Integrated After-Market Solar Panel Antennas for Small Satellites
(Patent Pending)

Timothy Turpin
Department of Electrical and Computer Engineering, Utah State University
930 N. 600 E. Logan, UT 84321; 801-661-0090
tim.turpin@aggiemail.usu.edu

Mahmoud N. Mahmoud
Department of Electrical and Computer Engineering, Utah State University
EL 150, 4120 Old Main Hill, Logan, UT 84322; 435-797-2955
m.mahmoud@aggiemail.usu.edu

Reyhan Baktur
Department of Electrical and Computer Engineering, Utah State University
EL 150, 4120 Old Main Hill, Logan, UT 84322; 435-797-2955
breyhan@engineering.usu.edu

Cynthia Furse
Department of Electrical and Computer Engineering,
University of Utah, Salt Lake City, USA; 801-585-7234
cynthia.furse@utah.edu

ABSTRACT

The majority of surface area on a small satellite is taken up by solar panels for power. Integrating antennas with solar panels, would save a valuable amount of satellite surface area, and thus directly contribute to the size reduction and multi-functionality of solar panel. Furthermore, such integration does not require deployed mechanism and therefore is cost-friendly design.

Two types of integrations are presented in this paper. The first type is to place optically transparent antennas directly on top of after-market solar cells. Meshed conductors with optical transparency higher than 90% are used to design antennas in this case. The second type is to utilize the area between solar cells on the solar panel to design slot antennas. The slot antennas are highly integrative and lie on the same plane with the solar cells without blocking solar energy.

The paper discusses both types of solar panel antennas that can be conveniently integrated with after-market solar cells, providing a novel and cost-friendly solution for small satellite system.

INTRODUCTION

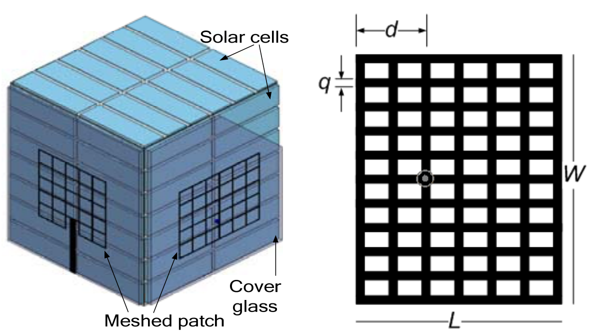
As small satellites are getting smaller to reduce the payloads in missions, there rises the challenge of how to manage limited satellite surface area to fit solar cells, antennas, and space instruments. A traditional satellite system has separate solar cells and antennas. An effective integration of them, however, would save valuable real estate. Although there are reported solutions of integrating antennas with solar panels by either placing patch antenna under the solar cells [1], or creating radiating slots on the ground plane under the solar cells [2], the solar cells for those designs need to be custom made to ensure the functionality of the antennas. The objective of this work is to present antenna designs that can be integrated on after-market solar cells.

Two types of antennas are designed and prototyped in this paper. The first type is the meshed patch antenna that has optical transparency of higher than 90%. This antenna solution is based on two facts: (1) The meshed conductor is optically transparent and can still be effective radiator in microwave frequency. (2) There is usually a cover glass on top of solar cells, and the cover glass can serve as the substrate for the antenna.

The second type of antenna is slot antenna by utilizing the space between solar cells on the solar panel assembly. Most solar panels of small satellites are made of printed circuit board material with solar cells laid on top, and narrow gaps exist between solar cells to enable electric connections. Slot antennas can be designed by realizing effective radiating slot elements in those gaps. The slot elements can be easily produced by etching the printed circuit boards. These slot antennas are highly integrative and lie on the same plane with the solar cells without blocking solar energy.

MESHED PATCH ANTENNAS

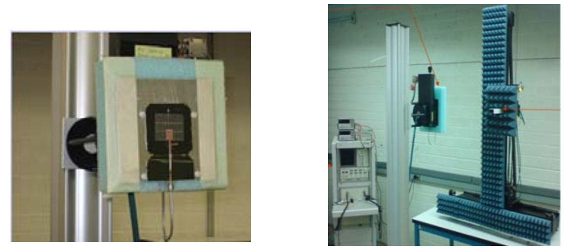
The geometry of the meshed patch antenna is shown in Figure 1. The optical transparency of the antenna is defined by the percentage of the see-through area of the patch antenna [3]. A prototype meshed patch antenna is fabricated and integrated with solar cells in this paper. The antenna is built from off-the-shelf electroformed meshed conductor (Unique Wire Weaving Co., BM0020-03-N) and is attached on a polyethylene terepthalate glycol (PETG) thermoplastic sheet. The meshed conductor has an optical transparency of 93%. The plastic substrate has a thickness of 0.762 mm and relative permittivity of 2.4 at 1 MHz, and is used to act as the cover glass for the solar cell. The solar cells are assembled on an aluminum plate with a silver-based conductive epoxy (Resin Technology Group, Silver Conductive 402). The plastic and aluminum plate are then fastened together with nylon screws. The simulations are performed with Ansoft's HFSS and the measurements are performed on a near field antenna range.



