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DESIGN OF LOW PROFILE WIDE BAND SOLPLANT WITH DGS

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ABSTRACT

This paper illustrates the composition of photovoltaic solar cells in planar antenna geometry. The nature of a solar cell kept intact in addition to receive and transmit electromagnetic waveforms. There shown a good agreement with measured and simulated results. Furthermore the application field of this new structure in wireless communication systems is summarized. Experimental and full-wave simulation results of the presented solar planar antenna, SOLPLANT, operating within the frequency band of 1.9-11.6 GHz, confirm the suitability of the proposed design for wideband communication systems with a wide impedance bandwidth of 18.36%, 452.3 MHz, and a high gain of 9.102 dB. In this paper, cross shape defected ground structure is projected to improve the Bandwidth, return loss, efficiency and compactness of micro strip patch antenna. The performance of antenna is characterized by the shape, dimension and location of defected ground structure at specific position on ground plane. These antennas have significant advantages such as low profile, light weight, relatively low manufacturing cost, and polarization diversity. This paper compares the performance of micro-strip patch antenna having radiating elliptical shape with varying DGS profile. To compare and analyse the performance, High Frequency Structure Simulator (HFSS) software is used.

Keywords: solar cell, poly-Si, elliptical, DGS, HFSS.

INTRODUCTION

Solar energy plays a significant role in powering communication systems in the areas where there is no electric grid connection available, such as space and the isolated regions on Earth. Moreover, increasing energy demands in the 21st century with decreasing amounts of fossil fuels to meet this requirement results in a continuous increase in the energy prices and a high level of greenhouse gases released as a result of the use of fossil fuels. Using an alternative sustainable energy source, the Sun, with decreasing panel manufacturing costs and increasing efficiencies, solar cells have a potential of addressing these challenges and thus have attracted much attention in different application areas, from houses to satellites.

The planar antennas, on the other hand, including micro strip patch antennas, printed on dielectric substrates are widely used in mobile communication, WLAN and WiMAX systems due to their simplicity, making them easy to manufacture, and compatibility with monolithic microwave integrated circuits (MMICs) at high frequencies, enabling them to be used as embedded elements in MMICs.

Although solar energy has become a primary choice for powering communication systems in an environmental friendly way with a low carbon footprint, the standalone involvement of solar panels and microwave antennas within these systems requires a compromise in the utilization of the limited available space. This becomes a significant problem when it comes to solar powering low-profile WLAN and WiMAX systems as the autonomous use of solar panels calls for an additional surface area in these systems with the advancement in wireless communication technology, the need for light weight and miniature size antenna have become a mandatory requirement in today's world. The most popular antenna in this category is micro-strip patch antenna.

The micro-strip patch antenna have several advantages over other antennas such as low profile, low weight, relatively low manufacturing cost, simple fabrication process, polarization diversity and can be easily modified and customized that can be mounted on a flat surface, here PV cell.

Figure-1 shows the straightforward integration principle of solar cell with antenna structure. The amalgamation of two separate devices via stacking them back-back without compromise in the radiation properties of the antenna.

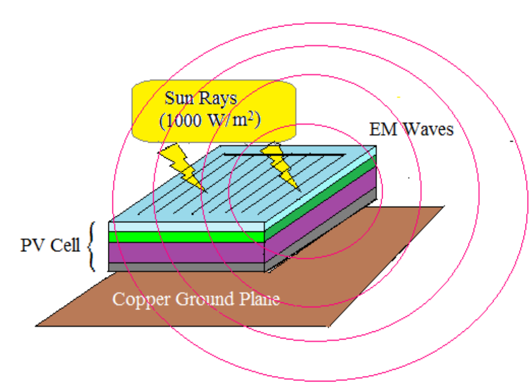

Figure-1. Solar cell planar antenna.

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This paper considers elliptical shape of the patch used in micro-strip patch. Figure-3 shows the structure of the cross shaped DGS etched on the metallic ground plane of a microstrip line.

SOLAR CELL

Four different solar cell technologies are considered for integration with antennas, namely, polycrystalline silicon (poly-Si) solar cell, monocrystalline silicon (mono-Si), emitter-wrap-trough solar cell (EWT), amorphous silicon (a-Si). We have chosen a standard polycrystalline silicon (poly-Si) solar cells which are available with solar energy efficiencies (>12%) which approach those of monocrystalline silicon (mono-Si) (>15%) but with a considerably lower cost. The presence of Silver lines affects the E an H radiation patterns and impact on slight reduction in Gain of the antenna.

