

Integrated Optically Transparent Solar Cell Antennas Made from Meshed Conductors

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ABSTRACT

This paper presents the feasibility of integrating meshed patch antennas directly onto the solar cell assembly to save valuable surface real estate of a small satellite. The solar cell cover glass is used as the substrate for the patch antenna. The integrated patch antennas are required to be transparent to light in order to ensure the proper operation of solar cells.

It is found that the mesh geometry can be designed to offer the optimal transparency and antenna radiation at the same time. To design the transparent solar cell antennas in the presence of photovoltaic cells, Ansoft's HFSS is used to model patch antennas on solar cells and the dielectric constant of solar cells is approximated with that of silicon.

In order to verify the design, meshed antennas are printed with conductive ink on plastic substrate and measured results are compared against the design data from simulations.

INTRODUCTION

Saving valuable surface real estate on a small satellite is one of the most challenging issues in small satellite industry. One solution to the issue is to integrate the antenna directly onto the solar panel. In order to endure the proper functioning of solar cells, the antenna is required to be see-through for light. Meshed patch antennas are a feasible and cost friendly solution and its basic properties have been studied¹. The design parameters not captured by Clasen have been presented by Turpin et. Al².

It has been shown that when the line width of the mesh is fixed, radiation properties of the antenna decreases as the transparency of the antenna increases^{1,2}. When the transparency is fixed, finer line widths result in better antenna properties². Turpin's results provide a method to design a see through antenna with both optimal transparency and radiation.

The purpose of this work is to show the effect of the orientation of the conductive mesh, solar glass and photo voltaic layer of solar cells on integrated solar cell antenna design.

DESIGN PARAMETERS

In order to understand the factors that affect the antenna properties, meshed patch antennas are simulated with Ansoft's HFSS. In order to speed up the process of simulation of the various parameters, HFSS is

automated with MATLAB controlling HFSS's scripting files. Throughout this study the impedance bandwidth is taken as the frequency range over which the VSWR is less than 2.0

Antenna Geometry

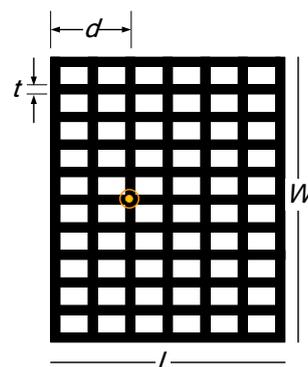


Figure 1: Geometry of Patch

The geometry of a meshed patch antenna is shown in Figure 1 with the location feed highlighted. As pointed out in a previous study², the transparent antenna can be designed with both optimal transparency and radiation by refining the line width. It is shown that the majority of the electrical current flow is in the direction parallel to the length of the patch³ (marked by L in Figure 1), and a meshed patch can be constructed with only those parallel lines plus the two lines at each end of the patch parallel to the width (marked by W in Figure 1). In

order to verify this statement, we set up the following simulation. To do this, the number of lines parallel to the width of the patch is gradually reduced while the length and width of the patch are held constant. The process results in increased antenna transparency. The length and width of the antenna are 41.3 mm and 49.4 mm respectively. The substrate for the antenna has a thickness of 1.588 mm and a dielectric constant of 2.2. The simulation results are shown in Figure 2.

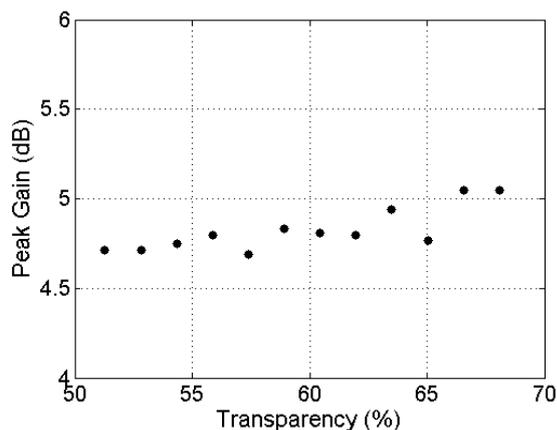


Figure 2: Horizontal Line Affect on Gain

These results show that the transparency of the antenna can be increased by reducing number of horizontal line without significant effect on antenna radiation. This shows an additional method to optimize the transparency of the antenna.

Substrate Thickness

In general, a thinner substrate results in a less efficient antenna⁴. To find out the acceptable thickness to be used as solar cell cover glass and substrate for the antenna, three different thickness of plastic substrate are examined. It should be noted that the dielectric constant of these transparent plastic substrate are the same or close to that of commercial solar cover glass. Antenna gain and impedance bandwidth are plotted as functions of substrate thickness and mesh line width, and these results are shown in Figure 3 and Figure 4.

