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Integration of Microstrip Patch Antenna with Flexible Thin Film Solar Cell

Naresh .B, Vinod Kumar Singh, V.K Sharma

Abstract: The implementation of flexible Dual band rectangular ring patch antenna combined with a thin film solar cell is reported. The multiple layers in the encapsulation of the thin film solar cell are used as substrate for the antenna design. The measured impedance bandwidth of the proposed solar antenna are 1.82 GHz-1.87 GHz (2.71%) centered at 1.85 GHz and 2.38 GHz-2.48 GHz (4.11%) at 2.45 GHz .The measured gain at 1.85 and 2.45 GHz are 4.47 dBi and 4.16 dBi respectively. The flexibility of the antenna is also tested by bending radius of 6cm was used and antenna performed well in bent Condition too. This antenna is suitable for applications like wearable Radio Frequency energy harvesting, to powering the implanted electronics or sensors.

Keywords:

I. INTRODUCTION

The electronic devices and sensors are integrated into clothing to become body worn is referred as wearable technology (e-textiles). Currently, usage of electronic gadgets is rapidly expanding. Electronic devices are miniaturized in size, and as such power consumption is considerably reduced by new design technologies. Technological advances allow many types of electronic devices to operate wirelessly to communicate and to recharge battery. These electronic devices could be powered through energy harvesting. Mostly the energy can be harvested from the energy sources like solar cell [1], piezoelectric thermoelectric and microwave energy sources [2-5].The energy harvesting technology will reduce weight burden. These batteries have negligible maintenance cost. Mostly RF power can be regenerated.

Integration of solar cell and microstrip patch antenna into a single device can harvest energy from both sun and microwave; moreover, it is used for communication purpose too. The solar cell antenna has more potential applications like wireless power sensors, autonomous remote control, microsatellites [6, 7]. Integration of antenna with Photovoltaic for communication purpose is reported in [8] and a compact flexible solar cell for remote tracking and control applications is given in [9, 10].The design of hybrid energy harvesting system has been discussed in [11].

By using basic formulas we can calculate the dimensions (length, width) of a dielectric substrate upon which antenna is designed; in that case there is no constrains on dimensions of the substrate. However, in this paper an attempt is made to integrate a microwave antenna with solar cell by using the space available around the solar cell in the form of encapsulation; which means the substrate dimensions are fixed and upon that encapsulation antenna must be designed. In references mention above, researchers designed antenna on FR-4, Plexiglas materials as substrate. Then antenna is integrated with solar cell surface to above, below or by making a cut with in solar cell, thus reduce the electrical performance, increase weight and system would not be wearable.

In this work, design of wearable and flexible dual band rectangular ring antenna is discussed. A thin film amorphous solar cell encapsulation was used as substrate for the dual band rectangular ring antenna, the encapsulation contains multi layers of fluorine-based plastic such as ethylene-vinyl acetate (EVA), Ethylene tetrafluoroethylene (ETFE), Polyethylene terephthalate (PET). The selected solar cells were flexible thin film amorphous silicon (a-Si) solar cells with open circuit voltage of V_{OC} = 2 V and short circuit current of I_{SC} = 420 mA.

II. DESIGN OF FLEXIBLE ANTENNA

The geometry of the proposed antenna is shown in Fig.1.At first, the rectangular patch with dimensions L1=58 mm and W1=198 mm is printed on the top surface of the solar cell. Then, A rectangular slot with dimensions L2=50 mm and W2= 188 mm is inserted to cut way the selected portion to form a rectangular ring. The dimension (L2 X W2) of the cut inserted is same as dimension of the stainless steel sheet used in flexible solar cell fabrication and is shown in Fig.2a. A partial ground plane has the dimensions Lg=22 mm and Wg=188 m and Inset feed technique is used to match the impedance of the rectangular ring to SMA connector for better results. Any microstrip antenna mainly required three elements that are radiating element, dielectric substrate and ground plane. The radiating rectangular ring and ground plane are designed by a copper foil tape and encapsulating materials are mostly dielectric materials. The overall thickness of the antenna is 1mm and thickness of the multilayers in the substrate (encapsulation) are shown in Fig.2b and the encapsulation layers electrical properties with thickness are presented in Table 1.

