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Feasibility analysis of additive manufacturing method for Graphene nano-conductive ink based super solar body mounting printed patch antenna structures in cubesat and aerospace applications

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ABSTRACT

In this project, a nano material based printed patch antenna structure has been integrated with a solar panel without affecting the optical efficiency of the solar panel. The proposed prototype is having the property of both antenna and solar module functionality. A Graphene based CPW fed E-Shaped microstrip patch antenna which has a return loss of -48.43dB at resonant frequency of 2.1GHz which is best suitable for UMTS-2100 Band (2.15GHz – 2.18GHz), GSM (2.15GHz – 2.18GHz) applications is printed on the solar panel using screen printing technique. In this project, conventional copper-based antennas are replaced with graphene-based antennas due to various advantages. In this experiment, the feasibility of material based body mounting antenna structure printing method is analyzed. This proposed design model is best suitable for satellites where antennas occupy one-third of the satellite's size. By mounting the small printed antennas on the solar panel, the space complexity of the satellite system gets reduced by one-third of its initial dimensions.

Keywords – Antenna characteristics; Body mounted antenna; Graphene nano conductive ink; Microstrip patch antenna; Screen printing

INTRODUCTION

In recent advancements in the satellite communication field like SmallSat and CubeSat which are very small in size, it is difficult to deploy antenna for communication and solar panel for energy harvesting within a small space. Hence integrating antenna with solar panel and making them as a single compact unit draws attention worldwide. The important consideration in this approach is, the antenna which is integrated with the solar panel should radiate efficiently without degrading the efficiency of the solar panel with its shadowing property.

The state of the art integration methods can be broadly divided into two categories: Sub-solar and Super-solar [1]. In Sub-solar, the antennas are placed below the photovoltaic (PV) panel and in super-solar, the antennas are placed above the PV panel. Slot antennas that are placed beneath the solar panel in a manner that, the radiating surface is not shadowed by the solar cells [2,3] were used in Subsolar approach. In this configuration the radiating antenna element need to be very small and also located carefully between the solar cells. This configuration affects the performance of the antenna, as the solar cells act as superstrate and it is difficult to place the fabricated antenna under the after-market solar panel. So it is of less interest among researchers. Hence super solar method gains much interest.

For super-solar approach both transparent and opaque patch antennas were used. Transparent antenna includes meshed antenna[4,5], conformal slot antenna[6] and patch antenna printed with Transparent Conductive Oxides(TCO) like Indium Tin Oxide(ITO)[6] and silver coated polyester film(AgHT) [7-9] whereas opaque antenna comprises of slot antenna[10,11] with small dimension of antenna shadowing the solar cells and patch antennas placed in the gap between the solar cells. Apart from these, this super-solar approach also include inverted F-shaped patch antennas that are placed vertically [12, 13] on the solar panel. Some comparative studies on transparent and meshed antenna were done in [14, 15] which shows that transparent antenna printed using TCOs are flexible as it can be placed anywhere on the solar panel and can be extended to arrays. Also, these transparent antennas can be fabricated easily on after-market solar panels. But it cannot be as efficient as meshed antenna. This meshed antenna is a bit difficult to design and fabricate when compared to patch antennas that can be printed uniformly on a smooth surface. Hence, an efficient antenna that can be easily fabricated on solar panel can solve this trade-off. One of the solution we examined is, Graphene patch antenna printed on solar panel.

Graphene is a two-dimensional material with high flexibility, good tensile strength, high electrical conductivity[16] of about 10^8 S/m which is greater than that of silver($6.25x10^7$ S/m) and copper($5.8x10^7$ S/m) and very high electron mobility. In addition to these it also possess good optical properties that are worth to be noted. Graphene is highly transparent *i.e.,* single layer of graphene allows 97.7% of light [17] to pass through it. Double layer of graphene increases electrical conductivity and absorbs only 4.6% of light which can compete with the existing TCO antenna. Hence, it can be used as transparent conductors. The high conductivity and radiation absorption nature of graphene along with the optical transparency make it the most suitable material for designing efficient patch antenna on solar panel without degrading the efficiency of the solar panel. One more advantage of using graphene is, its weight. Since graphene is only one-sixth of copper density, it reduces the weight of the antenna payload because of its amorphous form of existence.

In our work an E-shaped patch antenna was printed with graphene Nano conductive ink using screen printing technique on the solar panel. In this paper we have discussed the antenna parameters and the properties of the printed structure, selection of printing mechanism, customization of printing material and the efficiency of solar panel mounted with antenna.

