

Dual Band a-Si:H Solar-Slot Antenna for 2.4/5.2GHz WLAN Applications

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Abstract. A simple and compact design of solar-slot antenna for dual band 2.4/5.2GHz wireless local area networks (WLAN) applications is proposed. The design employs amorphous silicon (a-Si:H) solar cells in polyimide substrate with an embedded twin strip slot structure to generate dual resonant frequencies. A T-shaped microstripline feed is used to excite the twin slot in the a-Si:H solar cell. The measured impedance bandwidths for the proposed solar antenna are 25.9% (642 MHz) centered at 2.482 GHz and 8.2% (420 MHz) centered at 5.098 GHz. The measured gain at 2.4 and 5.2 GHz are 3.1 dBi and 2.1 dBi respectively.

Keywords

Solar antenna, slot antenna, amorphous silicon.

1. Introduction

The idea of integration of photovoltaic solar cells with microwave antennas offers a wide range of advantages in terms of surface coverage, volume, mass, cost and electric performance when compared with a simple juxtaposition of antennas and solar cells. Recently, communication systems integrated with photovoltaic technology for low cost and stand alone applications received much interest [1-5]. The photovoltaic systems of power generation when combined with communications systems can provide compact and reliable autonomous communication systems for many applications.

In most of the reported attempts of integration of solar cells with printed antennas, commercial solar cells are glued or placed next to the radiating patch or in the ground plane of slot antennas [6]. Other combinations like placing the solar cells behind the reflectarray antennas have also been studied [7]. Successive development of an amorphous-Si cell on a flexible thin film polymer substrate realized an improved photovoltaic performance at lower cost. Here a higher level of integration was then made possible by integrating amorphous silicon solar cells with microstrip slot antennas [8]. 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

antenna introduced drawbacks such as narrow bandwidth and poor circular polarization performance. Complex laser cutting of the solar cells is required to achieve desired shapes of slots. This makes the design of dual-frequency and multi-frequency solar slot antennas difficult, as complex slot structures in solar cells are hard to engrave. Moreover, the large dimension of the slot structures will degrade the solar cell efficiency. Printed slot antennas are widely studied for WLAN operation [9, 10]. The key to provide a flexible design is to make the slot in the solar cell as small as possible with a basic geometric shape to excite the dual resonant modes.

In the present approach, flexible amorphous silicon solar cells are used to design a compact dual band microwave slot antenna operating at 2.4/5.2GHz WLAN application. The proposed design consists of an amorphous silicon solar cell in polyimide substrate where a twin strip embedded rectangular slot is imprinted at the centre of the solar cell. The performance of the proposed solar antenna is optimized using a finite integral equation based electromagnetic simulator. Details of the proposed solar-slot antenna design are described, and experimental results for the dual broadband performance are presented and discussed.

2. Solar-Slot Antenna Design

The photograph of the proposed a-Si:H solar-slot antenna design for 2.4/5.2GHz WLAN application is shown in Fig. 1. To realize total integration of the photovoltaic solar cell and the antenna, amorphous silicon solar cells of dimension 72.58 x 68.76 mm were used as the ground plane for the microstrip slot antenna. The a-Si:H solar cell consists of a p-i-n silicon layer of thickness 0.39 μm and $\epsilon_r = 11.7$ sandwiched between two zinc oxide (ZnO) layers of thickness 1.5 μm . An aluminum layer of thickness 1 μm acts as the back contact. The transparent and conductive ZnO layer (1.5 μm) on the top acts as the collector. Finger patterns with silver forms (Ag-bus bars) the top layer of the cell. The bottom and top layers of polyimide ($\epsilon_r = 3.4$, $\tan\delta = 0.0018$) and silver electrodes are 50 μm and 0.7 μm respectively.

A rectangular shaped slot of length $L=30$ mm and width $W=17.7$ mm is located on the solar cell at its centre as shown in Fig. 2(a). Two rectangular PEC strips of

dimension $l = 15.7$ mm and $w = 1.8$ mm are etched on one side of the FR-4 substrate as shown in Fig. 2(b).