(a) (b)

Figure 1: Meshed patch antennas: (a) Isometric view of meshed patch antennas integrated on solar panels of a small satellite, (b) Geometry of the meshed patch antenna.

The antenna is measured using a near field antenna range as shown in Figure 2. The maximum directivity of the antenna is measured to be 8.2 dB in comparison to 8.6 dB of a solid patch antenna with the same dimension. The decrease in the directivity is expected because meshing the antenna results in less antenna efficiency [3]. The cross polarization level is measured and it is found that meshing lowers the cross polarization level, and the antenna has a cross polarization level of lower than -19 dB.



(a) (b)

Figure 2: Measurement set-up for meshed the patch antenna: (a) Meshed patch antenna integrated on solar cells, (b) Near field antenna range.

CAVITY BACKED SLOT ANTENNAS

As described in the introduction, a typical solar panel assembly has gaps between solar cells, and one can design slot antennas from these gaps.

Design Basis

According to Babinet's principle [4] a slot cut on a perfect electric conductor (PEC) can be treated as ac complementary dipole as shown in Figure 3. A more realistic design for small satellite application, though, is modified slot antennas. In this case, the slot is backed by a cavity filled with a substrate to separate the electronics inside the small satellite from the solar cells. Figure 4 is an illustration of a typical cavity backed slot.

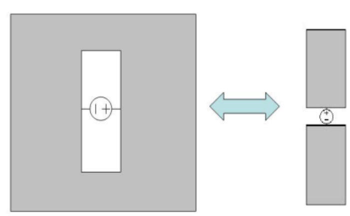


Figure 3: Slot antenna and its complementary dipole

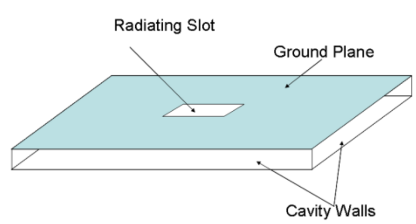


Figure 4: Cavity backed slot antenna

Feed Design and Circular Polarization

Three types of feeding methods of the antennas were surveyed for solar panel integration. These methods are simple probe feed, coplanar waveguide (CPW) feed, and microstrip line (ML) feed. Ansoft's HFSS is used to design and study antenna properties with these feeding methods and it is found that the microstrip line (ML) feed is the most effective and simple design to implement. The geometry of the antenna and the feed (Figure 5) is as follows. Two substrates are used to fabricate the slot antenna and the feed individually. The top plane of the upper substrate is grounded and a radiating slot is etched on the grounded metal coating. The metal coating on the bottom plane of the substrate is etched out. For the lower substrate, a microstrip line is printed on the top plane, and the metal coating on the bottom plane is grounded. The two substrates are then assembled together and the four walls are coated with conductor and grounded.

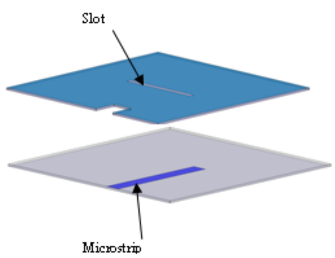
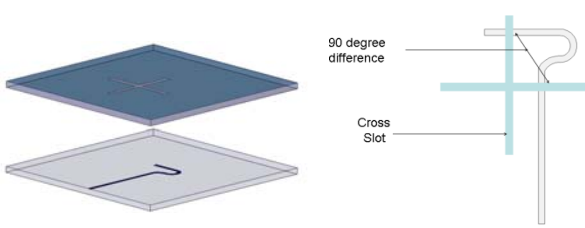


Figure 5: Microstrip line fed slot antenna

Because in circular polarization (CP) is favored for small satellites, the slot antenna geometry in Figure 5 is modified to achieve CP. Two slots are placed perpendicular to each other and phase-shifted for 90 degrees (Figure 6) to generate a circular polarized radiation.



(a) (b)

Figure 6: Circular polarized slot antenna. (a) Assembly of cross slots and feed geometry, (b) Feed design of the circular polarized cross slots.

Prototype Integrated Slot Antenna Array

A 2 by 2 circular polarized slot antenna array are designed and fabricated to function at 5.0 GHz. The spacing between the slot elements are uniform and is half wavelength (in free space) apart. The antenna array and feed design are shown in Figure 7.