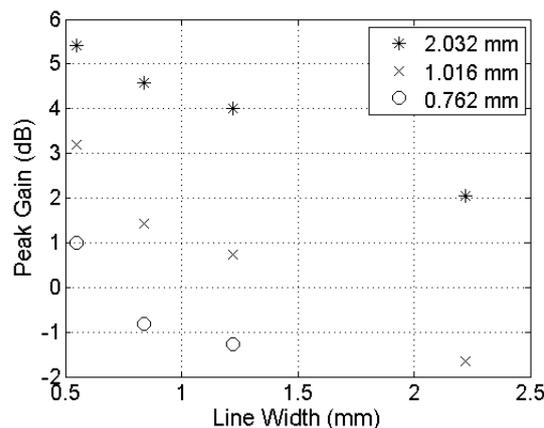


Figure 3: Substrate Thickness Affect on Gain

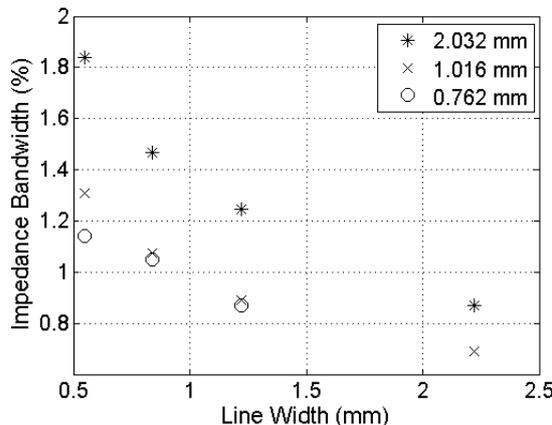


Figure 4: Substrate Thickness Affect on Bandwidth

Although antenna properties can be optimized by refining the mesh line width, it is seen from Figure 3 that when the substrate thickness is less than 1mm, the antenna has a fairly low gain. This is an aspect to be compensated when choosing solar panel assembly. Otherwise, methods to increase antenna gain need to be researched if a thin cover glass is inevitable.

Conductivity of Silicon Layer

To determine the affect of photo voltaic layer on the integrated antenna, simulations are performed by adding a silicon layer (to emulate photo voltaic layer) under the antenna substrate then backed by an electric conductor (to emulate the base of solar panel). The thickness of the silicon layer is taken as 0.16 mm, and the dielectric constant is taken as 11.9. Because it is hard to determine the conductivity of a solar cell as the number varies with different production process and vendor, the conductivity of the layer is varied from 0.0 S/m to 100 S/m to check the affect of conductivity on antenna radiation. Simulation results to show the affect are plotted in Figure 5-Figure 8 .