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Naresh.B*, Electrical Engineering, Bhagwant University, Ajmer, India. Email: nareshbangari@gmail.com

Vinod Kumar Singh, Electrical Engineering, SRGI, Jhansi, U.P, India. Email: singhvinod34@gmail.com

V K Sharma, Electrical Engineering, Bhagwant University, Ajmer, India. Email: viren_krec@yahoo.com

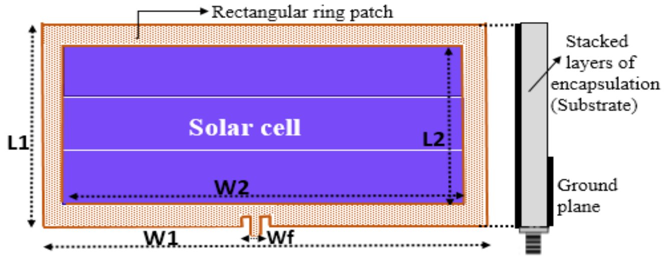
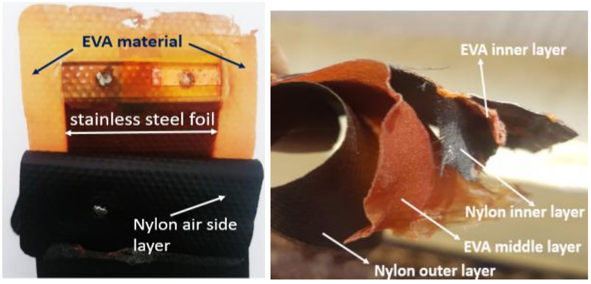


Fig. 1. Geometry of a rectangular loop microstrip antenna

The flexible solar cell consists of a p-i-n silicon layer of thickness 0.4 μm and dielectric constant (ε_r) = 11.7 sandwiched between two zinc oxide (ZnO) layers of thickness 1.5 μm is modelled in Computer Simulation Technology (CST) Microwave software to observe the effect on antenna. The solar cell encapsulation layers (substrate) are modelled in CST Microwave Studio as a six layer structure as Nylon-EVA-Nylon-EVA-ETFE, with all material and electrical properties defined.



a *b*

Fig. 2 a) solar cell back view b) layers in encapsulation of a solar cell

Table- I: Layers presented in encapsulation

S.No	Parameter	Thickness [μm]	Dielectric permittivity(ε_r)
1	Nylon outer layer	30	3.6
2	EVA middle layer	250	2.92
3	Nylon inner later	30	3.6
4	EVA inner layer	150	2.92
5	ETFE layer	50	2.6

III. SIMULATION RESULTS

In this section, the performance of the proposed antenna has been studied by changing the physical dimensions. A parametric study is first performed by changing the width (W2) of the inner rectangle and partial ground plane length (L_g) of the proposed antenna. The proposed antenna is designed in CST microwave studio software is shown in Fig.3 and the layers inside the encapsulation are also modelled, shown in Fig.4. The effect of varying inner rectangular width is shown in Fig.5. It is clearly shown in the figure that by selecting the proper value of W2 (188 mm) only have dual band resonance frequencies. For a width of 186 mm there is no resonance frequency and for the widths of 187 mm &189 mm, proposed design has dual band response but out of the selected resonance frequencies.

