SSC17-P1-01

A Clear Antenna on CubeSat for Big Data

Muhammadeziz Tursunniyaz, Reyhan Baktur, Charles Swenson
Utah State University
4120 Old Main Hill, Logan UT 84322; (435)994-8736
muhammadeziz@aggiemail.usu.edu

Ryan Martinau
Space Dynamics Laboratory
1695 Research Park Way, Logan, UT 84341
ryan.martineau@sdl.usu.edu

Serhat Altunc, Eleanya E. Onuma, Harry Shaw
NASA, Goddard Space Flight Center
Greenbelt, MD, 20771, USA
serhat.altunc@nasa.gov

Marta B. Shelton
Wallops Flight Facility
Chincoteague Island, VA 23336
marta.b.shelton@nasa.gov

ABSTRACT

The paper reports the latest development of a clear solution for CubeSat antennas where an X band optically transparent antenna are inkjet printed on a glass that goes on top of the solar panel of a 6U CubeSat. The antenna has an optical transparency of 95% and gain of higher than 21 dB after being integrated on the solar panel. Tests include antenna and solar panel's individual properties such as antenna's gain and I-V curves of the solar panel, and interaction between the two. This integrated solar panel antenna will be an alternative solution for high data rate for LEO, GEO, Lunar and interplanetary CubeSat missions which currently have to use deployable reflector antennas.

1. INTRODUCTION

As CubeSat applications are calling for faster and bigger data transmission, a paradox on the antenna design is inevitable, where an antenna with high gain and data rate requires larger size that challenges CubeSat's payload. NASA's ISARA is a great solution to resolve such problem as it integrated a reflectarray antenna under the solar panel [1]. But ISARA is not applicable when the sun and the communication front-end are required to be of the same direction. This paper presents an alternative design where a highly transparent antenna is directed printed on top of solar cells. As the antenna is integrated on top of solar cells, it does not require additional space or deployment. Such an integration provides a conformal, low cost, highly efficient, and low risk antenna design that enables big data transmission.

This project is a collaborative effort that includes Utah State University, Space Dynamics Laboratory, NASA Goddard Space Flight Center, and Wallops Flight Facility. Both the solar panel and antenna use only space certified material and modular design.

2. ANTENNADESIGN AND PROTOTYPING

We designed the reflectarray at 8.475 GHz (near earth network (NEN) radio frequency) to for a solar panel of 20 cm by 30 cm that can easily fit a 6U CubeSat. An illustration the reflectarray and the feed location is as shown in Figure 1, where the substrate for the reflectarray includes a clear glass of size 20 cm by 30 cm and the solar cells together with all bounding layers. The reflectarray design followed the guidelines presented in [2] and [3], where the most optimal elements are chosen to of square loops with a quarter-wave spacing. The reflected beam (θ in Figure 1) is pointed at 22.7 degree, and considering the optimal aperture efficiency and having an edge taper of -10 dB, the feed horn gain and the focal distance (F in Fig. 1) were determined to be 12 dB and 135 mm, respectively.

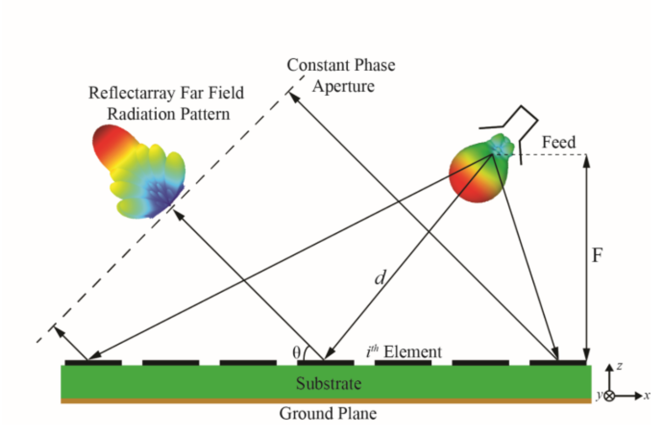


Figure: 1 Illustration of the reflectarray and feed

2.1 Considerations of the Substrate

The main challenge is to choose a suitable glass to print the reflectarray on. The substrate needs to provide a minimal thickness to provide minimum needed phase range for the antenna, and sufficient transparency. At this time, we have chosen a Schott Borofloat Glass from Howardglass [4] to print the initial design on. The properties of the glass are as follows. Optical transparency is around 92.5%, thickness is 2.75 mm, dielectric constant (25 °C, 1 MHz) is 4.6, and the loss tangent tan δ (25 °C, 1 MHz) is 37 x 10-4. The glass still has a potential issue for a future mission because it is thick and the blackening issue may not be avoidable. Hence, our team is in search of an alternative cover glass material such as acrylics for the next prototype.