ANTENNA DESIGN METHODOLOGY

A) Elliptical radiating patch

The most commonly used configuration for the patch antenna is elliptical. It is easy to analyze using both transmission line model and cavity model which are most accurate for thin substrates. A quarter transformer feeding is used to excite the antenna. This feeding is often used for matching purposes.The elliptical patch antenna dimension is 18mm×11mm using the dielectric substrate having permittivity 4.4 and thickness is 1.6mm.

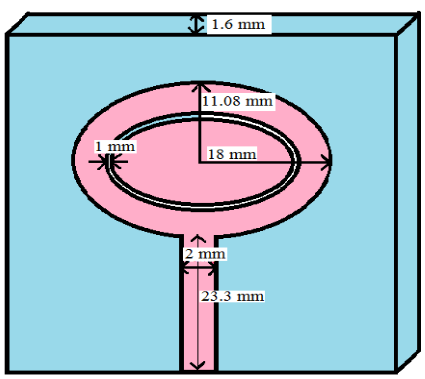

Figure-2. Radiating elliptical patch.

The dimension of quarter transformer feed which is used for the elliptical patch antenna of the resonant frequency 3GHz are length 23.2mm and feed line width is 2mm which results in a good match with 50Ω.

The design of proposed patch antenna with DGS is shown in the Figure-2. This figure shows the process of building the cross shaped DGS patch antenna.

In this antenna design, a rectangular patch on the upper plane of the antenna and etched meander shape structure on the ground plane. The dimension of cross shaped DGS are 22 mm, 24mm, 28mm, 4mm in length and 4 mm is wide.

B) DGS ground plane

In the past few years several new techniques have been applied to designing radio frequency RF/microwave components. One of them is the Defected Ground Structure (DGS). The DGS is a deliberately etched periodic or non- periodic cascaded configuration defect in the ground plane of a planar transmission line.

It disturbs the shield current distribution in the ground plane which eventually changes the characteristics of a transmission line such as line capacitance and line inductance. The use of various DGS geometries has been reported in the literature, such as rectangular, circular, square, dumbbell, spiral, L shaped, concentric ring, U-shaped and V-shaped, hairpin DGS, hexagonal, cross shaped, arrow head slot, inter digital DGS etc. Depending on the shape and dimensions of the defect the shielded current distribution in the ground plane is disturbed resulting in a controlled excitation and propagation of the electromagnetic waves through the substrate layer.

The work reported in this paper mainly focuses on the cross shaped DGS for high frequency filtering applications. Figure-3 shows the structure of the cross shaped DGS etched on the metallic ground plane of a micro strip line.

It consists of four rectangular slots of dimension a x b connected by two narrow slot of dimension g x w thereby resembling a cross shaped DGS. Thus the microstrip antenna without DGS, the bandwidth is narrow and the return loss is high. On the other hand, microstrip antenna with DGS will provide higher operating bandwidth and less return loss

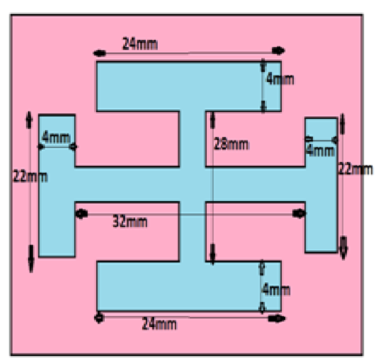

Figure-3. Cross shaped DGS.

Therefore, the DGS can be integrated onto the ground plane of such antenna in order to improve its radiation, besides not requiring additional circuits are for implementation.

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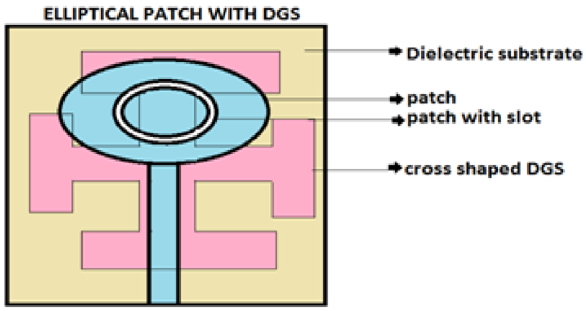

Figure-4. Resultant elliptical antenna with DGS.