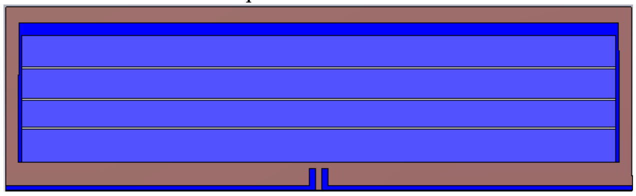


Fig. 3. Rectangular loop microstrip antenna designed in CST software

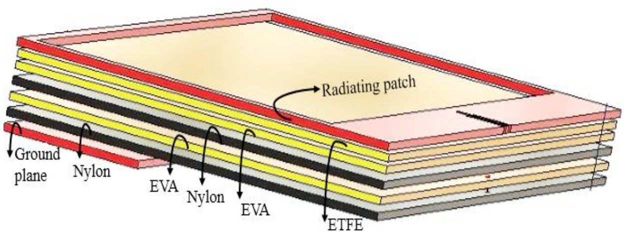


Fig.4. Substrate layers modelled in CST microwave software

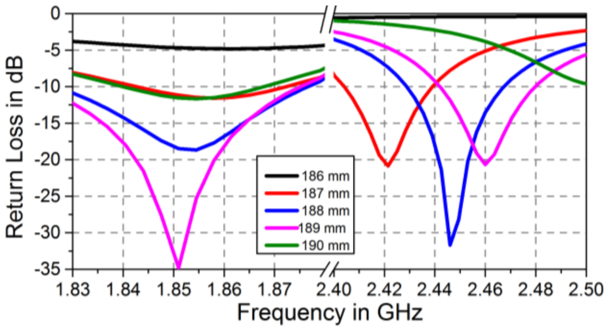


Fig.5. Variation of return loss for different values of length (W2)

The Fig.6 shows the effect of variation of the ground plane length (Lg) from 22 mm to 24 mm. Ground plane length mostly affects the higher resonance frequency because in return loss plot second operating frequency (2.45GHz) is shifting towards higher frequency side with increasing length of the ground plane. At the same time there is no much effect on lower resonance frequency (1.85GHz), except for the fact that the return loss magnitude is increases. Therefore a length of 22.5 mm is selected as the optimum value for the design.

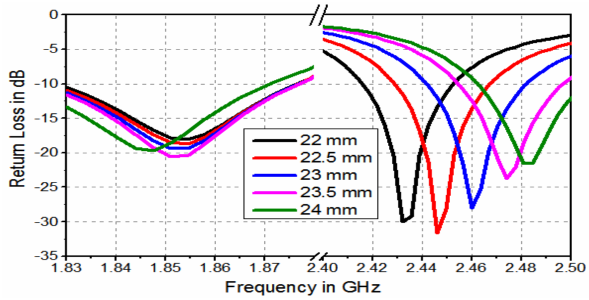


Fig.6. Variation of return loss for different values of length

(Lg)

Fig.7 and 8 shows the simulated surface current distribution of the proposed antenna in both the resonating bands.

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It has been observed in that, radiating patch as more current at lower at resonance frequency compared to upper resonance frequency which in turn validate gain.

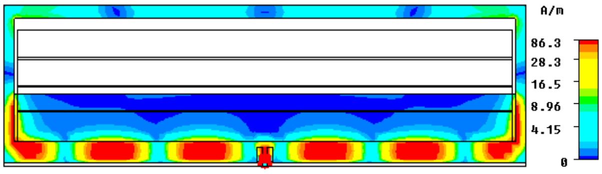

Fig.7. Simulated surface current distribution of the proposed antenna at 1.85 GHz, 0°

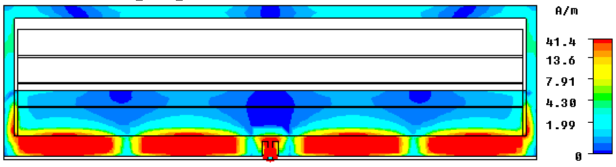

Fig.8. Simulated surface current distribution of the proposed antenna at 2.45 GHz, 0°

Simulated 3D radiation pattern of the antenna designed in CST microwave software is shown in Fig.9. The directivity obtained in first band is 5.24 dBi at 1.85 GHz and 4.79 dBi at 2.45 GHz.

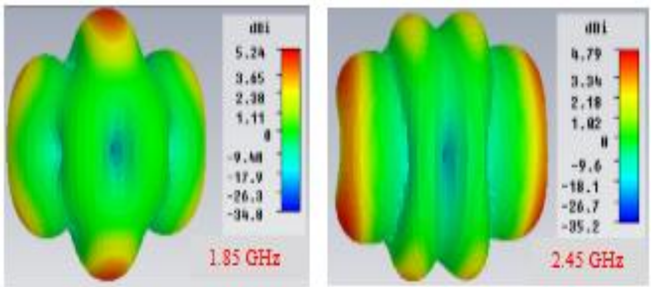

Fig. 9. Simulated 3Dradiation pattren of principale planes

IV. RESULTS AND DISSUSION

The fabricated antenna on flexible multilayer substrate is depicted in Fig.10. Rectangular ring shape radiating patch is on the top of the solar cell and partial ground plane is on the back side of the solar cell shown in Fig 11.

