13	13.1	1.05	8.60
Copper	2.276	2.347	2.42	13.4	2.60	8.84

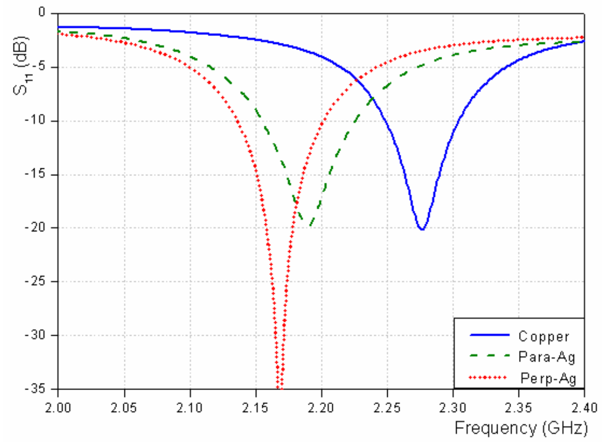

Figure 5. Measured S_{11} for the microstrip poly-Si solar antenna configurations.

both the microstrip patch and the dipole with the poly-Si solar cell can be found in Table I. It can be seen that the dipole with reflector is less sensitive than the patch to the orientation of the solar cell. It offers also greater bandwidth and gain. The main advantage of the microstrip patch with the solar cell ground plane is its flat profile and no need for a complex balun arrangement in the feed, which clearly simplifies the design and integration with the solar module.

A summary of the radiation properties for the transparent antenna seen in Fig. 3 is presented in Table II. This shows that the gain of the transparent patch on solar substrate is only 1.85 dBi below its copper counterpart for the frequency band. It is worth mentioning that, for the transparent antenna, the electromagnetically-coupled copper line was replaced by a transparent film feed line and a peak measured gain of –0.8 dBi was obtained. An early attempt to employ the *Solarex* panel directly as a single-layer substrate (without Perspex and using copper microstrip feed) for the transparent patch resulted in a peak gain of –2.5 dBi, thus the combination of the Perspex and the proximity coupling are key in improving gain.

In the antenna design presented in Fig. 4, a totally different approach was considered. The EWT solar cells connected in series as folded dipole are used for power generation and as the radiating element. The parabolic structure acts as a solar

TABLE II
SUMMARY OF RADIATION PROPERTIES FOR THE TRANSPARENT PATCH ON A-SI GLASS SOLAR MODULE, AND COMPARISON WITH ITS COPPER COUNTERPART.

Configuration	Frequency (GHz)	Bandwidth (%)	Gain (dBi)
Copper	3.598	12.7 %	5.81
Transparent	3.618	13.1 %	3.96

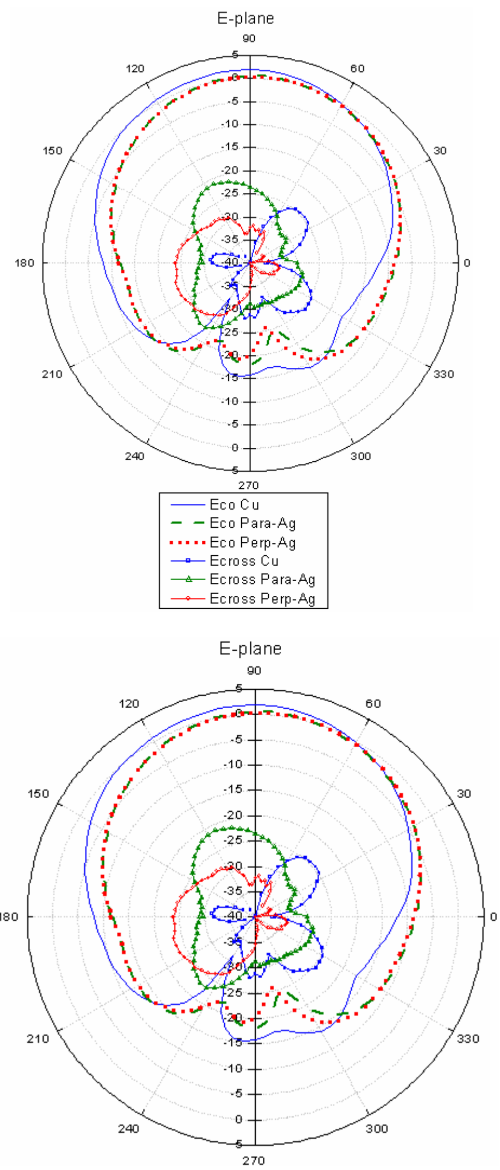

Figure 6. Measured radiation pattern for the two Ag- lattice orientations and the copper microstrip antenna.

concentrator for the photovoltaic cells increasing the illuminated flux on the PV surface, thus reducing the amount of PV material required, and simultaneously acting as an antenna reflector. The measured and simulated S11 of the proposed antenna is shown in Fig. 7 with good agreement. The E- and H-plane radiation patterns for center frequency can be seen in Fig. 8 for the center frequency, with a measured cross-polar rejection better than 20 dB for both planes. The bandwidth was 21 % in the 1.5 GHz band, with a maximum gain of 11.1 dBi. A 10% increase in the current was achieved due to solar concentration as shown in Fig. 9, providing an output of 73.7mW for an irradiance of $1000 W/m^2$.

