Koch Fractal Loop Circular Polarization (CP) Antenna Integrated with Solar Cells

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***Abstract*—Minimal profile antennas for wireless devices which characteristics consisted of being low cost, highly reliable, and lightweight, it bears a new challenge for the design of the antenna in wireless communications. In this paper, we propose a design of circularly polarized microstrip patch antenna integration with solar cells for green wireless applications. Two techniques have been proposed to form the prototype between the communication system (design of antenna) and solar panel (solar cell). Both methods will face two issues generally; the solar system needs to get 100% sunlight and the magnetic field produced by radio communication systems as well as the electric field produced by solar cells should not affect the efficiency. The antenna is composed of a Koch fractal loop patch and the substrate is employed using a transparent material. This enables the light to pass through with high efficiency to illuminate the solar panel cells while the RF performance is maintained with minimal degradation. The communication frequency measures 2.6, 3.5 and 4.4 GHz. CST MWS simulation is also studied and compared among the different substrates which show different results based on the same parameters, which is implemented with a lattice of 2×2 square solar cells. With this arrangement, the solar cells will be able to obtain 100% of sunlight exposure. The characteristics of the broadband are achieved by combining resonances and the minimum axial ratio points created by the driven patch and solar cell surface.**

Keywords: Compact Meshed patch antenna, transparent substrate, integration antenna and solar panel, Trade-off RF performances and transparency, Microstrip patch antenna, Frequency, Gain, CST MWS, Wireless communication.

I. INTRODUCTION

With the rapid development of solar cell technology and the urgent need to be prepared to work on green connectivity with earth and space communications systems, many independent devices are using solar energy to power devices. Yet, the surface area available for solar cell manufacturing is limited and have to be effectively shared with other components and communication systems. Hence, the integration of antennas with solar cells is one of the primary solutions for sharing the exposed surface area more effectively, reducing the cost of devices and providing compatibility between solar cells and antennas. Various kinds of antennas were integrated with solar cells for terrestrial and satellite applications [1-6]. In these arrangements, solar cells were structured to contribute ground function, while antennas were designed to reduce its shading. Overall, two methods were used to create the prototype. between the communication system (antenna design) and the solar panel (solar cells). For both methods, the combination not only produces a wide range of bandwidths, but also allows total exposure to solar cells for sunlight. The effect of cellular communication systems has been determined by the magnetic field produced by radiocommunication systems as well as by the electric field produced by solar cells.

II. BACKGROUND

The manufacture of a microstrip patch antenna is very simple by the use of a common microstrip fabrication technique[7]. The transmission line model and the cavity model are the most used models of the rectangular patch antenna.

A. Antenna Properties

Overall, microstrip antennas consist of both patch resonator and a metallization as a ground. These antennas can be used in low-power transmitting and receiving applications because of their capability to handle the low power. Microstrip antennas have many advantages compared to the traditional microwave; for instance, they can cover the broad frequency range between 100 MHz and 100 GHz[8].

B. Antenna Shape

The antenna of microstrip patch has a ground plane on the one side of a dielectric substrate, the other side of it has a radiating patch as shown in Fig. 1. The main radiator is created by using a rectangular patch. Overall, the patch is made of conducting material such as copper or gold. It can also take any possible shape. The dielectric constant of the substrate (ϵr) is typically in the range of $2.2<\epsilon r<12$ [9].

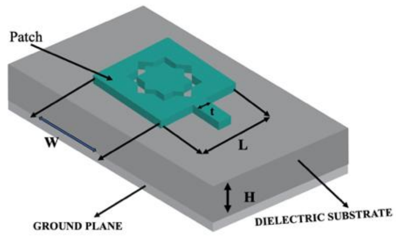


Fig. 1. Microstrip antenna (Reprint permission from Ref. [10]).

A low dielectric constant with a thick dielectric substrate is required for ideal performing antenna, as it produces better radiation, higher efficiency, and wider bandwidth [11].

