Inkjet-Printed Transparent Antennas Integrated on Solar Cells

Tursunjan Yasin
Department of Electrical and Computer Engineering,
Utah State University
4120 Old Main Hill, Logan UT 84322; (435)713-5765
tursunjan.y@aggiemail.usu.edu

Reyhan Baktur
Department of Electrical and Computer Engineering,
Utah State University
4120 Old Main Hill, Logan UT 84322; (435)797-2955
reyhan.baktur@usu.edu

Jason Saberin
Department of Electrical and Computer Engineering,
University of Utah
50 S Central Campus Drive, Salt Lake City, UT 84112; (801) 585-7234 / 581-6941
jasonsaberin@gmail.com

Cynthia Furse
Department of Electrical and Computer Engineering,
University of Utah
50 S Central Campus Drive, Salt Lake City, UT 84112; (801) 585-7234 / 581-6941
cynthia.furse@utah.edu

ABSTRACT

This paper presents the experimental study on an optimal circular meshed patch antenna inkjet-printed on transparent substrate. Meshed patch antennas provide a cost-effective solution for applications where the antennas need to be optically transparent. An earlier study has shown that it is feasible to integrate a rectangular meshed patch antenna with 93% transparency directly on solar cells. Although circular meshed patch antennas are as important as the rectangular ones, the study on the subject is rather limited due to the limit in fabrication method and lack of an effective feeding method. This paper focuses on the feed design and fast-prototyping with inkjet printing technique, where the antenna geometry is printed on a thin transparent substrate with conductive ink using a commercial printer. The transparent substrate can then be integrated on solar cells. It is found that a non-contact feed using coupling between the feed line and the antenna is more effective and realistic than other feeding methods for solar cell integration. Although the design approach is tested with inkjet printed prototype, it is highly feasible that one can print meshed circular antennas directly on substrates such as cover glass of solar cells.

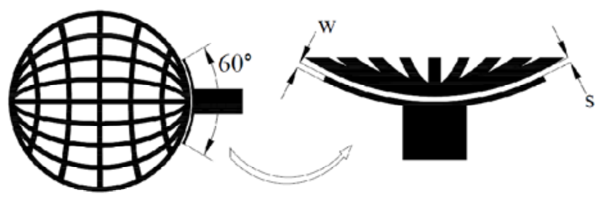
INTRODUCTION

Optically transparent antennas have been receiving growing interest where one either needs to hide the antenna, or save surface real estate in small satellite application by integrating those antennas with solar cells. Turpin et al. has demonstrated a meshed patch antenna with 93% transparency where the antenna could be either fabricated from electroformed metal mesh or screen printed on transparent substrates with conductive inks [1]. For a faster and more accurate fabrication, it is favorable to print antenna with an inkjet printer as described by Rida [2]. Rida's approach focused mainly on using paper substrates and on ring or dipole type antennas, and are not applicable for solar cell integration. Solar panel assemblies for small satellites always have metal ground planes and feasible antenna design is limited to planar geometry such as patches. Also, the antennas need to be printed on transparent substrates such as solar cell cover glass so that the antennas will not reduce the solar cell functionality. Turpin's antenna [1] suggests the feasibility of integrating conductive ink-printed meshed transparent rectangular patch antennas with solar cells. Circular meshed antennas, however, although equally important, have not received enough attention. The reason for such limited study can be partially due to the limitation in fabrication method and lack of an effective feeding method. To address such limitation and to prove the feasibility of fabricating effective transparent circular meshed antenna, this paper focuses on the feed design and fast-prototyping with inkjet printing technique. The antenna geometry is printed on a thin transparent substrate with conductive ink using a commercial printer. The transparent substrate can then be integrated on solar cells. Inkjet printing is more accurate than screen printing and can provide higher optical transparency when printing mesh design. The printing method can also yield better feed design because one can print fine feed geometry that cannot be prototyped with traditional circuit board method or screen printing method.

Although the functionality of meshed circular antennas and the feed designs are validated by inkjet printing with conductive ink on plastic-like substrate, the design method can be easily adapted to other printing or surface writing method so that one can fabricate transparent meshed antennas directly on solar cells.