IV. CONCLUSIONS

A variety of technologies for the integration of PV and antennas was investigated. A 2.19 GHz microstrip low-profile antenna design with acceptable performance is

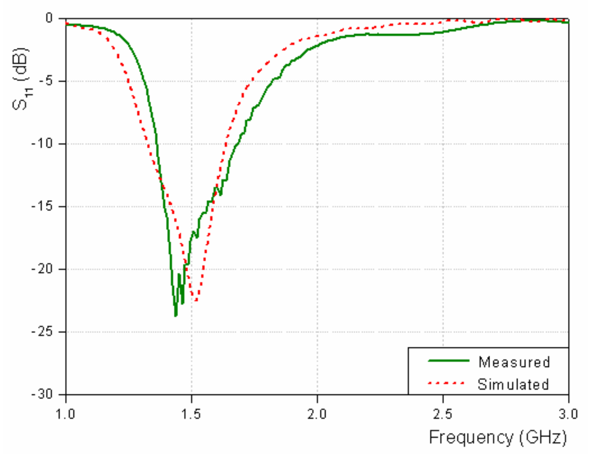

Figure 7. Measured and simulated S_{11} for the folded dipole with parabolic reflector.

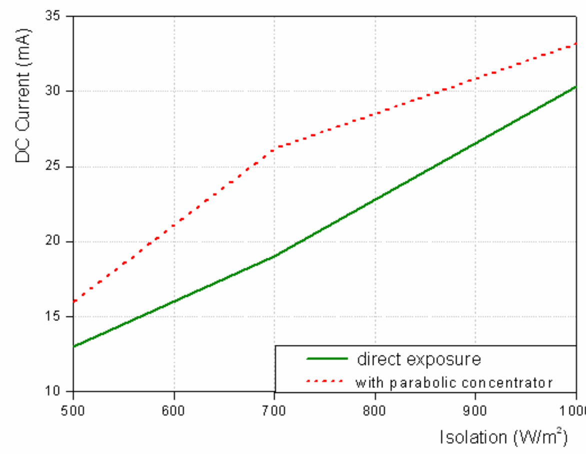

Figure 9. Measured DC current with isolation for direct exposure of the solar cells and concentration due to parabolic reflector.

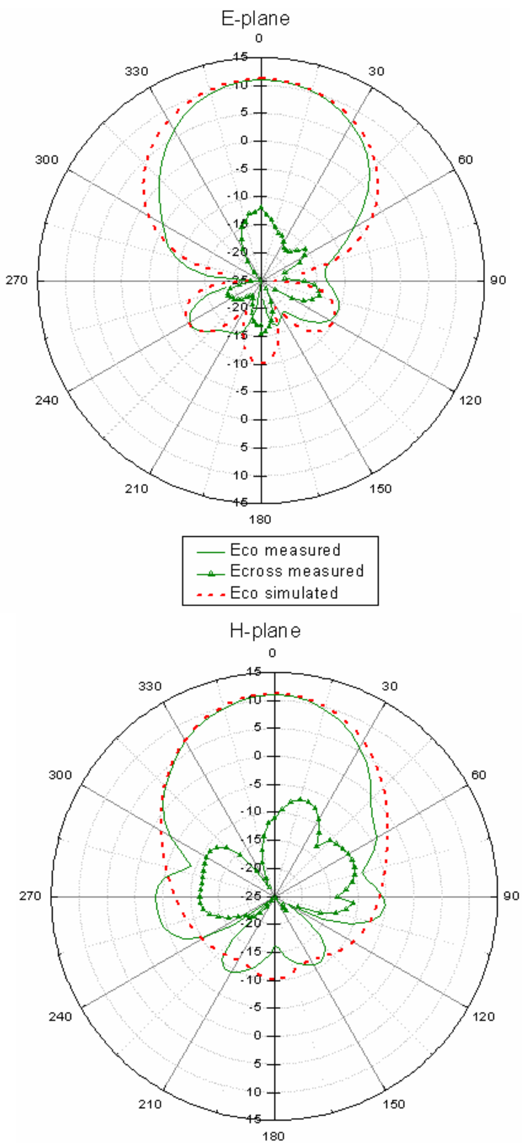

Figure 8. Measured and simulated radiation pattern for the folded dipole with parabolic reflector.

reported using a poly-Si solar cell as ground plane. The same poly-Si solar cell used as reflector for a dipole provides a high-efficiency structure with the radiation properties independent of the orientation of the front silver lattice of the solar cell. In order to minimize the shading of the solar element, a transparent microstrip patch was successfully deployed in a 3.9 dBi antenna for the cover of an a-Si glass solar module. A novel folded dipole comprising EWT rear contact solar cells with a parabolic reflector is also proposed, in a structure where the PV cells act as the RF radiating element, and the antenna reflector works simultaneously as solar concentrator, for greater antenna and solar efficiency.

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