ANTENNA DESIGN

In this paper, an E-shaped microstrip patch antenna has been designed by introducing rectangular slots to the conventional basic rectangular microstrip patch which has a length of 25mm and width of 31mm and is fed with CPW feeding mechanism as shown in the figure 1. E-shaped antenna provides wide bandwidth [18], dual band [19] and enhanced antenna parameters [18]. Along with this it also occupies less area which reduces the shadowing and also reduces the quantity of conductive material used to print the antenna structure. Hence, this shape is chosen for experimentation.

The proposed prototype is based on super-solar approach that is the designed antenna is printed on after-market solar panel. In this approach, mostly the glass layer above the solar panel acts as substrate for the patch antenna. The ground plane, for the antenna to radiate effectively is of great concern, since it could also affect the solar panel efficiency. Some solutions so far used were meshed ground plane with coaxial feeding[1,5], body of the satellite as ground plane[11], separate ground plane that need to be electrically isolated from the solar panel[6,10] and the solar cell itself as ground plane[8] with line feeding or electromagnetic coupling. All these methods are complex in fabrication and feeding .So, in order to reduce the fabrication complexity CPW feeding [7] is used. In this feed the patch and the ground plane is printed on single side of the substrate which makes the fabrication easier.

The chosen microstrip patch is designed on a glass substrate of length 31mm, width 41mm and 1.6 mm thickness with dielectric constant of 4.4. The antenna is fed with 50Ω microstrip line using CPW based inset feeding mechanism. This proposed antenna was designed and simulated in ANSYS HFSS and the results were obtained.

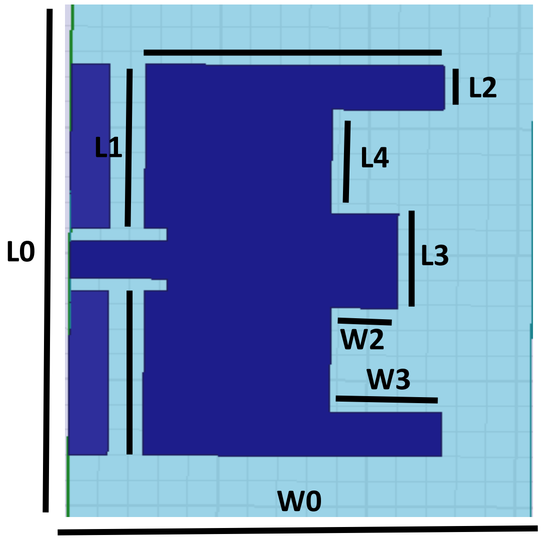

Figure1 Proposed E- shaped Microstrip Patch Antenna

SELECTION OF PRINTING

Graphene is the most widely studied material for printed electronics. Common printing technologies used were inkjet, screen printing, flexographic and gravure printing and offset lithography [20]. Apart from these spraying and doctor blading technique were also used in printing microstrip patch antennas. Flexographic and offset lithography were least methods used in printed electronics. Spraying is a good method but because of uneven coating thickness [21] it will not be suitable for experimentation. Doctor blading[22] is a simple method to spread highly viscous graphene ink but its accuracy is less when compared to inkjet and screen printing because of the thickening lattice structure on the top when compared to the bottom lattices.

Inkjet printing can be done with low viscosity graphene ink of about 10-12 mPa.s[23] which is highly accurate and also high cost. This type of printing is very useful in flexible printed electronics [24]. In inkjet printing there is a possibility for agglomeration of graphene nano particles due to the low viscosity nature of the ink that is used. And also inkjet printing is best technique when the substrate used is very thin. The substrate used here is the glass on the solar panel with thickness of 1.6 mm. The surface of the glass is also very polished so the adhesion of low viscosity conductive ink is poor because of the poor atomic bonding over the solar panel surface.

Screen printing is the best method when accuracy, cost and conductivity [21] are of main concern. In this technique, the thickness of the substrate is not a problem. The main concern here is the viscosity of the graphene conductive ink because low viscosity inks cannot be used for screen printing [20]. Also, high viscosity inks can be printed on smooth polished surfaces like glass, which is used as the substrate in our prototype. Hence screen printing is chosen for the fabrication of the prototype but the graphene ink used for this should be properly customized for the printing.