ANTENENNA DESIGN

A circular meshed patch antenna geometry is illustrated in Figure 1. The fine geometry of the feed design is illustrated separately in Figure 1-(b) for clarity. As seen from Figure 1-(b), the antenna is excited through coupling from the feeding arch. Such feed design has been chosen due to the fact that the antenna will be eventually assembled on a solar panel, and it is not reasonable to excite the antenna with a probe feed or an inset feed. With the proposed passive feeding, one can easily place the feed part on the edges of the solar panel so that the feed does not block solar cells. It is found that with passive feeding through an arch, it is simple and effective in matching a meshed antenna to a 50 Ohm microstrip line, which is essential for laboratory validation. Also, one can simultaneously print the feed together with the antenna design.



(a) (b)

Figure 1: A Meshed Circular Patch Antenna and Its Feed Design

When designing the arch line-width (w) and coupling gap (s) (Figure 1-(b)), Ansoft's HFSS was used to perform initial simulation without considering the loss of the conductive ink. The simulated results were then used as guidelines for fabrication. The initial values for the coupling distance (s), length and the width (w) of the branch lines (Figure 1) were taken referencing Zhu [3] and Liu [4], and then were refined during the simulation. It is found that for most antennas, the length of the arch does not change much and a 60 degree line (Figure 1-(a)) is effective to be applicable for most circular antennas.

When studying the meshed geometry, it is found that the relation between the antenna transparency and functionality is similar to those meshed rectangular patch antennas [5]. When the line-width (or mesh width) is fixed, increasing the transparency of the antenna decreases the efficiency of the antenna. On the other hand, for a given transparency, it is found that one can improve antenna efficiency by refining the meshes. This means as long as fabrication tolerance allows, one can print a very fine-lined mesh antenna to achieve both optical transparency and antenna efficiency at the same time.

PROTOTYPING AND VALIDATION

Based on the design of antenna geometry and excitation method described in the previous section, we have prototyped two circular meshed antenna using inkjet printing method.

Inkjet Printing Method

The antennas studied in the paper were printed on a thin transparent substrate polyethylene terephthalate (PET) which has been specially processed to hold conductive ink better than regular plastics. Although it is not critical to choose special substrate, at current stage in our study, such specially treated PET can help to ensure the conductivity of the ink.

A commercial Epson C88+ inkjet printer was used to print the antennas and the feedlines. To ensure the quality of the printing, all four cartridges filled with conductive ink provided by NovaCentrix [6] were all turned on and the printer was configured as color printing mode. Although it is possible to use only one cartridge and configure the printer as black and white mode, it is found that the conductivity of printed lines is higher when printing under color mode. When higher conductivity is needed, one can repeatedly print the antennas and feedlines on the same prototype.

In this particular study, the ink we have used is JSB-35P, and it is a silver nano-particle based ink. After the antennas and feedlines were printed, one needs to proceed to the curing stage that is critical in inkjet printing. The curing process can be performed on a special machine PulseForge by NovaCentrix [6], or can be performed by baking the printed antennas and feedlines in an industrial oven under 375 °C for two to three hours. We have chosen to use PulseForge because the process takes only a few seconds and there is no damage to the substrate where the antennas were printed.

Antenna Assembly

After the antennas and feedlines were printed and cured, we proceeded to assembling the antennas for testing. The antenna assembly is illustrated in Figure 2 where the printed antenna is placed on top of a transparent plexiglass substrate. The plexiglass is then backed by a copper substrate to function as a ground plane for the antenna. Such assembly is chosen because the solar panel for small satellites always has a ground plane. Although plexiglass is not the same substrate as the cover glass of solar cells, it is the cheapest substrate to perform laboratory validation at this time. After insuring the antenna functionality through testing with plexiglass, the design method can be easily adapted to different substrates.