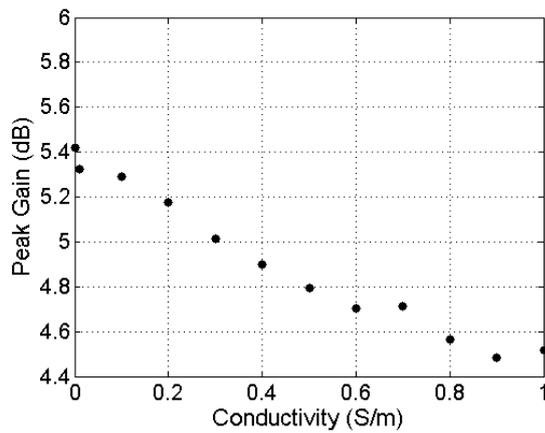


Figure 5: Gain vs. Conductivity 1

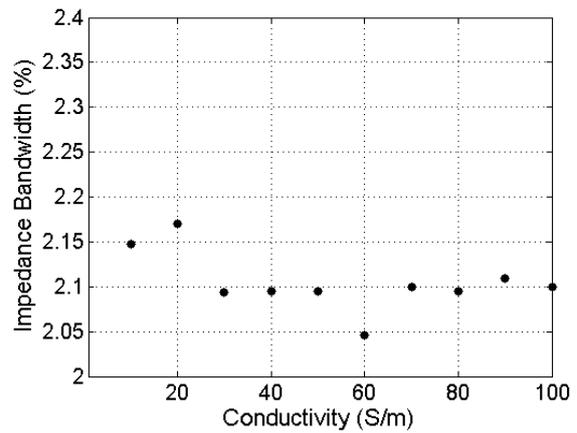


Figure 8: Bandwidth vs. Conductivity 2

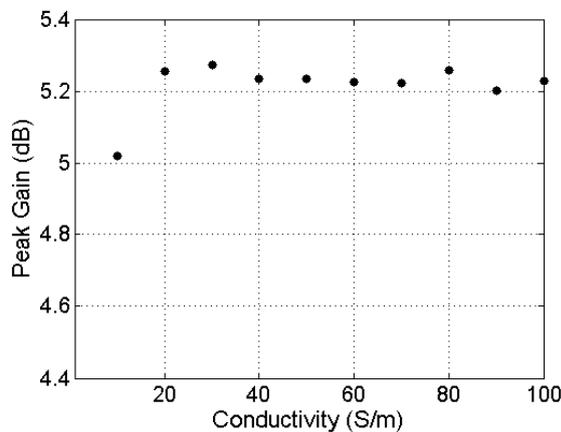


Figure 6: Gain vs. Conductivity 2

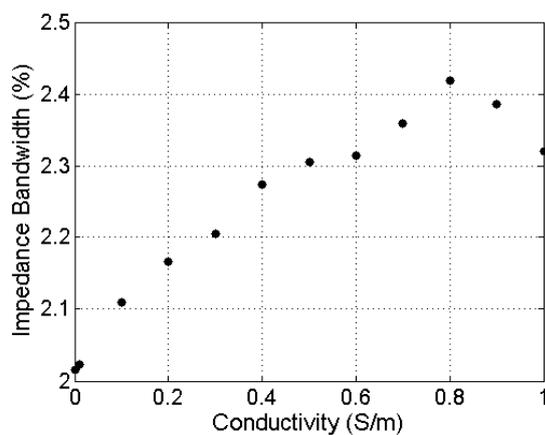


Figure 7: Bandwidth vs. Conductivity 1

It is seen from Figure 5 and that when the conductivity is between 0.0 and 1 S/m, there is a decrease on antenna gain with respect to the increase in the conductivity. When the conductivity is above 20 S/m, increasing conductivity seems having no effect on antenna properties as shown in Figure 6. A possible explanation is that at a low conductivity, the substrate acts as a lossy media, while the conductivity is higher than a certain lever, the media acts as a conductor. A similar trend is seen with the bandwidth, and it is seen that there is an increase in the bandwidth at a low conductivity which is understandable as the silicon layer contributes to the increase of antenna substrate.

EXPERIMENTS

According to the design parameters obtained from simulations and discussed above, two meshed patches are designed and fabricated on Plexiglas. The thickness of the Plexiglas is 2.032 mm and the meshes are fabricated by silk-screening conductive ink onto the sheets in the form of the patch. Inset feed is used due to its simplicity. One design has a length and width of 37.4 mm and 45.1 mm respectively with a line with of 1.04 mm. This geometry produces an antenna with a transparency of 56% if the effect of insert feed is not counted. The other patch has a length and width of 37.5 mm and 45.0 mm respectively and a line width of 1.23 mm to create the transparency of 65%. The antennas are tuned for impedance matching which results in that the 56% transparent antenna resonates at 2.4 GHz and the other one at 2.3 GHz. Comparisons of simulation and measurements are shown in Figure 9 and Figure 10.

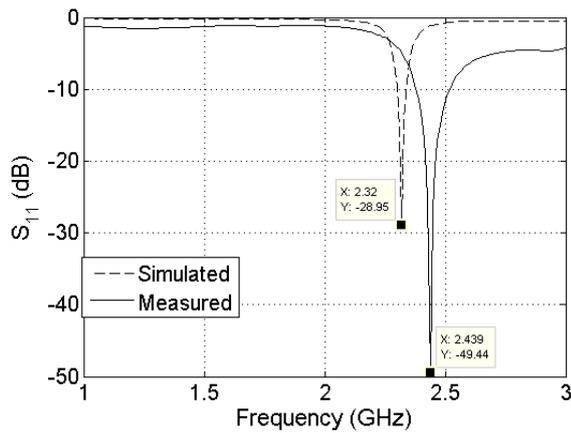


Figure 9: Patch of 56% Transparency

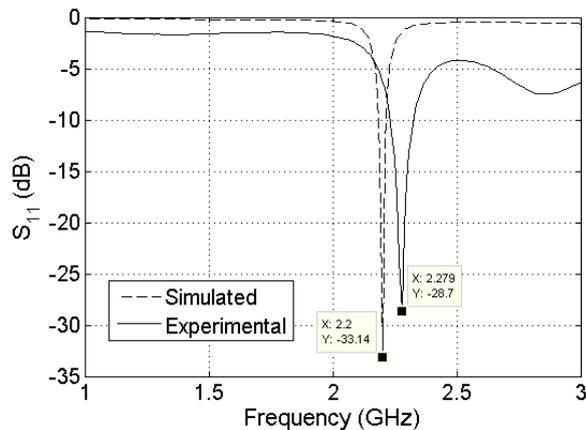


Figure 10: Patch of 65% Transparency

A discrepancy is seen between simulation and experiment and this can be due to the fabrication precision when the Plexiglas is assembled on a steel ground plane.

CONCLUSION

It is seen that there are several design factors to consider when integrating transparent meshed patch antenna with solar cells. The thickness of the cover glass is important to ensure the radiation of the antenna and there is an increased challenge in antenna design if a very thin cover glass has to be used.

The largest affect of the conductivity of the solar cell is when the conductivity of it is in the range of 0.0 to 1 S/m. When the conductivity is higher than certain lever, there is no significant effect on antennas.

The experimented mesh antennas printed by conductive ink show good agreements with simulations and suggest a more refined fabrication process.

ACKNOWLEDGMENTS

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