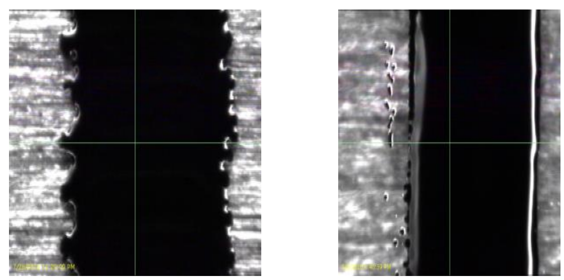
2.2 Inkjet Printing

A Dimatix Material Printer (DMP-2831) from Fujifilm has chosen to be the main tool to inkjet print the antennas on glass using the Novacentrix JS-B40G ink. The antenna geometry to be printed can be created in the pattern editor embedded in the Dimatix Drop Manager (DDM) software that comes with the printer. Another method, which has been found more effective, is to use an EM simulator such ANSYS HFSS, ADS Momentum etc. to generate geometries, and then export them in a file format such as dxf. ACE3000, which is provided by Fujifilm. After that, the dxf file can be converted to bitmap file which can be recognized by the DMP-2831. The second method allows one to create more complicated figures and to use Matlab scripting for periodic geometries.

A clean glass surface is a prerequisite for quality printing. The glass surface can be cleaned with 75% Ethanol or Acetone solution, which also will change the hydrophobic glass surface to hydrophilic by attaching hydroxide ion on the glass surface, resulting in an optimal wetting of the glass surface for hydrophilic inks such as Novacentrix JS-B40G.

We used a 1 picoliter DMC-11601 cartridge which has 16 nozzles. It is challenging to keep all the 16 nozzles jetting. So it is important to tune the nozzles and choose the most stable nozzles while printing. There are several parameters such as jetting voltage, jetting waveform, and drop velocity, which can be tested and optimize to get the best printing quality.

Before starting to print, the cartridge angle and drop offset need to be adjusted manually. After the printing is done, one can observe the printed traces using the fiducial camera built in the DMP-2831 as illustrated in Figure 2. The drop formation can be observed by using drop watcher camera built in DMP-2831. It can be optimized by adjusting the jetting voltage and waveform. Figure 2 shows the difference in printing quality before and after tuning the nozzles.



(a) Before tuning nozzles (b) After tuning nozzles

Figure 2: Fiducial camera view of the feed line of a patch antenna

Curing is the last step for the inkjet printing process and it can be performed in an industrial-grade oven. Controlling the curing time and temperature is crucial to achieve optimal electrical conductivity and adhesivity of the printed trace to glass surface. These two parameters are usually listed by the ink provider, or can be achieved from experimenting. We cured the printed reflectarray at 250 C° for 10 min, which was recommended by the ink manufacturer.

2.3 Coating

Given the fact that the printed reflectarray must be capable of being handled under normal working conditions such as touching and minor scratching, the printed glass was coated with Parylene HT, a fluorinated variant of the basic di-para-xylene. Parylene is applied by vapor deposition of the reactive monomer. Parylene HT has a very low coefficient of friction and capable of withstanding temperatures up to 450 C. It was applied to a thickness of 0.5 mil to 1 mil.

3. MEASUREMENTS AND DISCUSSIONS

The measurements have been performed on the antenna (gain, efficiency) with or without solar panel underneath, and on the solar panel with or without the antenna on top. The antenna tests were performed at Utah State University and at Wallops Flight Facility for verification. The solar panel tests were performed at the Space Dynamics Laboratory.