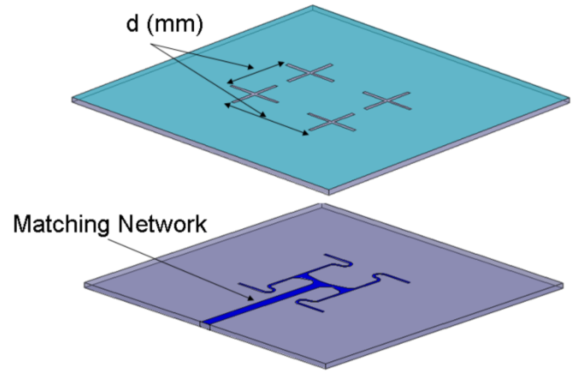


Figure 7: Four element circular polarized slot array

The feeding network is shown in detail in Figure 8. To facilitate a better matching and an ease in fabrication, two quarter-wave tapered transmission lines are used. The 50 Ohm line is then connected to a SMA connecter to feed the array. There are two kinds of ML layouts to avoid reflection at the bending in the microstrip line [9]: the swept bend and the mitered bend. In this paper the swept bend was used, and the radius of the bend was set equal to or more than triples the line width.

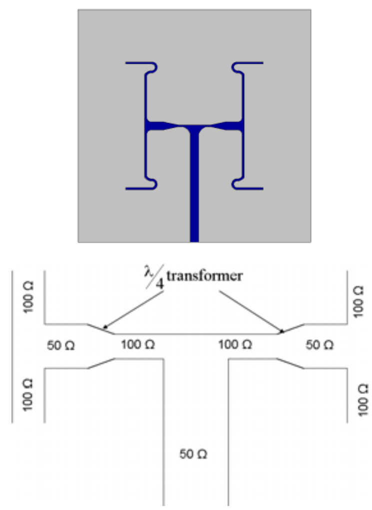
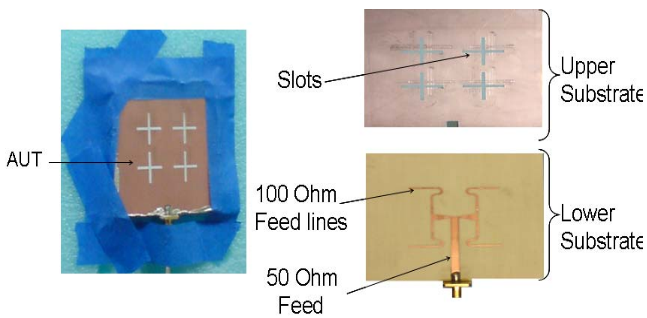


Figure 8: Feeding Network of the antenna array in Figure 7

The four-element circular polarized slot array antenna was fabricated using a milling machine as described in session III on a substrate (RO 4003C). The substrate has a permittivity of 3.5, height of 1.54mm, and a loss tangent of 0.002. The implemented antenna array is then measured with a vector network analyzer and the near field antenna range. Fig.9a is the assembled antenna under test (AUT), and Fig.9b is the close up view of the fabricated antenna and its feed before being assembled together. The measured S_{11} parameter and the radiation pattern agree fairly well with the design data from HFSS. It should be noted that the solar cells are not yet assembled with the slot antennas. But the simulation results show that the affect of solar cells on antenna performance is not large. It is also clear that slot antennas lay on the same plane as the solar cells and therefore does not block any solar cell functionality.



(a) (b)

Figure 9: Fabricated four element slot antenna array

CONCLUSION

The paper shows two novel antenna solutions for integrating antennas directly with solar panels of small satellites. The antenna designs do not affect solar cell functionality, and do not need to custom design solar cells.

Acknowledgments

This work is supported by Space Dynamic Laboratory (SDL) under the 2008-2009 IR&D research grant.

References

1. S. Vaccaro, P. Torres, J. R. Mosig, A. Shah, J. F. Zurcher, A. K. Skrivervik, F. Gardiol, P. de Maagt and L. Gerlach, Integrated Solar Panel Antennas, Electron. Lett., 36 (2000).
2. S. Vaccaro, P. Torres, J. R. Mosig, A. Shah, J. F. Zurcher, A. K. Skrivervik, F. Gardiol, P. de Maagt and L. Gerlach, Stainless Steel Slot Antenna with Integrated Solar Cells, Electron. Lett., 36 (2000).
3. Gisela Clasen and Richard Langley, "Meshed Patch Antennas," IEEE Transaction on Antennas and Propagation, Vol. 52, No 6. June 2004, pp 1412-1416.
4. John D. Kraus, Ronald J. Marhefka, "Antennas for all applications" NY, USA, Mc-Graw-Hill, 2002.