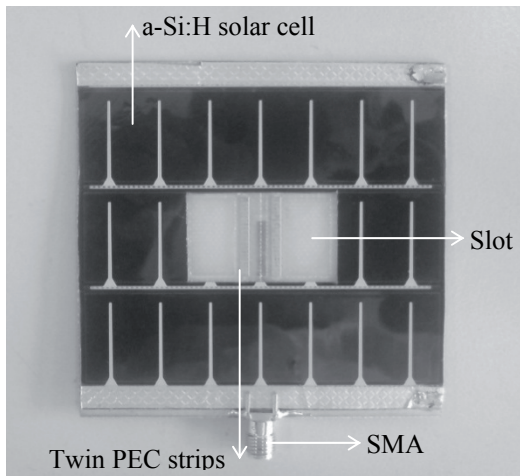


Fig. 1. Photograph of dual band a-Si:H solar-slot antenna.

The separation between the twin PEC strips is $d = 4.5$ mm. To achieve good impedance matching for the two resonant modes, a T-shaped microstripline feed imprinted on the other side of the FR-4 substrate is used. The optimized dimension of the feed line are $l_f = 36.09$ mm, $w_f = 1.41$ mm, $l_t = 2.6$ mm and $w_t = 1.41$ mm. The a-Si:H flexible solar cell with the central rectangular slot is then attached to the FR-4 substrate of permittivity $\epsilon_r = 4.3$ and thickness 0.8 mm. Once attached to the FR-4 substrate, the central rectangular slot of the a-Si-H silicon solar cell along with the twin PEC strips forms a dual strip loaded slot structure as seen in Fig. 1. Accordingly the ground plane of the above formed solar-slot antenna constitutes the solar cell with two rectangular PEC strips.

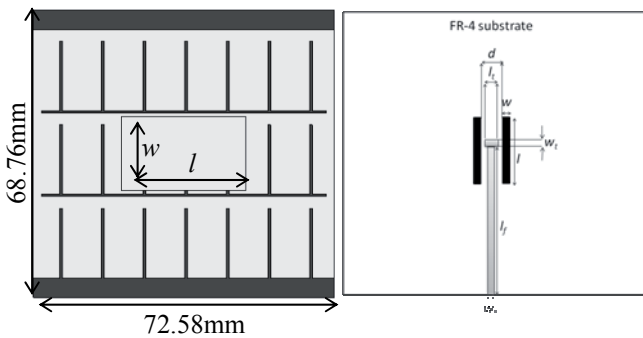


Fig. 2. (a) Solar cell with rectangular slot. (b) Twin PEC strip and T-shaped feed on the rear side of FR4 substrate.

This fully integrated unit has both DC and RF functions closely linked, sharing the same metallic structure. Neither the antenna nor the solar cells can function without this common layer. The metallic and semi-conducting silicon layers in the solar cell together form the RF ground plane of the solar-slot antenna. In order to establish the effect of the slotted solar cell acting as the ground plane material for the slot antenna, a comparative study is being carried out with a similar conventional slot antenna with copper in ground plane (PEC). The various dimensions of the central

rectangular slot and twin strips are given in Fig. 2. For the proposed 2.4/5.2GHz WLAN operation, the design parameters used are, $L = 30$ mm, $W = 17.7$ mm, $l = 15.7$ mm, $w = 1.8$ mm, $d = 12.6$ mm, $l_f = 36.09$ mm, $w_f = 1.41$ mm, $l_t = 2.6$ mm, $w_t = 1.41$ mm, $\epsilon_r = 4.3$, $\tan\delta = 0.02$ and substrate height $h = 0.8$ mm.

The solar cell is modeled in the finite integral equation based CST Microwave Studio as a six layer structure as Polyimide-Al-ZnO-Si-ZnO-Ag, with all material and electrical properties defined. The presence of the twin inner strips effectively excites the second resonant frequency of the slot. Moreover, the spacing between the twin strips gives an effective way of fine tuning the resonant frequencies of the slot and its impedance matching without altering the slot dimensions in the solar cell. This feature is highly desirable in solar antenna design due to the constraints in etching the complex slot geometries which in turn deteriorate the solar cell performance.

3. Results and Discussion

Based on the parametric studies carried out using CST MWS, a prototype solar slot antenna is fabricated and measured. Fig. 3 shows the simulated S_{11} of the proposed solar slot antenna. It is clearly seen that two separated resonant modes at the desired operating frequencies are successfully excited with a single microstripline T-feed element. From the measured results, the lower resonant frequency has a -10dB impedance bandwidth of 642 MHz (25.9%), which is sufficient to cover the 2.4GHz ISM, WLAN and WiMAX bands.