3.1 1Antenna Measurements

The printed antennas were measured at USU with and without a 6U solar panel underneath. When there is no solar panel under the antenna, a copper or aluminum ground layer were added under the glass. Figure 3 shows how the printed reflectarray was assembled on the solar panel. For these tests, in order to reuse the antenna and solar panel, we did not use any adhesive to bond the glass and solar panel. Figure 4 and Figure 5 were provided by Wallops Flight Facility when the antenna was shipped there for further measurements. USU and Wallops results match well and are summarized in Table I.

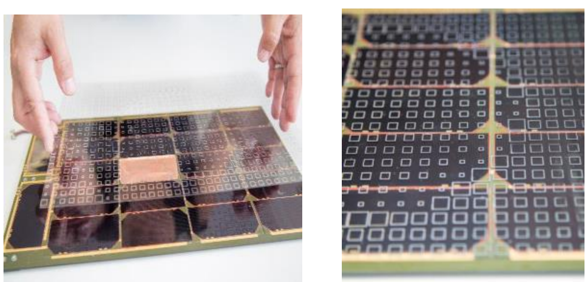


Figure 3: Antenna Placed on Solar Panel

In Table I, the simulation is the design data where a reflectarray is simulated on a glass substrate with copper elements (i.e. those loops are copper with sufficient thickness). When inkjet printing the antenna on glass, there is a gain loss due to the conductivity of the ink being not as high as copper. After being integrated on solar panel, there is a further gain reduction due solar cells and this is understandable. Overall, one is confident to predict a more than 20 dB gain of this design when integrated on a functional solar panel.

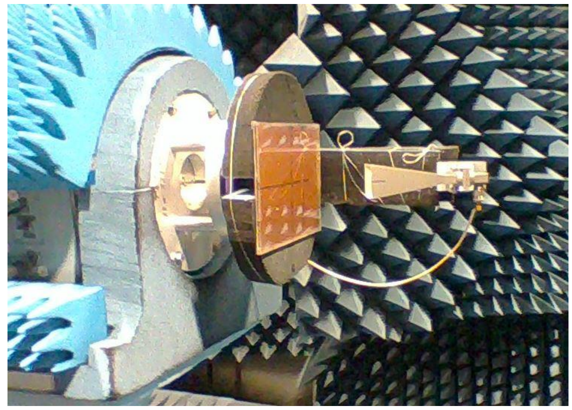


Figure 4: Antenna under Test at Wallops

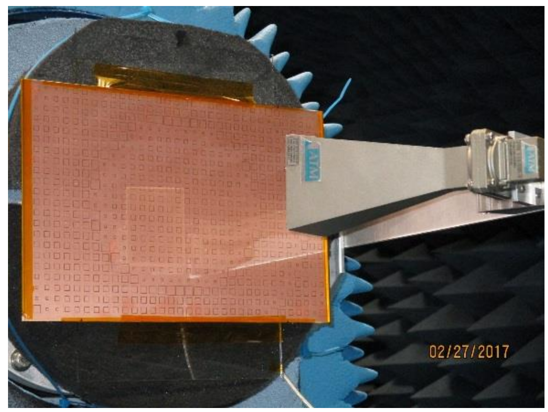


Figure 5: Close-up of Antenna under Test at Wallops

Table I: Gain of the Reflectarray

Reflectarray	Gain (dB)
Simulation	24
Inkjet Printed on Glass	22.6
Integration on Solar Panel	21

3.2 Solar Panel Measurements

Solar panel tests were performed using a 3U solar panel and half of the reflectarray printed on glass with a size of 10 cm by 30 cm (Figure 6). The reason for this arrangement is that by the time of I-V curve measurements, our team has not finished assembling a 6U solar panel. Hence, we scaled the problem to a 3U. As the reflectarray is symmetric, cutting it to half does not change its transparency. These tests were performed at the Space Dynamics Laboratory and the tests are as follows. The first test is to measure the I-V and P-V curve of a 3U solar panel. The second test is to repeat the solar panel measurements when placing a clear Schott Borofloat Glass of 10 cm by 30 cm. In the third test, the glass that goes on top of the solar panel has half of the reflectarray printed on it. The measured results are shown in Figure 6 and Figure 7. The efficiency of the solar panel under those three tests were then calculated and listed in Table II.