Slotted elliptical slot in combination with the cross shaped DGS offers enhanced performance in terms of frequency and bandwidth under limited profile situations.

Figure-4 demonstrates the suggested structure amongst the diversified sketches enabling harmonic reduction, cross-polarization suppression and mutual coupling reduction along with appreciable parameter values.

ANTENNA DESIGN CONSIDERATIONS

Elliptical Shaped Patch Micro-Strip Antenna (EMPA)

In many practical applications circular polarization is required. Circular polarization may be obtained by using multiple feeds or by altering the shape of a rectangular Micro-strip antenna.

An elliptical patch on a microwave printed circuit board can be made to radiate circularly polarized waves. Such an antenna requires only one feed, and its geometrical shape is simple enough to permit theoretical analysis to be carried out in a standard coordinate system.

The effects of the fringe field at the edge of the elliptical patch and those of the dielectric substrate are taken into account in the following formula:

For an ellipse of semi major axis *a* and semi minor axis *b*, the foci are at where

$c = (a2 – b2)^{0.5}$

$a = p/(f^*(\mu\varepsilon)^{0.5}$

$\varepsilon_0 = 8.854*10\text{-}12$

$\mu_0=4\pi* 10\text{-}7$

Where μ and ε are the permeability and the permittivity of the substrate respectively.

The values of the relative permeability and relative permittivity for the FR4-epoxy substrate are 1 and 4.4 respectively. Frequency *f* for the antenna is taken as 3.21 GHz. P is an empirical constant ranging from 0.27 to 0.29.

Normally P is taken as 0.275 which agrees very well with the empirical value.

The eccentricity of the ellipse is defined as $E_c = C/a$

The desired circularly polarized radiation communicability may best be achieved by limiting the eccentricity of the ellipse to a range of 10 to 25%. We have taken E_c as 11.62% of semi major axis.

Calculation for the EMPA

Area of the Elliptical patch A= πab

For Major axis (a) = 18 mm; Minor axis (b) = 11.08mm.

Area of the Elliptical patch=627.092 mm^2

Quarter transformer feed line = **λ/4** = 23.32mm; λ/2 =23.32 mm

Where

λ = 0.09328m; λ =0.04664m

Frequency,*f*= c/λ = 3.216 GHz;

f= 7.196 GHz

Foci $c = \surd (a^2 - b^2)= 0.014$

$a = P/[f *\surd(\mu\varepsilon)]$

Where

μ - permeability of the substrate,

$(\mu o = 4\pi *10^{-7})$

ε - Permittivity of the substrate,

$(\varepsilon_o = 8.854* 10^{-12})$

μ_r & $\boldsymbol{\varepsilon_r}$- relative permeability & relative permittivity for the FR4-epoxy substrate as 1 & 4.4 respectively.

f - Frequency for the antenna = 2.43GHz.

P is an empirical constant=0.275(0.27 to 0.29)

Table-1. Eccentricity to frequency relation.

S. No.	**Frequency** (GHZ)	**Eccentricity of the ellipse Ec=c/a**
1	1.9950 GHz	7.208
2	2.5829 GHz	9.332
3	3.2161 GHz	11.62
4	7.1961 GHz	26.01
5	7.8744 GHz	28.45

The desired circularly polarized radiation communicability may best be achieved by limiting the eccentricity of the ellipse to a range of 10 to 25 percent.

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DESIGN PARAMETERS

Table-2. Design values.

S. No.	Parameters	Description	Optimized value
1	ε_r	Dielectric constant of FR-4 substrate	4.4
2	H	Thickness	1.6mm
3	F	Operating frequency	1.995 GHz to 7.874GHz
4	a	Major axis of ellipse	18mm
5	B	Minor axis of ellipse	11.08mm
6	W_s	Width of the elliptical slot	1mm
7	L_f	Length of the feed line	23.3mm
8	W_f	Width of the feed line	2mm
9	W	Width of the dgs	4mm
10	L_c	Length of the cross shape	28mm
11	W_c	Width of the cross shape	32mm
12	L_d	Length of the dumbbell	22mm
13	W_d	Width of the dumbbell	24mm
14	L_g	Length of the ground plane	50mm
15	W_g	Width of the ground plane	50mm

