Design modifications and multilayer impact in the electronic parameters of printed graphene patch antenna

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Abstract

The stack antenna technique used to improve the antenna characteristics of the printed patch antenna structures. The method of stacking varies for each material. In this work we used graphene as the radiating material. The improvement in the parameters is achieved by edge truncation and ground plane optimization techniques. The main factor to affect the stacking is the curing temperature and the heat absorbing nature of the substrate and air gap between layers. In this work we have experimented and analysed the effect of multilayer stacking on printed antenna structures and its effect on the antenna performance. The antenna is designed for 2.45 GHz ISM Band applications and the gain is more than + 5 dB. In this paper we tried to replace the copper with multilayer graphene based printed structure.

Keywords Graphene · Printing technique · Patch antenna · Stack structures · Radiation pattern · Gain

1 Introduction

Microstrip antennas are low profile antennas, that are conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when the particular patch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization, pattern, and impedance [1]. Compared to conventional antennas MSA have some disadvantages such as; Narrow bandwidth, Lower Gain and low power handling capability.

Many techniques have been introduced in the design of MSA to overcome the disadvantages like narrow bandwidth and low gain. One among them is reducing the size of the ground plane. Reducing the ground plane changes the antenna parameters especially the Bandwidth. Bandwidth of the antenna is increased [2] by decreasing the

ground plane to one third of the substrate size. This reduction in ground plane leads to increase the back lobes and also changes the operating frequency of the patch antenna. This change in antenna parameters like resonant frequency which is an important parameter due to partial ground plane can be rectified by edge truncation technique [3]. Reduction in the ground plane also provides better impedance matching [4]. Ground plane slots [5] and ground plane reduction optimizes the operating frequency range of the antenna. Ground Plane reduction minimizes the material used for printing patch antenna thereby decreasing overall manufacturing cost.

To rectify the changes in antenna parameters due to ground plane reduction techniques like truncation and slots in patches can be used. In this paper edge truncation technique is used for optimizing the antenna parameters. Truncation improves gain, bandwidth [6] and directivity [7]. Truncation can be done by removing a portion of patch from edges or corners. This part can be

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of any shape and size. Shape of the truncation affects the axial ratio bandwidth of a circularly polarized antenna [8]. Edge truncation affects the impedance bandwidth of the antenna [9] which is used in this paper.

Recently, printed electronics is an interesting field of research which provides many advantages such as ease of fabrication, light weight etc. Under this category material based printed antennas are of great interest. Conventional patch antennas use copper or aluminium as the radiating patch. In this paper conventional copper radiating patch is replaced with graphene because of its extremely good electrical and thermal properties [10]. For graphene antenna printing applications, spraying is a less reported method, suffering from lacking of uniformity in films. Inkjet-printing and doctor blade methods are complementary, the former having high accuracy and cost, in contrast to the latter [11].

In printed antennas single layer and multilayer printed antennas [12] shows difference in the antenna parameters which are discussed in this paper. Multilayer stacking of different feeding patches increases the axial ratio (AR) bandwidth [13]. Gain, which is an important factor for satellite applications, can be increased by increasing the area of the patch since gain is directly proportional to the aperture area of the antenna. Instead of increasing the size of the patch array can be used which also increases the overall size of the antenna. A solution to increase gain without increasing the size of the antenna [14] is stacking of patches one above the other vertically. Stacking with air gap increases the bandwidth [15, 16] and also gain.

In this work edge truncated patch antenna is designed, simulated and fabricated using both copper and graphene and the parameters were studied. Double layer graphene is also fabricated and the results were discussed.

2 Proposed design

A normal square patch is designed with less than one fourth ground plane in ANSYS HFSS and simulated for 2.45 GHz frequency. The square patch is of size 60 mm which is designed on FR4 substrate with relative permittivity, ϵ_r is 4.4 and loss tangent is 0.02. The length, width and height of the substrate are 110 mm, 110 mm and 1.6 mm respectively. The feeding method used here is microstrip line feed with line thickness 1 mm as shown in Fig. 1a. The ground plane size is about 110 mm × 25 mm as shown in Fig. 1b.

2.1 Truncated design

In this design the opposite corners of the radiating patch is truncated in right angled triangle shape as in Fig. 2a to increase the gain of the antenna. The ground plane is also truncated at the right and left edges as in Fig. 2b. Because of truncation the area of the patch is reduced by 3.3% which in turn reduces the amount of conducting material used.