C. Solar Cell Review

There are three types of the solar cells which can be presented as follows:

Wafer Based Crystalline Silicon Solar Cells: Two types of crystalline silicon (c-Si) are used in the industry. The first is

- mono-crystalline silicon (mono-Si), also called single-crystalline, and produced by slicing wafers (typically 200 – 300mm diameter, and 200 –400μm thick) from a high-purity single crystal cylindrical ingot obtained with methods for crystal growth like the Czochralski (CZ) or Float-zone silicon (FZ-Si) processes [12] .

- Bifacial Solar Cells: Bifacial solar cells are sensitive to light in both sides due to the lack of the rear side complete metallization [13].

- Back-Contacted Solar Cells: Concentrating solar energy onto a photovoltaic material can drastically reduce the solar cell area required per peak watt output. However, standard solar cell structures have both contact metallization in both front and rear side to extract the current, and they do not perform efficiently under the high illumination intensities of the concentrators, among other things due to the shadowing of the contacting fingers in the illumined surface [14].

D. Polycrystalline Silicon Solar Cell As Ground Plane

Various configurations have been suggested recently to address the integration of antennas and solar cells in a multifunctional compact device. This configuration indicates that the implementation of a solar cell based microwave ground plane for a printed antenna is highly feasible and leads to a significant reduction in footprint. Regardless, the results of this development showed an impaired RF efficiency that was responsible forthe difficulties in characterizing the electrical properties of the micron-scale features of the solar cell which is acting as an inhomogeneous ground plane, and the consequent limitation to antenna performance.

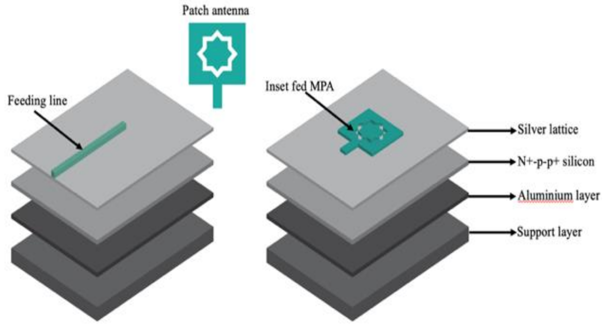


Fig. 2. Exploded layout of the poly-Si solar MPA antenna geometry with coordinate (Reprint permission from Ref. [15]).

E. Polycrystalline Silicon Solar Cell As Reflector

The use of a metallic reflector structure behind an antenna is a common technique used to achieve enhanced directivity and gain [16].

F. Tr Transparent Antenna On Amorphous Silicon Thin Film

Electrically conductive materials used for microwave antennas are typically metals which are opaque to visible light. Fortunately, materials that are both optically transparent and electrically conductive have been developed by coating clear polyester sheets with nanolayers of metal oxides or carbon nanotubes [17] , [18].

III. METHODOLOGY

The concept of an antenna for solar applications shows how the antenna is designed to increase antenna performance, especially radiation and gain efficiency, which is important and must be considered. We use two methods in this paper to accomplish the prototype between the communication system (antenna design) and the solar panel (solar cells).

A. Method 1

The antenna will be integrated on the top of the solar cells (solar panel). This feature has the advantage of making the design small in size and cost appropriate but has no effect on the antenna. It must be high transparency and suitable for integration with renewable energy to ensure that the antenna does not block sunlight from the solar cell (Fig.3)