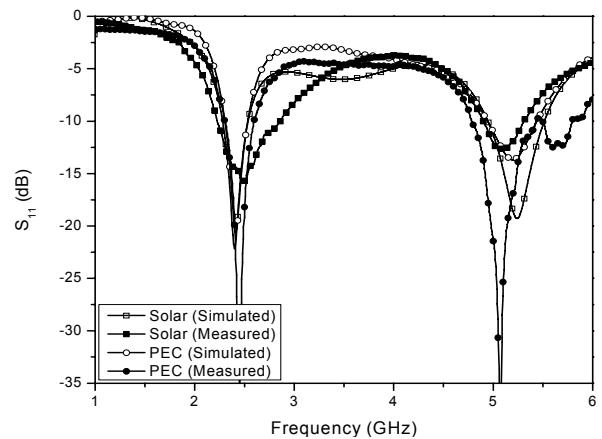


Fig. 3. Measured and simulated S_{11} of the solar antenna and ideal PEC slot antenna.

For the second resonant frequency, the measured -10dB impedance bandwidth is 420 MHz (8.2%) to cover the 5.2 GHz band for WLAN & UNII operation. From the measured and simulated S_{11} of the solar and PEC type antennas in Fig. 3, it is apparent that the a-Si:H solar cells can effectively act as ground plane for a microstrip slot antenna. The results obtained are given in Tab. 1. The effect of the solar cell ground plane on the slot antenna was determined by comparing the gains of the solar antenna and its PEC counterpart. A reduction in antenna gain of 1.3 dB

and 1.4 dB are observed for first and second resonant frequencies respectively, with the solar antenna design. The gain of the solar antenna at the two operating frequencies is measured in a far field anechoic chamber. The measured gain of the proposed slot antenna across two operating bands is better than 3.1 dBi and 2.1 dBi in 2.4 and 5.2 GHz operation bands, respectively. The variations of measured gain in both operating bands are plotted in Fig. 4.

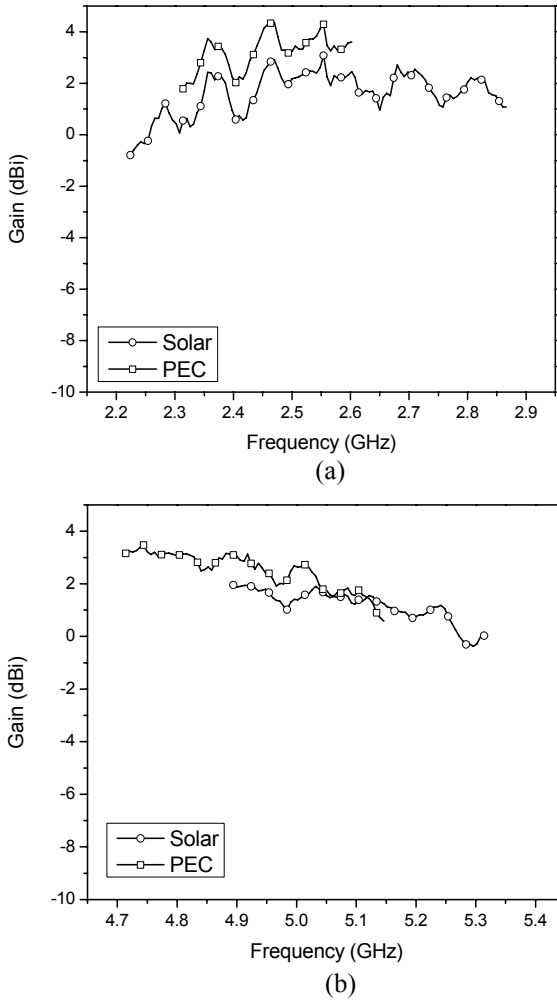


Fig. 4. Measured gain for solar and PEC type antennas. (a) 2.4 GHz and (b) 5.2 GHz.

The measured and simulated far-field non-normalized radiation patterns at the two operating WLAN frequencies for the proposed slot antenna are plotted in Fig. 6. Both resonant modes are in same polarization plane and show similar broad beam radiation characteristics. It is worth noticing that the radiation patterns of the solar antenna in both resonant modes are not distorted, which in turn validate the proposed method of solar/RF integration. Fig. 5 shows the surface current distribution at 2.4 GHz and 5.2 GHz showing the excitation of the dual mode.

	f_1 (GHz)	f_2 (GHz)	%BW ₁	%BW ₂	Gain ₁ (dBi)	Gain ₂ (dBi)
Solar	2.486	5.098	25.9	8.2	3.1	2.1
PEC	2.440	4.948	11.8	8.7	4.4	3.5

Tab. 1. Measured solar and PEC antenna parameters.

