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An X Band Patch Antenna Integrated With Commercial Triple-Junction Space Solar Cells

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An X Band Patch Antenna Integrated with Commercial Triple-Junction Space Solar Cells

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ABSTRACT: An X band patch antenna was integrated on top of the cover glass of commercial space-certified solar cell and was studied for understanding the interaction between the solar cell and the antenna. It was found that the solar cell acts as a lossy substrate for the antenna and reduces the gain of the antenna by about 2 dB, and such a reduction remains consistent for different working states of the solar cell. The patch antenna reduces the efficiency of the solar cells because it blocks light, however, at 10 GHz, the impact of a patch antenna alone to the solar cell's efficiency is less than 1%.

Keywords: CubeSat, solar cell, integration, patch antenna, gain loss.

1. Introduction

CubeSats, due to their modular design, low cost, and versatility, are receiving increased interest in space missions [1], and consequently, designing a reliable and effective antenna system compatible with CubeSat specifications is in demand. Considering disadvantages such as being mechanically expensive of deployed wire antennas, and limited surface real estate of a CubeSat (Fig. 1), it is favorable to integrate planar antennas with CubeSat's solar cells. Integrations of antennas under or around solar cells have been reported [2-6]. This paper is to present our study in printing a 10 GHz antenna directly on top of the solar cell and examination of how solar cells and the antenna affect each other. Due to the high operational frequency, the size of the antenna is small and the effect on the solar cell's efficiency is manageable. The study also provides a baseline for extending the printed antenna to optically transparent meshed antenna [7] as well as a completion for previously reported integration [8], where a patch antenna with its own substrate was placed on solar cells. While the study in [8] has its own merit, this paper examines a modular printing of the antenna on all off-the-shelf space-certified components that are convenient for a flight mission.

2. Antenna Geometry and Test Fixtures

The assembly of the integrated solar cell antenna is as shown in Fig. 2. The geometry information is as follows. From bottom to top, there are a copper layer as the ground followed by a Kapton layer, solar cell, and cover glass with antenna printed on top. The Kapton layer is very thin (~ 0.06 mm) and it is used to isolate the metal coating on the bottom of the solar cell from the ground because the metal layer is the electric positive of the photovoltaic cell. The cover glass is common for space solar cells to protect them from complex environment, and can be conveniently utilized as the dielectric substrate for the antenna.

In order to assess how solar cells affect the printed patch antenna, we prototyped two fixtures as shown in Fig. 3, where the fixture in Fig. 3.a has two functional solar cells connected in serial, and the one in Fig. 3.b does not have solar cells. A cover glass with a printed antenna is then tested on the two fixtures for comparisons. The size and material information of the fixture are as follows. Emcore's triple junction bare cells [9] and a glass (AF32 [10]) with high optical transparency (93%) and high temperature resistance are used. The dielectric constant and loss tangent of the AF32 glass are 4.5 and 0.015 at X band. The design frequency is 10 GHz and the values for parameters marked on Fig. 2 are listed in Table 1. The antenna was designed using HFSS and screen printed multiple times using silver conductive ink [11] on the glass to ensure that the thickness of the antenna is significantly higher than the microwave skin depth.

In order to eliminate the interaction between the SMA connector with the antenna, the fixture is such that the connector is under the ground plane (Fig. 3.c). We have also printed antennas with two orientations: parallel and perpendicular. In the parallel orientation (Fig. 3.a), the length (L in Fig. 2) side of the patch antenna is parallel to the width of the solar cell. In this case, the direction of the surface current on the patch is parallel to the copper electrode lines of the solar cell [12]. The other orientation is denoted as perpendicular (Fig. 3.d). After printing an antenna on an AF32 glass, the glass is then assembled on the test fixture and fastened with nylon clips.

3. Results

The antenna with an orientation as explained in section 2 was put on the fixture without solar cells for measurements and then the procedure was repeated on the fixture with solar cells. The measurements were performed using Agilent’s PNA network analyzer and NSI’s spherical scanner in a near-field anechoic chamber. Frequency response, normalized radiation pattern of the antenna were measured for both orientations and presented in Figs. 4-7. Table 2 lists the absolute gain of the antenna with and without solar cells underneath.

3.1. Effect of Solar Cells on the Antenna

From Fig. 4 and Fig. 5, it is seen that the solar cell acts as a lossy substrate. As the dielectric constant of the solar cell is normally higher than the cover glass, one expects a resonant frequency shifts downward whereas Fig. 4 and Fig. 5 show an upward shift. This is because of the air bubbles between the solar cell and cover glass that is inevitable when using nylon clips as discussed in [13]. The solar cells show little effect on the shape of the radiation pattern and the cross polarization level (Fig. 6 and Fig. 7). The gain reduction of the antenna due to the lossy solar cells can be read from Table 2 and is slightly higher than 2 dB. The results in the Table 2 were obtained through repeated tests that showed consistent data. This gain loss also remained consistent for different cover glass material or thickness, as long as it is thick enough to support an effective antenna radiation and thin enough not to excite higher modes.

3.2. Effect of Working States of Solar Cells

To verify the antenna's performance under different working states of the solar cells, the antenna with solar cells under it was measured while the solar cells were terminated with different loads at the output port (Fig. 3.c) and under different illumination. No visible effect was noted on the antenna's resonant frequency (Fig. 8), radiation pattern (Fig. 9), or gain for different status of solar cells.

3.3. Effect of the Antenna on Solar Cells

To assess the effect of the patch or the blockage of the patch on the solar cells, a series of tests were performed in a controlled environment to measure solar cell's output voltage, power, and I-V curve. Before each test, the solar cells were cleaned with alcohol and an ionizer was turned on near the test bench for air purifying. The measurement setup consists of artificial light, pyrometer, computer-controlled variable resistor, and multimeter. The test procedure is that first a bare solar cell was measured, then a clear cover glass was placed on the solar cell to repeat the tests, and finally a cover glass with printed antenna on top was placed on the solar cell for measurements. The results are summarized in Fig. 10 only for the antenna with parallel orientation because the other orientation was found to have the same effect. The efficiency of the bare solar cell is calculated accordingly and summarized in Table 3. The efficiency of the bare cell is lower than factory data [9] because it has stayed on shelf for more than seven years. From Fig. 10 and Table 3, it is seen that the antenna together with the cover glass reduces the output power and efficiency of the solar cell, however, as a 10 GHz patch antenna has a small size, the efficiency reduction due to the antenna alone on a solar cell with cover glass is only 0.6%. This provides an important entry in the link and power budget consideration for a CubeSat mission.

4. Conclusion

This paper examines the interaction between a commercial space solar cell and the patch antenna printed on top of the cover glass of the solar cell. The operational frequency is 10 GHz, and therefore, the size of the antenna is small enough not to cast significant shadow on the solar cell. It was found that the solar cell reduced the antenna's gain to about 2 dB and did not affect the shape of the radiation pattern. The working states of the solar cell was also found to have little effect on the antenna. In other words, the DC current in the electrodes of the solar cells does not affect the antenna's performance. The same conclusion holds for the different orientation of the antenna on the solar cell. When the solar cell's performance was explained, it was found that the antenna together with the cover glass reduced the efficiency of the solar cell. But, the antenna alone has only 0.6% effect on the solar cell, and therefore, providing support in integrating antenna directly on solar panels of CubeSats to save surface real estate.

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