Fig. 2 Truncated design **a** Top radiating patch, **b** bottom Ground plane

Fig. 1 **a** Top radiating patch, **b** bottom ground plane

Fig. 3 Fabricated copper antenna **a** top view, **b** bottom view

2.2 Fabricated prototype

Figure 3 shows the copper fabricated antenna in which the copper thickness is 0.035 mm. To prevent the oxidation of copper the antenna is coated with Sn-Pb. The prototype is measured using Key sight Handheld Vector Network Analyzer N9923A. Two techniques to attach the SMA connector with antenna were examined in this work. One is conventional soldering method and the other one is using polymer based conductive bonding composite for attaching the SMA connector.

Graphene antenna is fabricated using doctor blade technique [11] which is one of the suitable methods for graphene printing is shown in Fig. 4. Single layer printing and double layer printing were done and the parameters were measured. The second layer is stacked vertically above the first layer without any substrate in between and also without any air gap. The material used for the purpose is of Graphene conductive ink type. The particles vary from 6 to 600 nm.

The fabrication is achieved by low cost printing method. The single layer is printed with a thickness of about 300 μm , double layer will be 600 μm . The variation in the thickness may be result of uneven temperature of sintering environment. So for the curing process the temperature is maintained at 80–85 $^{\circ}\text{C}$. The CADD model generated using the Ansoft HFSS will be printed over the substrate. The problem lies with connecting the SMA-F connectors with the printed patch over the substrate. This will be achieved by using the lead free silver based polymer composites.

Fig. 4 Graphene antenna **a** top view, **b** bottom view

The prototype antenna is measured for its characteristics using Key sight Handheld Vector Network Analyzer N9923A. The nature of the Graphene material used for the fabrication are Purity is 99%, Average Thickness is 3–8 nm, Average Lateral Dimension is 5–10 μm , Number of Layers, 3–6 Layers, Surface area is 180 m^2/g , Strength is 130 GPa, Thermal Conductivity is 5000 W/m k, Electrical Conductivity is 10×10^7 Siemens/m, Weight is 0.002 g/m^3 , Sheet Resistance is < 4 mil ($\Omega/\text{sq.}$), Coating thickness is 20 μm , Sintering temperature is 80 $^{\circ}\text{C}$, Boiling Temperature is 200 $^{\circ}\text{C}$, Density is 0.97 g/cm^3 , Viscosity is 6 Pa s. These values were taken from the Datasheet of the graphene material provider: Ad-Nano Technologies Private Ltd.

3 Results and discussion

3.1 Normal and truncated patch

The simulated results of normal and truncated patch are shown in Table 1. From the results obtained it is clear that Gain of the truncated patch is greater than that of the normal patch and its radiation pattern is shown in Fig. 5. Also there is a change in the polarization and because of the truncation the polarization shift from linear to circular with improvement in the gain parameter.

Fig. 5 Radiation pattern

Table 1 Simulation comparison of return loss, VSWR, gain and bandwidth

	Resonant frequency (GHz)	Return loss (dB)	VSWR	Gain (dB)	Return loss bandwidth ($S_{11} \leq 10$ dB) in MHz	VSWR bandwidth ($VSWR \leq 2$) in MHz
Without truncation	2.675	-14.5968	1.4578	4.8506	350.1	381.1
With truncation	2.545	-11.1451	1.7669	5.3925	228.6	281.6

3.2 Return loss

The return loss plot for simulated, fabricated copper and graphene antennas are shown in Fig. 6. Due to ground plane reduction the resonant frequency of the square patch is shifted to high frequency i.e., -14.5968 at 2.675 GHz as shown in trace 1. This frequency mismatch is rectified by truncation and the return loss curve is shown by trace 2 in which the frequency band is 2.545 GHz with return loss of -11.8571 dB which is nearer to ISM band. The measured return loss of copper antenna with conventional soldering and using polymer based conductive bonding composite are -35.3707 dB at 2.610 GHz and -19.7495 dB at 2.525 GHz respectively. These are shown in trace 3 and 4. Single layer graphene resonates at 2.625 GHz which is nearer to conventional copper antenna with return loss of -13.2719 dB whereas Double layer graphene stack antenna has very good return loss of -29.5184 dB at 2.580 GHz which are shown in trace 5 and 6 respectively.

3.3 Vswr

Figure 7 shows the VSWR plot for all the simulated and fabricated antennas. The simulated values for normal square patch and truncated patch are 1.4578 and 1.7669 respectively. Copper antenna gave VSWR of 1.0962 with soldering and 1.2562 with polymer based conductive bonding composite. Graphene antenna shows VSWR value of 1.5723 in single layer and 1.0896 in double layer.