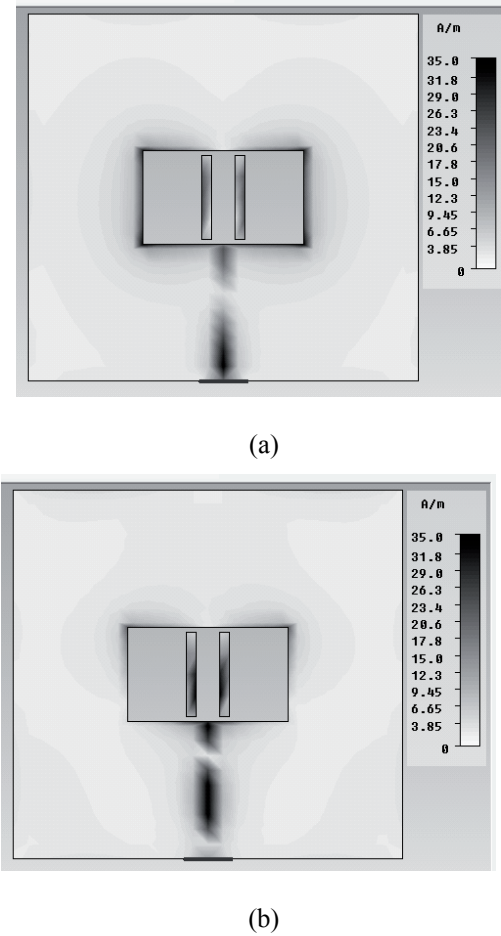


Fig. 5. Simulated current densities of the solar antenna. (a) 2.4 GHz and (b) 5.2 GHz.

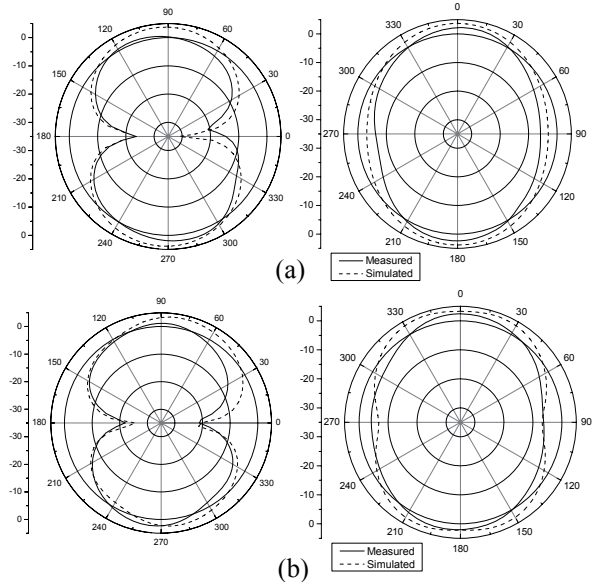


Fig. 6. Measured and simulated co-polar radiation pattern for solar-slot antenna. (a) 2.4 GHz and (b) 5.2 GHz.

A parametric study has been carried out to determine the effect of twin strip loading in the rectangular slot. In the absence of twin strips, the second resonant mode of the rectangular slot is not well excited with the T-shaped

microstripline feed (Fig. 7). The inclusion of the two strips excites the second resonant mode with a matching better than -10 dB. The central rectangular slot dimension in the solar cell has less degree of freedom because cutting the slot distorts the DC bus bars of the solar cell, adversely affecting its DC output. Hence, for the present design, the dimension of the central slot is fixed as 30 x 17.7 mm, which is 10.6% of the total solar cell surface area.

As this slot dimension is fixed, tuning of the two resonant modes of the solar-slot antenna is carried out by varying the spacing d between the twin strips. With $d=4.5$ mm, both resonant modes can be excited simultaneously using the T-shaped feed. Fig. 7 shows the simulated S_{11} variation of the proposed antenna with the twin strip spacing.