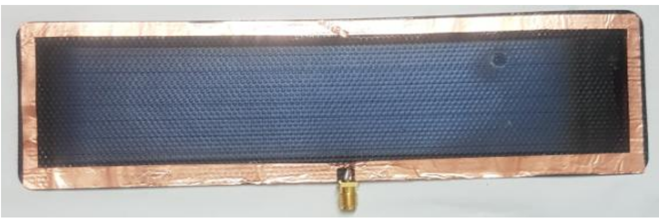

Fig.10. Fabricated flexible antenna on solar cell front view

Fig.11. Fabricated flexible antenna on solar cell back view

The key-sight microwave analyzer is used to measure the return loss parameters of the antenna in both bent and flat conditions. The photograph of the experimental setup for measuring return loss of flat antenna is shown in Fig.12. The measured return loss for bent antenna radius (r=14mm) with the help of microwave analyzer is shown in Fig.13.

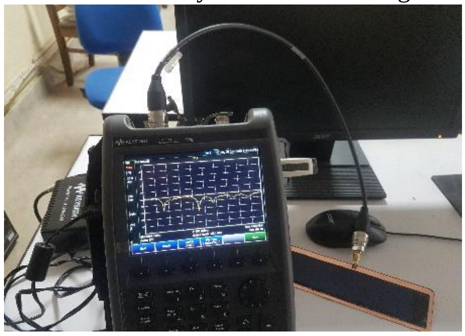

Fig.12. Experimental setup for measuring return loss of flat flexible antenna

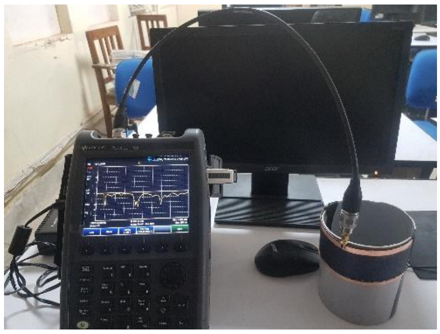

Fig.13. Experimental setup for measuring return loss of the H-plan bending (r=6cm) antenna

In Fig. 14 the measured result shows that the antenna has dual band nature, The resonance frequencies are 1.85 GHz and 2.45 GHz with bandwidths of 1.70 – 1.90 GHz (200MHz) and 2.35- 2.48 GHz (130 MHz). The resonance frequency of first band is 1.85 GHz with return loss magnitude of -27dB and the resonance frequency of the second band is 2.45 GHz with the return loss magnitude of -28 dB. The antenna return loss in bent format has no effect in lower band, whereas, at upper band the return loss character has two resonance frequencies. Furthermore, antenna has maintained the dual band nature in bent conditions with return loss less than -20dB though it has multiple layers of substrates. In case of stacked layers there may be some air gaps in between layers; however, in encapsulation process air between layers is removed and a high pressure is applied on multilayer so that they becomes single layer. As a result proposed flexible antenna has better performance in flat as well as bent condition.

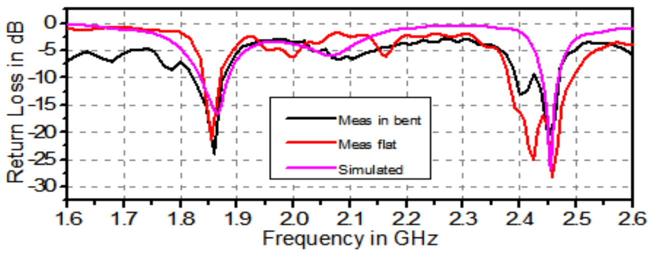

Fig.14 Comparative simulated and measured return loss (S11) in dB

The E-plane and the H-plane radiation patterns are measured at both the frequencies in flat and bend format (r=6cm).

The Fig.15 shows the E-plane and H –plane radiation pattern at 1.85 GHz, nature of the H- plane radiation pattern is closely Omni-directional with small reductions at 1.85 GHz and the Fig.16 shows the radiation pattern at 2.45 GHz. There is not much change in antenna radiation patterns in flat and bent conditions and the performance of the flexible antenna is explained in Table 2.