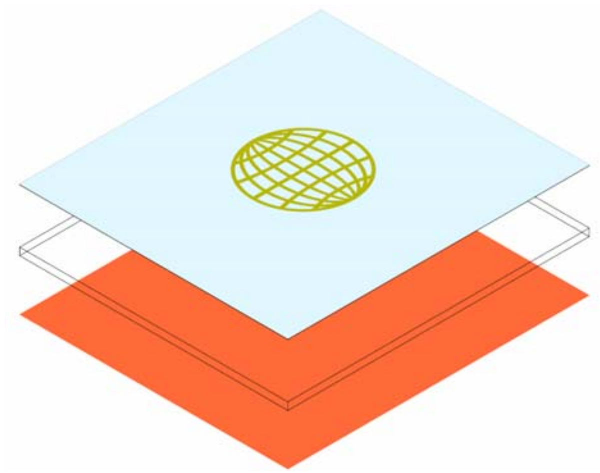


Figure 2: Antenna Assembly

A prototype circular meshed antenna assembly is shown in Figure 3. The size of the plexiglass substrate is 150 mm by 150 mm and it has a thickness of 2.032 mm. The relative permittivity and loss tangent of the plexiglass are taken to be 2.6 and 0.0057 respectively. The plexiglass is then backed by copper tape to form a ground plane for the antenna.

We have prototyped two antennas. One is designed to operate at 2.6 Ghz and has an optical transparency of 60%. This antenna has a line-width of 0.72 mm. The other prototype has a more refined line-width of 0.2 mm to achieve an optical transparency of 90%.

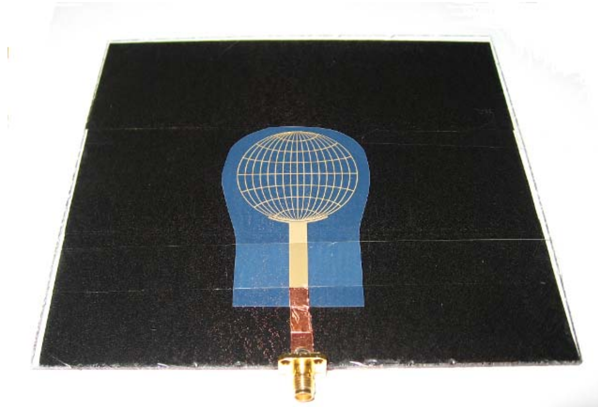


Figure 3: A Prototype Inkjet Printed Circular Meshed Antenna

Experimental Result

The prototyped antennas were measured at Utah State University to validate the design and printing methods. We have performed return loss (S11 parameter) measurement and radiation pattern measurement. The return loss was measured using a vector network analyzer (Agilent 8510C), and the radiation pattern was measured using NSI's spherical near-field antenna range.

Figure 4 shows the return loss of the 60% transparent antenna. It is seen that a very good return loss level has been achieved, validating the effectiveness of the feed design. Figure 5 shows the cross- and co-polarization pattern of the 60% antenna in principle E plane. It can be seen that the radiation pattern closely resembles that of solid circular patch antenna [7] and a very good cross-polarization level has been achieved.

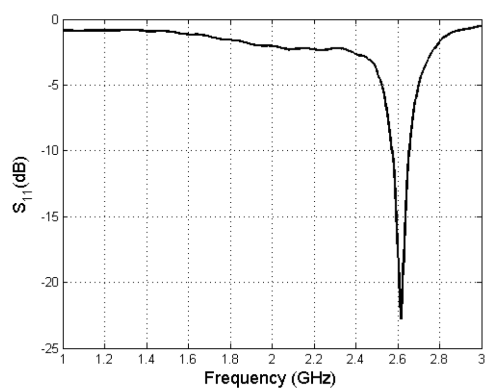


Figure 4: Measured Return Loss of a 60% Transparent Meshed Circular Antenna

Figure 6 is the measured return loss of the 90% transparent meshed antenna. Initially the printed prototype gave only -13dB return loss, which is acceptable, but not outstanding. We manually cut the gap between the meshed antenna and feeding arch and adjusted the width of the coupling gap (w in Figure 1) and achieved a return loss level of -18dB. This shows one advantage of the proposed feeding method. When there is any possible tuning of the antenna needed, one can easily re-assemble the antenna to achieve an acceptable matching.