From the solar point of view, the DC output of the solar antenna deteriorated due to the etching of the rectangular slot in the solar cell. In ambient conditions, the cell can provide an open circuit voltage, $V_{oc} = 2.3$ V and short circuit current, $I_{sc} = 0.25$ mA. However, at an incident insolation of 1000 Wm^{-2} the measured characteristics of the solar cell used are $V_{oc} = 4.6$ V and $I_{sc} = 49$ mA.

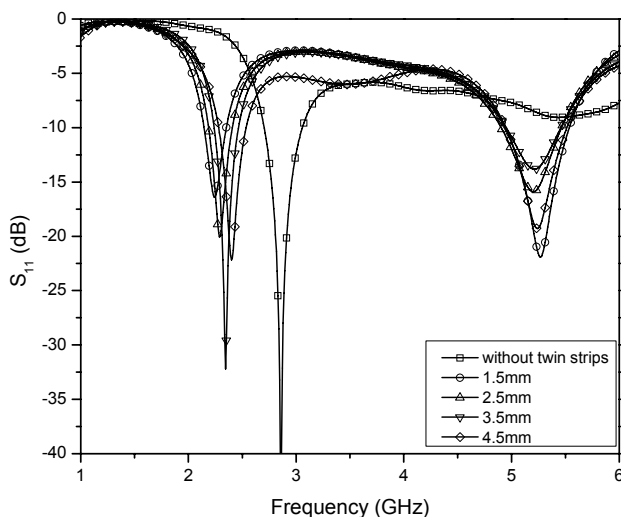


Fig. 7. S_{11} variation of solar-slot antenna with twin strip spacing.

4. Conclusion

A novel compact design of solar-slot antenna for dual band 2.4/5.2GHz WLAN applications is proposed. Amorphous silicon (a-Si:H) solar cells in polyimide substrate with an embedded twin H-shaped slot structure are used to generate dual resonant frequencies. A T-shaped microstripline feed is used to excite the twin H-slot in the a-Si-H solar cell. Good impedance bandwidth of 25.9% (642 MHz) centered at 2.482 GHz and 8.2% (420 MHz) at 5.098 GHz is achieved. The measured gain at 2.4 GHz and 5.2 GHz is 3.1 dBi and 2.1 dBi respectively.

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About Authors

SHYNU S. V. received his PhD in Microwave Electronics from Cochin University of Science and Technology, Kochi, India in 2006. He was awarded STEC research fellowship (2002) from Govt of Kerala to carry out research on electronically reconfigurable microstrip antennas with PIN diodes and varactors at the Dept of Electronics, Cochin University, which subsequently lead to his Ph.D. Later on, he worked as a senior project fellow to develop reconfigurable microstrip antennas for mobile and satellite communication systems, in a major project sponsored by University Grants Commission of India. His PhD has resulted in more than 20 international papers and conference participations widely cited in international technical literature. He is a member of IEEE. In 2006, he joined Dublin Institute of Technology, Dublin, Ireland as a post doctoral research associate. Since then he has been involved in the integra

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Maria J. ROO ONS received her M.S degree in Telecommunication Engineering from the University of Vigo, Spain, in January 2006. Her master was carried out as Erasmus student in University of Applied Sciences, Saarbrücken, Germany. After an internal training in the prototyping department of BenQ-Siemens Mobile (Germany), she joined the Antenna & High Frequency Research Group of the School of Electronic and Communications Engineering at the Dublin Institute of Technology (Ireland) for her doctoral degree in October 2006. Ms. Roo Ons current research focuses on the integration of antennas with photovoltaics.

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Brian NORTON received his MSc and PhD degrees, in Engineering Experimentation and Applied Energy respectively, from Cranfield University and DSc from the University of Nottingham. He is a Fellow of the Irish Academy of Engineering, the Energy Institute and the Institution of Engineers of Ireland. He is a Chartered Engineer (both in the UK and Ireland) and Member, Higher Education Academy. Among his awards are the Gold Medal of the Amir of Bahrain for "outstanding research achievement in solar thermal applications.", the Napier Shaw Medal of the Chartered Institute of Building Services Engineers (CIBSE), the Roscoe Award of the Energy Institute and the Honorary Fellowship of the CIBSE, the highest honor for his professional discipline. From 1989 he was Professor of Built Environmental Engineering at University of Ulster (UU) and in 2003 he was made an Honorary Professor of UU. He has been with DIT since 2003. In 2007 he was made an Honorary Professor of Harbin Institute of Technology and was awarded a "Solar Energy" journal best paper award.