3.4 Bandwidth

Both return loss bandwidth and VSWR band width are calculated for all designed and prototyped antenna. Table 2 shows all the measured values of the antenna. From the table it is evident that copper antenna with polymer based conductive bonding composite gives broad bandwidth when compared to conventional lead soldering method. Single layer graphene antenna gives very narrow bandwidth even though it has good electrical conductivity. But double layer provides ≈ 90 MHz bandwidth which is much greater than single layer and also greater than copper antenna with soldering connection.

Single layer of graphene printing is giving a gain of $+4.6002$ dB and double layer of graphene successively printed without any airgap using screen printing technique is giving a gain of $+5.1000$ dB. The performance is observed as better when compared to copper material with improvement in the gain from $+4.8023$ to $+5.1000$ dB. This is due to the conductivity nature of the graphene conductive ink. The conductivity of copper is in the range of 10^4 – 10^5 S/m whereas the conductivity of graphene conductive ink material is having a value of 10^8 S/m. This is the primary factor which defines and improves the performance of printed patch antenna structures comparatively better than that of copper material. Because of the conductivity of the material used there is an improvement in the performance of the gain parameter of the proposed design using graphene conductive ink.

The electrical conductivity of graphene is determined by 4 probe conductivity meter and it is examined at a temperature from 50 to 100 °C and it is observed that the

Fig. 6 Return loss plot for simulated and measured

conductivity remains constant at 10^8 S/m. We have examined only the solid state conductivity of the printed structures. From this the chemical potential is obtained to be 0.24 eV using the formula

$$\sigma_{\text{graphene}} = e^{17} \mu + 0.0012[\text{S}]$$

and with the relaxation time $\tau = 0.5$ ps. In [17] 0.25 eV chemical potential is obtained for microwave frequency which is almost equal to the value obtained in this work.

Radiation efficiency is defined as the ratio of radiated power (P_r) to accepted power (P_a). Here we have set an

input power of 1 W for testing purpose and it is inferred that the radiated power is measured as shown in the Table 3.

There are many forms of graphene available in the market such as graphene oxide, graphene conductive ink, single layer graphene, double layer graphene, multilayer graphene, low density graphene powder, high density graphene powder and exfoliated graphene. We are using graphene conductive ink for screen printing mechanism which will be more suitable for microwave applications such as printed patch antenna structures. The graphene

Fig. 7 VSWR plot for simulated and measured antenna

Table 2 Measured comparison of return loss, VSWR and bandwidth

	Resonant frequency (GHz)	Return loss (dB)	VSWR	Gain (dB)	Return loss bandwidth (S11 ≤ 10 dB) in MHz	VSWR bandwidth (VSWR ≤ 2) in MHz
Copper antenna with conventional soldering	2.610	−35.3704	1.0962	4.8023	84.4	81.4
Copper antenna with conductive glue	2.525	−19.7495	1.2562	4.6026	208.4	231.1
Single layer graphene antenna	2.625	−13.2710	1.5723	4.6002	6.7	7.3
Double layer stacked graphene antenna	2.580	−29.5184	1.0896	5.1000	87.9	91.8

Table 3 Performance comparison

	Input power (W)	Accepted power (W)	Radiated power (W)	Radiation efficiency (%)
Copper antenna with conventional soldering	1.0	0.8301	0.6890	83.0
Copper antenna with conductive glue	1.0	0.8438	0.6708	79.5
Single layer graphene antenna	1.0	0.8738	0.6334	72.5
Double layer stacked graphene antenna	1.0	0.8279	0.6921	83.6

conductive ink will comparatively perform better than graphene for microwave application.

The proposed design will be more suitable for ISM band applications, Wi-Fi and indoor communication modes, as external power absorber in rectenna setups for microwave wireless power harvesting.

4 Conclusion

In this project, we replaced conventional copper based antenna with carbon allotrope based Graphene material and it is observed that the effect of Graphene in function of the proposed antenna design is performing better compared to that of the copper. In this experimental trail we have fabricated successive lattice structure with uniform bonding to achieve stacking performance of antenna. The effect of different bonding materials for electrical conductivity was also performed inferred that using material based conductive polymer substance will allow suitable bands which is absent in terms of using Lead based soldering technique. The proposed stack structure is performing better in terms of Return Loss, VSWR and Gain when compared to the same structure with copper so we conclude replacing the copper with Graphene composite will be more fruitful in patch antenna structures.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest

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