CUSTOMIZATION OF PRINTING MATERIAL

In graphical printing the ink is composed of pigments, binder, solvents and additives [20]. For printed electronics the pigment is replaced by conductive materials. The graphene conductive ink prepared for our project is composed of low density graphene powder, binder dispersions and solvent. The high viscous graphene ink was prepared by mild heating of low density graphene powder with binder at a ratio of 1:2 and mixed with isopropyl alcohol which is the solvent used. In order to maintain the conductivity in the same line after printing, no additives are added.

FABRICATION

After solvent exchange, the graphene ink was applied to the substrate by screen printing using 45^0 angle polyurethane squeegee, at printing speed of 50mm/s followed by drying in air at 100^0 C for 5 minutes. The thickness of printing is measured as 23μm. Subsequently, printed structures were thermally cured at 350^0 C for 30 minutes in air and finally, compression rolled. Printing was done with EKRA E2 semi-automatic screen and stencil printer (ASYS Group) in air at controlled temperature and relative humidity. But graphene is a bit brittle like ceramic which might cause mechanical issues which can be solved by coating the microstrip patch with a polymer-based enamel without affecting the efficiency of the antenna and its performance.

RESULTS AND INFERENCE

The designed CPW Fed E shaped microstrip patch antenna model as shown in Figure 1 has two reflections below |*S*11| = -10dB when simulated using HFSS software. It has return loss values of -30.48dB and -11.14dB at resonant frequencies of 2.1GHz and 2.7GHz respectively as shown in the figure 2. It has VSWR values of 0.51 and 4.84 for 2.1GHz and 2.7GHz respectively as shown in the figure 3. It has impedance bandwidth of 25.87% at |*S*11| ≤ -10dB at a range of 2.13GHz to 2.77GHz and has a reduced area of 617.55mm (i.e. 79.6% of the conventional basic rectangular patch area). A 3-D view of the antenna gain is given in Figure 4. From the results, the antenna design is suitable for UMTS-2100 Band (2.11GHz – 2.17GHz) applications.

