

Integrated solar panel antennas

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A new antenna which combines solar cells and printed patches is presented. The antenna is designed so as to accommodate the solar cells that provide power to an MMIC amplifier. A 2×4 array is presented, which operates at the frequency of 3.76GHz and has a bandwidth of 16% and gain up to 30dBi (active).

Introduction: Autonomous communications systems often involve the use of separate solar cells and antennas, which necessitate a compromise in the utilisation of the limited surface area available. These separate items may be combined thus saving valuable 'real estate', provided that the antennas and solar cells are compatible [1]. One method for achieving this is to integrate the two kinds of device on the same element.

In particular, solar panels occupy a large proportion of the total surface area of communications satellites, providing large flat surfaces over which antennas can be mounted, or printed. Printed antennas, commonly used in microwave communications, are naturally suited for this combination, in particular when their radiating patches can be isolated from the feed circuits [2]. Amorphous silicon solar cell technology has been found to be suitable for realising the solar antennas [3]. Of course, the integrated combination of these devices would also be of interest for terrestrial systems.

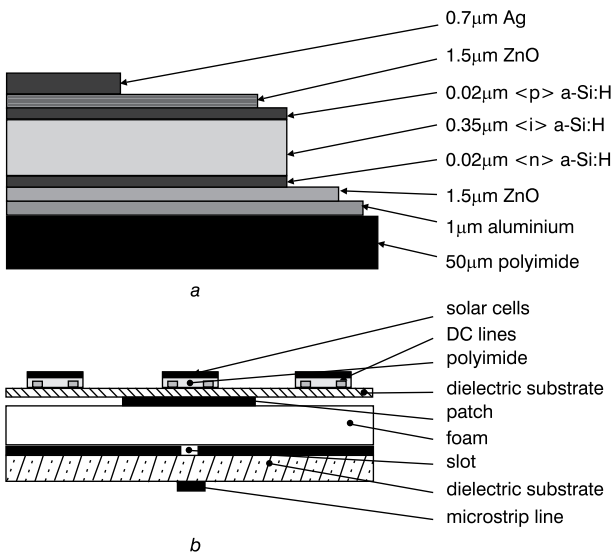
Solar antenna concept 'SOLANT': In the first reported attempt to combine solar cells with printed antennas, commercial solar cells were merely placed next to a patch antenna [1]. In the present approach we use a more advanced concept, in which specifically designed solar cells are intimately combined with printed antennas, providing a new device called SOLANT.

In the work presented in this Letter, we have selected a patch printed on a multilayered substrate as the candidate antenna. The SOLANT concept allows solar cells to be incorporated in the final structure as thin additional layers or stacked patches. This has been made possible owing to two breakthroughs: the use of innovative thin film solar cells and the inclusion of them in the electromagnetic design to achieve a compact and optimised structure.

A polyimide substrate is covered by an aluminium layer (back contact) and by a ZnO layer which prevents aluminium diffusion. These two layers also form a mirror.

The actual solar cell comprises three silicon layers: a thin high conductivity phosphor doped *n*-layer ($\sim 10^{-3}$ S/cm), an intrinsic (undoped) layer with a low defect density and a highly conductive (10^{-6} S/cm), very thin *p*-layer. Most photons are absorbed in the intrinsic layer, while the doped layers are responsible for the build-up of an electric field within the solar cell.

The collector layer on top of the cell must be both transparent and conductive and hence it is made of transparent conductive oxides (TCOs). Since even the best TCO has ohmic losses, a silver finger pattern is deposited on top. Overall, the cell thickness is $< 5\mu\text{m}$, to which must be added the currently used $50\mu\text{m}$ thick polyimide substrate. Although showing a lower efficiency (5–10%) than GaAs solar cells, which are currently used in space applications, a-Si:H cells give the best W/kg ratio due to their low weight. Moreover, they are inexpensive and some preliminary tests demonstrate that a-Si:H cells have a promising degree of hardness against cosmic radiation.

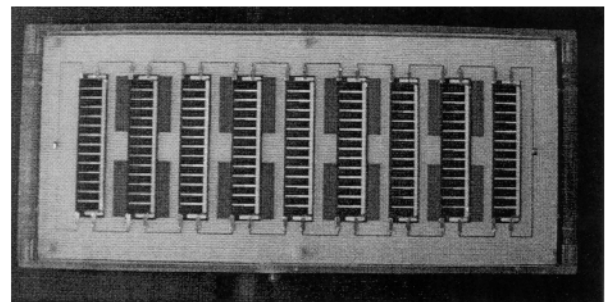


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Fig. 1 Cut outs of amorphous solar cell and antenna (thickness not to scale)