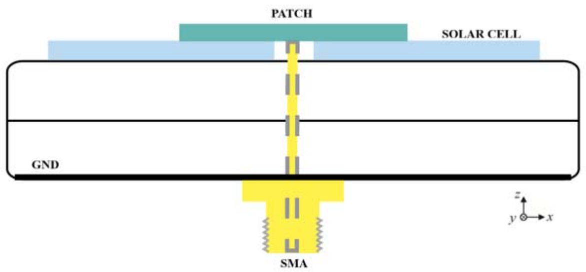


Fig. 3. The geometry of proposed antenna with solar cell on top

B. Method 2

Make the antenna and solar cells in one cell using materials that can be used for both systems. For the solar cell, we will focus on the semiconductor silicon layer p-type. And for the antenna design, we use the silicon layer as the antenna substrate. This method may solve the problem caused by the communication system from blocking sunlight and may not require the antenna to be transparent. Fig.4

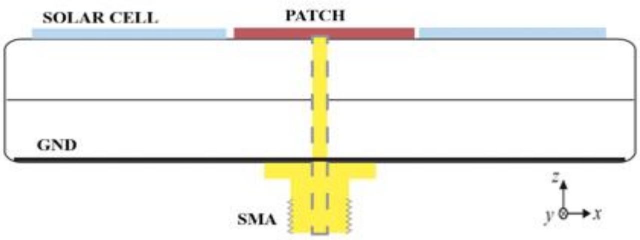
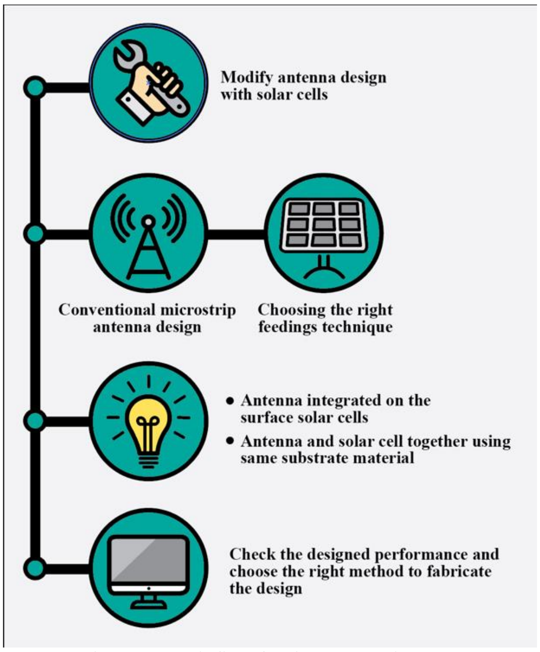


Fig. 4. The geometry of proposed antenna sharing same substrate

Both methods will face two issues generally. The solar system must receive 100% sunlight, the magnetic field produced by radio communication systems as well as the electric field produced by solar cells may affect the efficiency.



Scheme1. Work flow for the proposed antenna

IV. ANTENNA DESIGN AND CHARACTERISTICS

Fig.5 presents the geometry of the first antenna, which is composed of a driven patch element on the surface of solar cells, a 50-SMA connector, and polyimide substrate. The driven patch element is a square patch One Koch fractal loop circular polarization (CP) has been designed to resonate at 2.6 GHz according to application requirements [19], [20]. To design this antenna a second iteration 45 degree Koch fractal loop designed to resonate at 2.6 GHz. It starts from one point and after finishing one Koch which contains three lines, the coordinate degree rotates by 45 degree and then continue to finish the loop by half wavelength showed in Fig. 1 The iterations can be increased but it's been refused due to the complexity for higher iterations. To design this antenna the transmission line feeding technique exploited and the feeding has the impedance as the previous antennas (50 Ohm).The driven patch element was designed on the top side of the substrate. The internal part of the SMA connector extended through the substrate and connected to the extended strip. The external part of the SMA connector was connected to the ground plane. [21] [22]

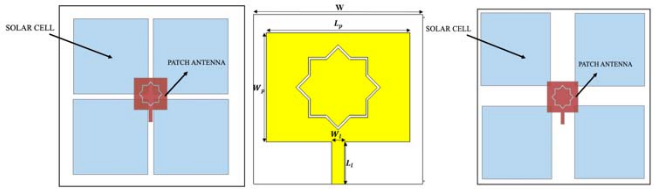


Fig. 5. Koch fractal CP antenna and top view for antenna with solar cell.