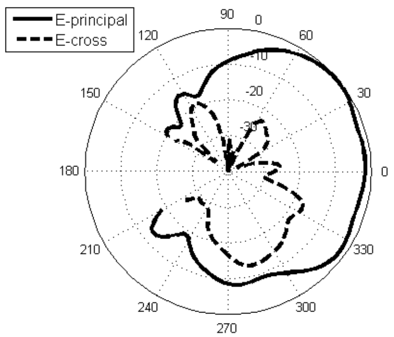


Figure 5: Radiation Pattern of a 60% Transparent Meshed Circular Antenna Operating at 2.6 GHz

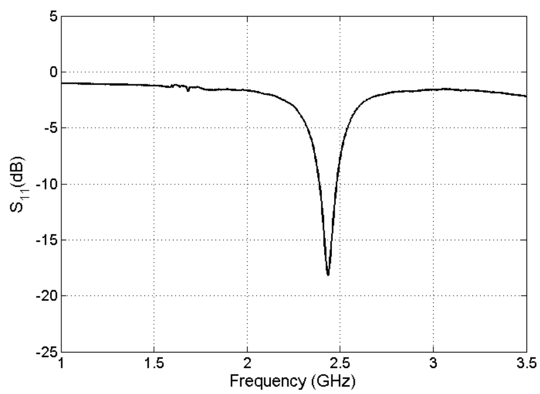


Figure 6: Measured Return Loss of a 90% Transparent Circular Meshed Antenna

CONCUSIONS AND FUTURE WORK

We have studied the design of transparent circular meshed antennas that will be integrated on top of after-market solar panels. It is found that one can easily achieve both transparency and antenna efficiency by carefully designing the mesh geometry. After studying the specific requirements of solar panel assembly, we found exciting the antennas using passive coupling is the most realistic and effective method. The design philosophy, prototyping method, and validation of the design were presented in this paper.

The study on inkjet printed antennas showed promises of printing antennas on transparent substrates and integrating them with surfaces such as solar panels. As for continued work, we plan to print highly transparent circular meshed patch antennas with transparencies higher than 90%, and then integrate them on solar panels as shown in Figure 7. We plan to validate antenna design after the antenna being integrated on solar panels, as well as solar cells' functionality while having a transparent antenna placed on top of them.

Figure 7: Solar Cell Integration

Acknowledgments

This work was supported by National Science Foundation (Award # 0801426).

We thank NovaCentrix for providing technical support, material supply, and help printing/curing some antenna prototypes.

References

1. Timothy W. Turpin, and R. Baktur, "Integrated Solar Cell Meshed Patch Antennas", IEEE Antennas and Wireless Propagation Letters, 8: 693-696, 2009.
2. Amin H. Rida, Conductive Inkjet Printed Antennas on Flexible Low-cost Paper-based Substrates for RFID and WSN Applications, Master Thesis, Georgia Institute of Technology, May 2009.
3. Lei ZHU and Ke Wu, "Line-to-ring Coupling Circular Model and Its Parametric Effects for Optimized Design of Microstrip Ring Circuits and Antennas", 1997 IEEE MTT-S Digest Volume: 1, page(s): 289-292.
4. Ji-Chyun Liu, Hui Chi Wu, Meng Shan Chiang, Hsin-Yi Tsou, "T-coupled Circular Microstrip Antenna with H-shaped Aperture for Bandwidth and Radiation-gain Improvements", Microwave

and Optical Technology Letters, Volume 37 Issue 6, Pages 414 – 417Redd, F.J. and G.E. Powell, “Project Thermion: Demonstration of Thermionic Heat Pipe in Microgravity,” Proceedings of the 9th Symposium on Space Nuclear Power Systems, Albuquerque, NM, January 1992.

5. T.W. Turpin and R. Baktur, “See-through Microstrip antennas and their optimization,” in Proc. General Assembly of the International Union of Radio Science, Chicago, IL, August 2008.

6. http://www.novacentrix.com/

7. Constantine A. Balanis, Antenna Theory: Analysis and Design, third edition, Wiley, 2005.