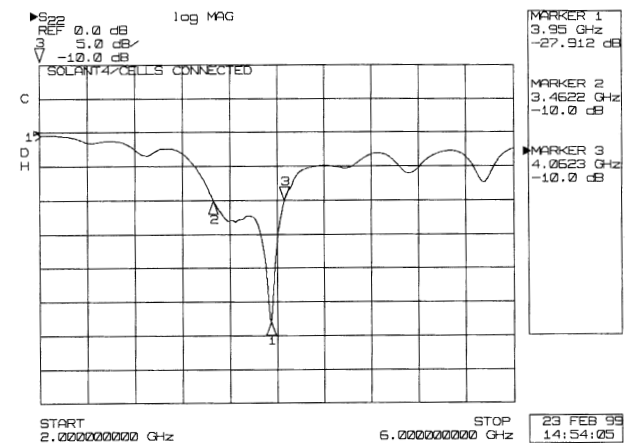
a Amorphous solar cell, showing different layers
 b Antenna

Description of solar cell technology: For the solar cell technology, innovative amorphous silicon (a-Si:H) solar cells developed by the University of Neuchâtel [3] were selected. These cells appear as thin, light, flexible films that can be cut to fit complex patch or array shapes and, eventually, conformed to curved surfaces. Fig. 1a shows a lateral view of the solar cell structure.



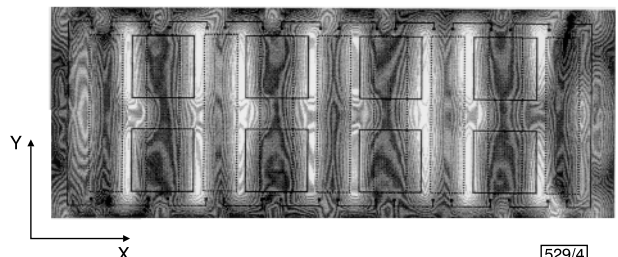
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Fig. 2 SOLANT 4 patches and solar cells



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Fig. 3 SOLANT 4 return loss (S_{11}) against frequency



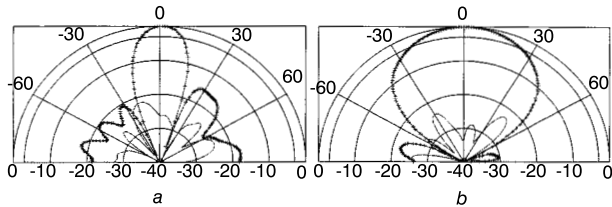
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Fig. 4 SOLANT 4 near field scan E_x at 3.95 GHz

Light grey represents maximum value of E_x

Description of antenna development: The antennas make use of the strip-slot-foam-inverted-patch (SSFIP) principle [2], in which radiating patches are excited through slots. The cut-out of the antenna (Fig. 1b) shows the different regions of the device, with the solar cells on top of the structure, because they must be exposed to the light. The radiating

patches are printed on the bottom side of a thin epoxy dielectric, and the DC connecting lines of the solar cells are printed on top of the epoxy. The solar cell strips are glued on the top of the antenna, and they are connected to the DC lines with small bronze-beryllium ribbons.



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Fig. 5 SOLANT 4 far field pattern at 3.95 GHz

a XZ cutting plane
b YZ cutting plane
 + co-polarisation
 — cross-polarisation

To design the antenna from an electromagnetic point of view, the thin (50 μm) polyimide substrate of the cells was considered to be an additional layer ($\epsilon_r = 3.5$) on top of the multilayered antenna substrate. The solar cells themselves are then modelled as zero-thickness patches with a surface boundary impedance condition [4]. This is reasonable since the relevant thickness (5 μm) is even smaller than the copper thickness used for the patches (10–30 μm). With this strategy, any commercial or homemade software based on the integral equation model [4] can be easily adapted to this problem.

Computer simulations have enabled us to study the case with partial or total overlapping of the solar cells and radiating patches and have provided design guidelines for the identifications of the antenna regions which cannot be covered by cells. Several prototypes were designed and built, starting with a single radiator followed by the combination of several elements to make a phased array.

In the most recent development, called SOLANT 4 (exhibited at Salon du Bourget, Paris in June 1999), an array of eight elements (4 \times 2) was realised, based on SSFIP antenna technology, integrated with nine solar cells strips supplying an MMIC amplifier on the back of the antenna (Fig. 2).

The antenna is matched at a frequency of 3.76 GHz, providing a bandwidth of 16% for an S_{11} level better than -10dB , and the nine solar cells

produce 252 mW at 4 V. The largest gain of the assembly, which reaches 13.75 dBi for the passive antenna, increases up to $\sim 30\text{dBi}$ with the MMIC amplifier. The measured input impedance (S_{11}), the near field distribution and the far field pattern are shown in Figs. 3–5, respectively, (in all cases, the cells are connected).

Conclusions: We have developed prototypes in which a printed antenna array has been combined with solar cells which show very good operational characteristics, thus demonstrating the validity of the concept. The technology for realising such designs has been developed to a practical level. The power already provided by the solar cells in a small sub-array is adequate for feeding a signal amplifier. Work is in progress to improve the accuracy of the computer simulation, in particular through a better estimation of the complex permittivity of a-Si:H solar cells at microwave frequencies.

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