The antenna was optimized via CST MWS simulation to acquire broadband characteristics at a frequency of around 2.6 GHz. Its enhanced design parameters are presented in the table [23][24].

TABLE I. KOCH FRACTAL CP ANTENNA DIMENSIONS

Parameters (mm)	W	L	W_p	L_p	W_l	L_l
Values	20	20	17	10	1.5	10

V. STRUCTURE OF PATCH ANTENNA DESIGN IN CST

The antenna patch design is presented in Fig 6. in the 3D model. It possesses of patch elements on one side of a dielectric substrate and a planar ground on the other side. It was attached with an airbox boundary and virtual radiation to form far-field radiation pattern and selected with excitation of the lumped port.

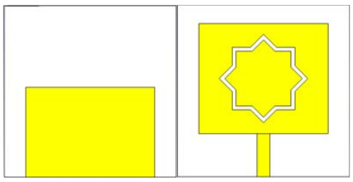
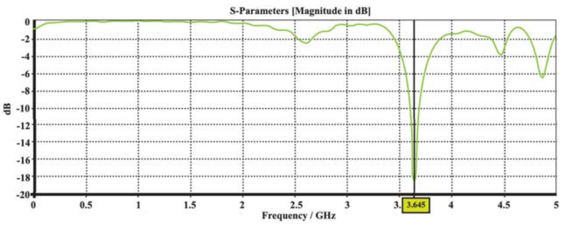


Fig. 6. Design of single patch antenna in CST

VI. SIMULATION RESULTS

To achievethe results,four antennas has been designed with circularly polarization. All of these antennas have been simulated on a polyimide, Plexiglas and crystalline silicon substrate with a copper layer as metallic part due to the cheap price and easy access. The first and second was simulated by using the first method. because the antenna will be on the top of the solar cell. The Second antenna is a rectangular patch antenna with transparent polyimide substrate which has been cut by a 60 degree Koch fractal antenna loop to make directional antenna. The dimension is 20 × 20 mm and the gain is decreased (2.985 dB) and the efficiency (58 %) also decreased. Fig. 8



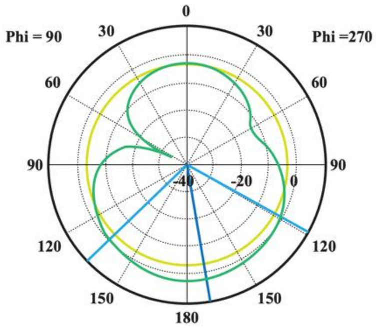
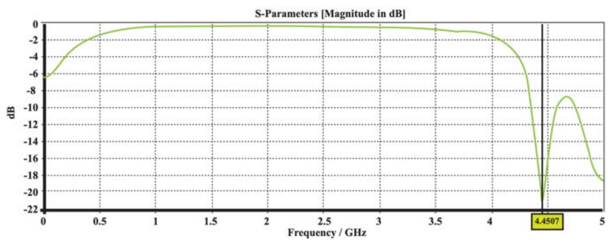


Fig. 8. S-parameter polyimide, radiation pattern in 2-Dof Koch antenna

The Third antenna is a rectangular patch antenna with transparent Plexiglas substrate which has been cut by a 60 degree Koch fractal antenna loop to make directional antenna. The dimension is 20 × 20 mm and the gain is increased (3 dB) and the efficiency (60 %) also increased. At the second and the third antenna, the X- coordinates and the back lobe is high. Fig. 9