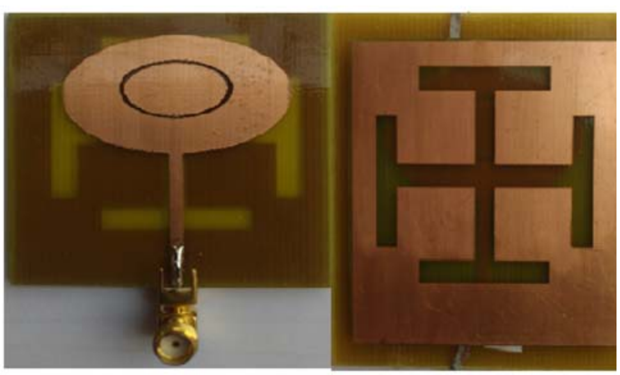

Figure-5. Elliptical radiating patch and cross shaped DGS.

Above Figure-5 shows the photograph of the realized antenna's radiating elliptical patch, with slot for the bandwidth enhancement, and the cross shaped defected ground structure.

Whereas the Figure-6 depicts the picture of the fabricated antenna integrated with the polycrystalline silicon (poly-Si) solar cell.

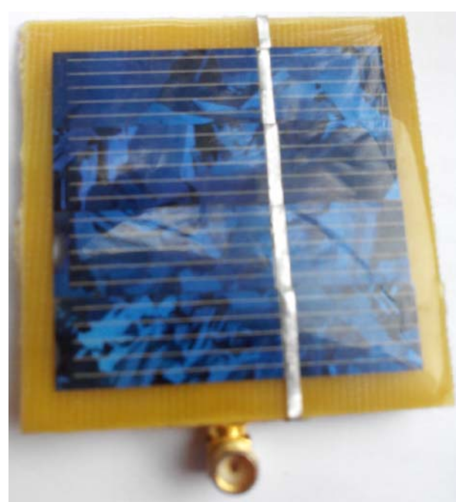

Figure-6. Resultant SOLPLANT.

RESULTS

The solar planar antenna performance with DGS has been investigated through simulation via a finite element program HFSS.

Electric field distribution over the radiating elliptical patch is shown in the Figure-7. The silver lines conductor of the PV cell has an impact over the current

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and field spreading in the patch as well in the DGS. The lines parallel to the feed line must give improved response in bandwidth, gain when compared to the perpendicular silver lines.

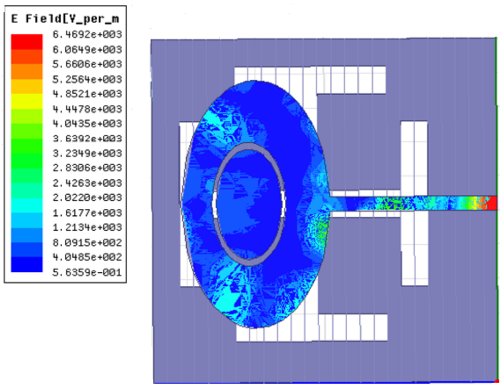

Figure-7. Field distribution.

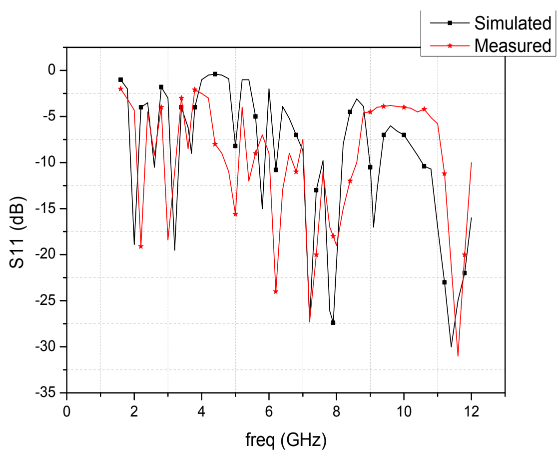

Figure-8. Comparison of simulated and measured return loss

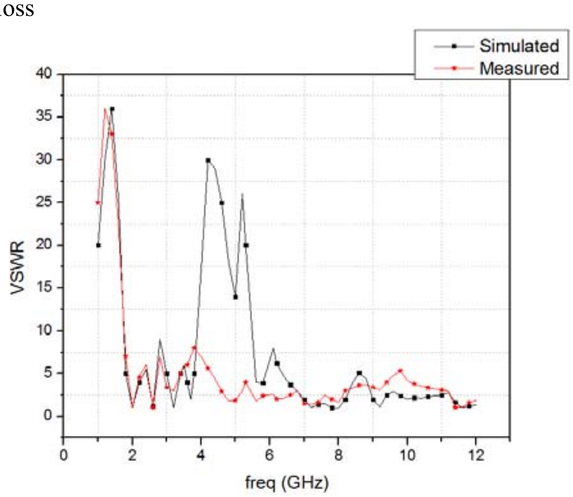

Figure-9. Comparison of simulated and measured VSWR

The antenna produces Return loss of -29.06dB at 11.5 GHz and VSWR of 1.015 at 11.6 GHz frequency during measurement showing better than the simulated results.