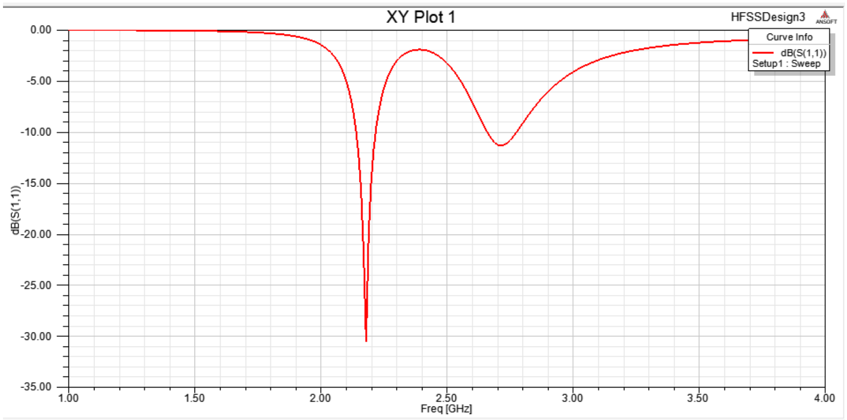

Figure 2 Simulated Return loss graph of the proposed design

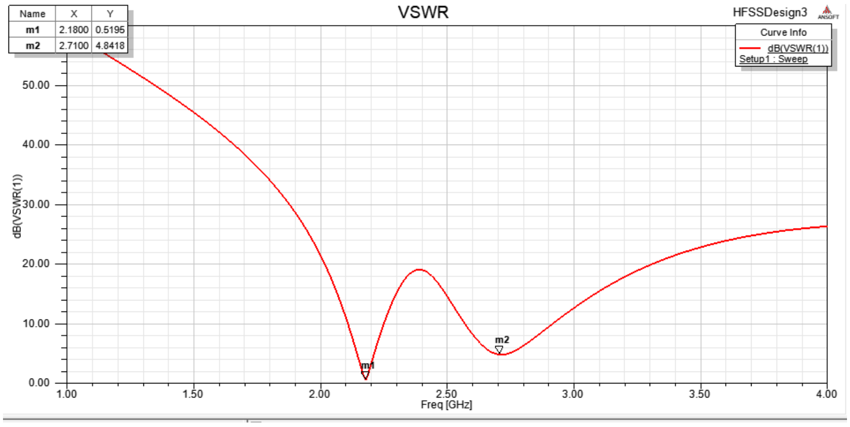

Figure 3 Simulated VSWR graph of the proposed design

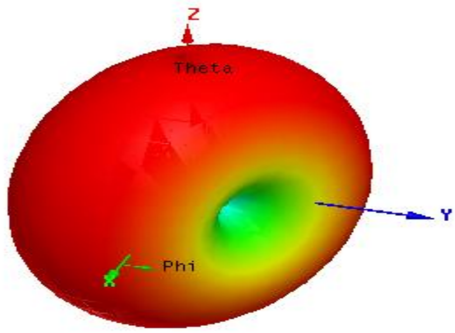

Figure 4 simulated 3D Polar Plot of Gain of the proposed design

The proposed Microstrip patch has been fabricated using graphene material as shown in the figure 5 using screen printing technique as mentioned earlier in section 5. When measured using network analyzer, we obtained a return loss of -48.43dB at resonant frequency of 2.09GHz as shown in the figure 6. The shift in the obtained value is due to the conductivity nature of the material used. The VSWR value lies between 0 to 2 as shown in the figure 7. It has an impedance bandwidth of 25.87% ($|S_{11}| \leq$ -10dB) in the frequency range of 2.06GHz to 2.11GHz with centre frequency 2.09GHz which covers UMTS-2100 Band applications.

Figure 5 Fabricated prototype of Graphene based CPW Fed E-shaped Microstrip patch antenna on the solar panel

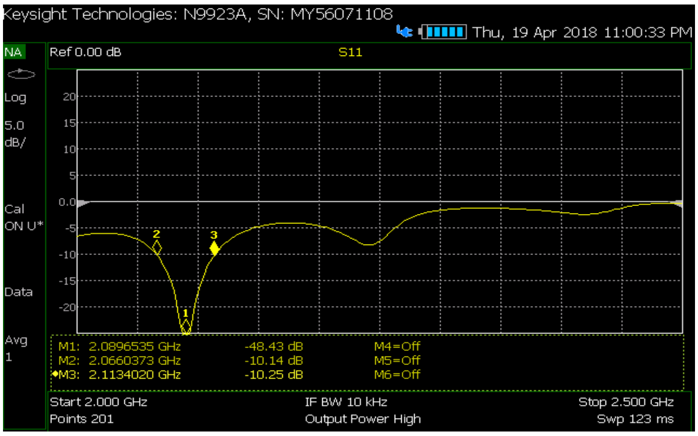

Figure 6 measured Return loss graph of the proposed design

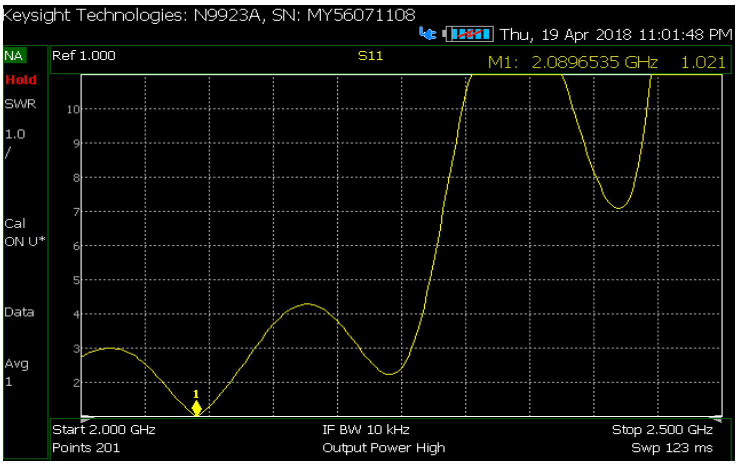

Figure 7 Measured VSWR Graph of the proposed design

The efficiency of the solar panel used without printing is 3W. With material printing the value obtained is 2.75W and the efficiency is degraded at a rate of 9.09% because of the shadowing caused by the printed antenna structures. By using screen printing the percentage of opaqueness is reduced and studied. It can be further improved by adapting atomic deposition mechanisms which are costlier than the used technique.

CONCLUSION

In this paper, a Graphene based CPW fed E-shaped microstrip patch antenna has been printed on the solar panel using screen printing technique and the antenna parameters are analysed and discussed. It is inferred that, due to the effect of Graphene material, the antenna parameters are enhanced and obtained at the same frequency expected which is more suitable for microwave applications. In this project the feasibility of screen printing method for Graphene antenna structure printing for body mounted applications are analyzed. By using Graphene material the antenna parameters are improved up to a considerable level and the efficiency of the solar panel is not degraded much because of the semi transparent property of the Graphene conductive ink. By these experiments the duality nature of integrated antenna module with solar panel is achieved and studied for its effectiveness without disturbing the individuality of the two modules.

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