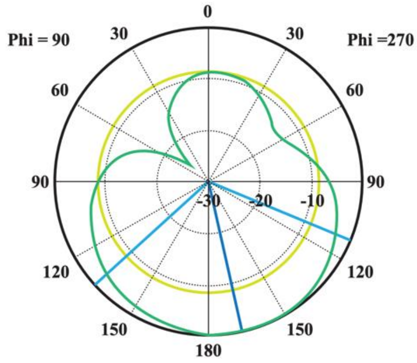


Fig. 9. S-parameterPlexiglas, radiation pattern in 2-D of Koch antenna

The Fourth antenna is a rectangular patch antenna with Silicon Crystalline (optical) substrate which has been cut by a 60 degree Koch fractal antenna loop to make directional antenna. The dimension is 20 × 20 mm and the gain is decreased (3.31dB) and the efficiency (54%) also decreased. The radiation pattern is directed to the Y- coordinates and the back lobe is high. But this antenna was designed following the second method. Fig. 10

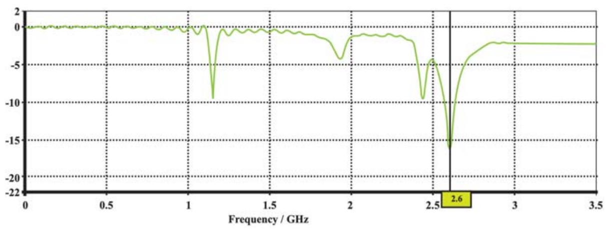


Fig. 10. Proposed antenna on a Silicon Crystalline S-parameters results

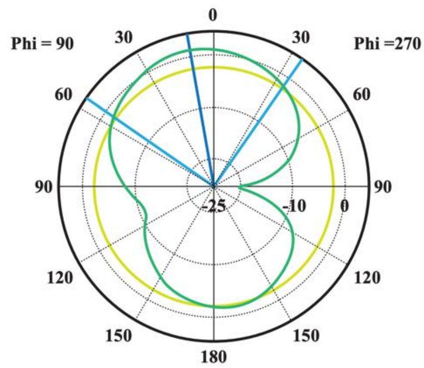


Fig. 11. Proposed antenna on a Silicon Crystalline radiation pattern in 2-Dof Koch antenna

The antenna performances can be increased even more if it has been exploited as array antenna by increasing the number of the element arrays. Other paper [4] has report the same idea about this integration but they are using non-transparent material so we will make a comparative listing with other similar type of paper after we fabricate the design and do the measurement. The structural performance of the antenna will be explained through current distribution and maintenance of proper sunlight absorption. Although it shows good results in the software, it is not guaranteed that it will be the same results in reality in terms of manufacturing environments and errors arising from different areas. Our aim is to fabricate the final prototype and measure the percentage of sunlight absorption, solar efficiency and effects from the antenna.

TABLE II. COMPARISON OF SIMULATION GAIN, EFFICIENCY AND FREQUENCY FOR FOUR ANTENNAE.

Frequency (Ghz)	Gain (dB)	Substrate	Efficiency (%)
2.6	3.3	crystalline silicon	54%
3.6	2.9	polyimide	58%
4.4	3	Plexiglas	60%

VII. DISCUSSION

This study confirms that antenna may affect and also enhance the efficiency of the solar cell. A possible explanation for this might be the shape of the antenna or the material used to design the antenna. We will investigate this issue when we fabricate this work and also check the results in the lab. to obtain enough knowledge to be able to produce the final prototype so that it can be used for IOT, IOE, or any wireless system. The CST software shows good result when the solar cell is added to the antenna. Based on the S-parameter result, the radiation efficiency of the antenna is increased by integrating to the solar cell. However, the solar in the CST software is not entirely made out of solar cell, it is just a Silicon Crystalline (optical) layer so it may not warrant a 100% success.

VIII. CONCLUSION

Hence, the design and simulation of the microstrip patch antenna were successfully created and investigated using CST MWS. The performance parameters were achieved with gain and beadwidth. The fabrication of patch antenna with solar cells following the method we mentioned above will be our targeted work in the future to make successful prototype for green wireless communication.

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