Table-3. Measured and Simulated results correspondence.

S. No.	Parameters	Simulated	Measured
1	Return loss	-27.53	-29.060
2	VSWR	1.0967	1.015

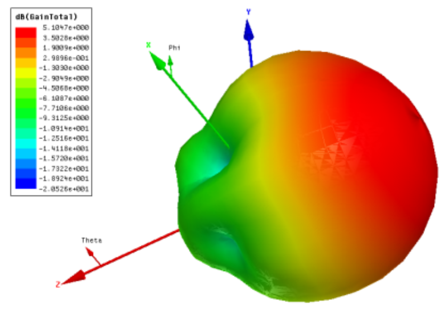

Figure-10. Realized gain.

The Gain of the antenna with dumbbell shaped DGS is realized as maximum as 9.04dB but at the cost of moderate S11 and reduced bandwidth and Directivity.

The realized SOLPLANTantenna, here, has Gain of 5.1021dB; Directivity = 5.3408 with improved bandwidth and VSWR.

Radiation pattern for the fabricated SOLPLANT at the frequency of resonance, 7.8744GHz, is shown for the two phi values with respect to varying θ.

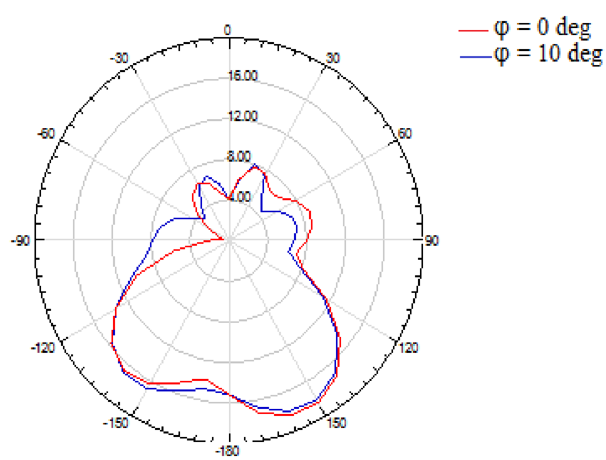

Figure-11. Radiation pattern at resonant frequency.

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Table-4. Comparative results with different DGS.

Parameters	Dumbbell shaped DGS	Swastik shaped DGS	Cross shaped DGS
Reflection co efficient	-15.2403	-39.1344	-27.1516
VSWR	1.4183	1.0223	1.0918
Band width	452.3MHz	90.4MHz	497.5MHz
Gain	9.04 dB	2.6994	5.1021 dB
Directivity	3.74	4.9404	5.3408
Resonant frequency	6.381 GHz	7.0603GHz	7.8744GHz
Frequency range	1.316 to 6.96GHz	3.48 to 7.603 GHz	1.9497 to 9.2312GHz

The Table-4 implicates the comparative results with different DGS depicting the better performance of the antenna associated with the cross shaped DGS.

CONCLUSIONS

The Solar elliptical patch antenna designed with cross structured DGS shows gain of 5.1dB. Slight reduction when compared to the antenna without PV cell due to the presence of silicon. Moreover, the radiating patch area is smaller as compared to the conventional antenna without DGS. So, this design not only improves the parameters of the antenna but also can provide a smaller size of radiating patches, which will cause an overall reduction in antenna size in autonomous communication systems. In future by employing shorting and feeding pins in the structure improves the impedance bandwidth. The measured results show the suitability of this SOLPLANT in wide range from Wi-Fi, Bluetooth, Zigbee, to space satellite and Radar applications.

FUTURE WORK

The integration of antenna with PV cell can be made complex interdigitated manner so as to improve the parameter values. The transparent patch can be used instead of copper to enhance the efficiency of the solar cell. Flexible solar cells also the good choice under consideration.

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