Figure 6: I-V Curve Measurement Set up

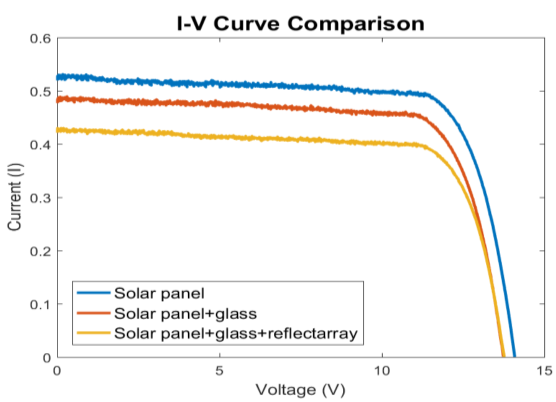


Figure 7: I-V Curve Comparison

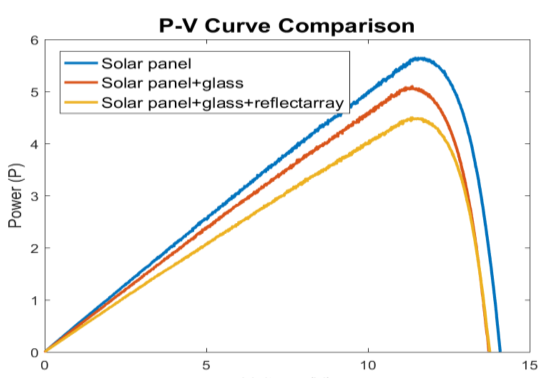


Figure 8: P-V Curve Comparison

Table II: Solar Panel Efficiency

Test set-up	Efficiency
Solar Panel	26.1 %
Solar Panel with Clear Glass on Top	23.6%
Solar Panel with Reflectarray (printed on glass) on Top	20.8%

It is seen that the efficiency of the solar panel reduces to about the 90% of when it is not covered with the Schott Borofloat Glass. This is consistent with the transparency of the glass, which is about 92%. The reflectarray itself, however, reduces the efficiency of the solar panel to 88% of when it is covered with the clear glass. This reduction is higher than expected because the transparency of the reflectarray is 95%. The reasons for the lower efficiency of the solar panel under the printed reflectarray are as follows. (1) From Figure 6, the 3U panel is smaller than the glass, hence the actual transparency of the printed antenna is lower than 95%, and (2) the shadows of the traces of the antenna may be higher than the dimension of the antenna elements, hence more blockage on the solar cells.

4. CONCLUSIONS

An optically transparent X band reflectarray has been inkjet printed on the glass cover of a 6U solar panel. The gain of the antenna is 21 dB when integrated on the solar panel. The I-V and P-V curves of the solar panel has been measured using a scaled 3U model. It is seen that the efficiency of the solar panel is reduced due to the transparency of the glass as well as the antenna. The combined effect reduces the efficiency of the solar panel to 20.8%, however, it is expected that the final efficiency can be improved to at least 22% with a 6U model and can be further improved with the choice of more transparency cover glass material such as acrylics.

Acknowledgements

We acknowledge NASA/GSFC Space Network and Near Earth Network Projects, Wallops Flight Facility, Specialty Coating Systems, S.I. Howard Glass, Harris Corp, and Sol Aero for supporting this project. Special thanks goes to Mr. Zakk Rhodes (USU/SDL) for assisting solar panel and antenna measurements.

References

1. "Integrated Solar Array and Reflectarray Antenna (ISARA) for High Bandwidth Cubesats", NASA document, https://www.nasa.gov/sites/default/files/files/ISARA Fact Sheet-15Oct14.pdf

2. Taha Yekan and Reyhan Baktur, “Design of Two Transparent X Band Reflectarray Antennas Integrated on a Satellite Panel”, 2016 IEEE APS/URSI Symposium.

3. Taha Yekan and Reyhan Baktur, “Conformal Integrated Solar Panel Antennas”, IEEE Antennas and Propagation Magazine, 2017, Page(s):69 – 78.

4. http://www.howardglass.com