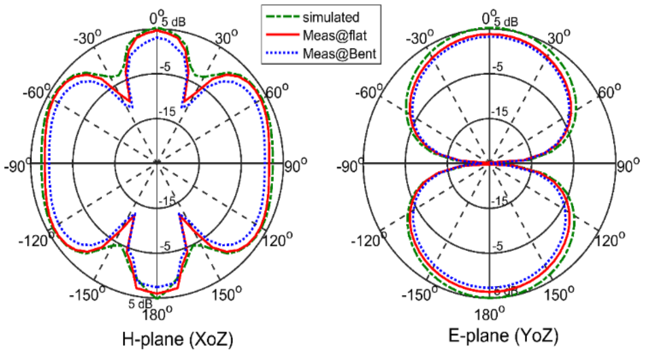

Fig.15 Simulated and measured radiation pattren of principale planes at 1.85GHz

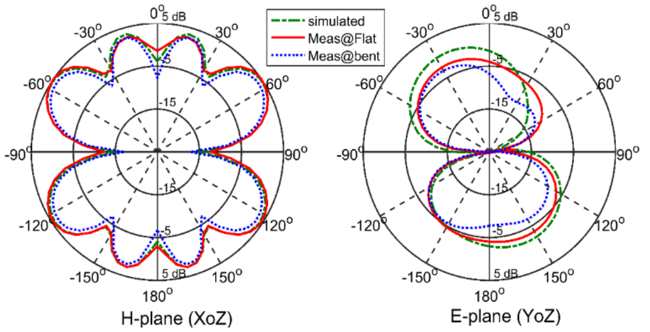

Fig.16 Simulated and measured radiation pattren of principale planes at 2.45GHz

Table-II: Flexible antenna Performance

S.No	Condition	Band width%	Gain (dBi)		Directivity (dBi)	
			Sim	Meas	Sim	Meas
1	Flat Antenna	2.71	4.66	4.47	5.24	4.86
2		4.11	4.31	4.16	4.79	4.32
3	Bent Antenna	2.17	NA	3.84	NA	4.13
4		2.04	NA	3.27	NA	3.88

V. CONSLUSION

A flexible microstrip antenna is successfully integrated with thin film solar cell. The multilayer encapsulation materials such as EVA, nylon and top layer ETFE are used as substrate. The measured impedance bandwidth of the proposed solar antenna are 1.82-1.87 (2.71%) centered at 1.85 GHz and 2.38-2.48 (4.11%) at 2.45 GHz .The measured gain at 1.85 and 2.45 GHz are 4.47 dBi and 4.16 dBi respectively for flat antenna. This antenna is flexible and wearable, the performance of the presented antenna in mechanical bending (radius =7 mm) conditions is better as compared to existing textile antennas. Accordingly, this antenna is well suited for powering the implanted electronic devices by means of harvesting solar and electromagnetic energies. Wearable electronics could be integrated into accessories and clothing such as shirts, glasses, watches, hats, which makes easy access of the everyday activities.

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AUTHORS PROFILE

Naresh B. received B.Tech and M.Tech degrees in Electrical and Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India in 2006 and 2012. He is currently pursuing Ph.D in Electrical engineering from Bhagewant University, Ajmer, Rajasthan, India.

Dr. Vinod Kumar Singh is an Associate Professor in Electrical Engineering Department of S.R. Group of Institutions at U.P. He received his Ph.D. degree in Electronics and Communication Engineering from B.U. Rajasthan, in 2013. He received M. Tech. in Digital Communication System from B.I.E.T., Jhansi in 2009. His area of expertise includes design of wide and dual band microstrip antenna, Ultra wide band textile antenna and wireless power transmission.

Dr. V. K. Sharma has done his B.E. from KREC (NIT) Surathkal, M.Tech from IIT Delhi and PhD also from IIT Delhi. He has done one year stint as post-doctoral fellow at Ecole Technologie Superiere at Montreal Canada. His area of interests include DSP control of electric drives, active filters, power electronics application to power systems and renewable energy conversion techniques, sensor networks, computational algorithms etc.