'GMPA'- A Comparative Study of Graphene Based Patch for Performance and Parameters Enhancement of Antenna at Terahertz Frequency for Wireless Communications

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Abstract- **The comparative analysis of microstrip feed traditional metallic rectangular patch antenna and novel "Graphene Microstrip Patch Antenna- GMPA" is been done. In this paper we used 'Graphene material' as a patch and silicon dioxide as a substrate material with a thickness of 1.8 μm and dielectric constant Ɛr=3.9 to resonate at a frequency of 6 Thz. The return loss and gain of antenna is very much improved in comparison. The return loss of -48.25 dB and gain of 4.50 decibel is achieved including much improved impedance bandwidth of 12.83% during its operating frequency between 5.66 to 6.43 Thz. Simulation is performed by latest and world's best Finite Element Method based 'HFSS.18' and 'CST-Suite 16' tools. Finally it is proved that graphene is one of the best alternative of metallic patches in present era.**

Keywords- *HFSS, CST, GMPA, CNT, FEM.*

I. INTRODUCTION

Graphene is a novel material which is atomically thin form of hexagonal carbon and a great substitute for conventional metallic patches of patch based antennas [1]. It had came into attraction since publications of seminal papers in 2002 [2, 3]. Metallic patch era is more than five decade old. Several metallic materials like copper, silver, aluminum etc are vastly used, out of which copper is very general and mostly used for making ground and patches of microstrip patch antennas. Single layer of graphite crystal is called as graphene. It has pure covalent bonded carbon atoms which are one atom thick in form of honeycomb lattice.

The single layer is detached from graphite and grown by cvd process [4]. Electrical and heat conduction properties of graphene are remarkably best along with optical and mechanical, as summarized in Table I [5,6,7]. The present generation requires keen advancement in field of wireless communications, whose possibility depends upon compact, cost effective, efficient and faster ultra broadband antennas [8,9]. For antenna based applications graphene exhibits highest carrier mobility: >100000 cm^2 V^{-1}. S^{-1} at room temp [10] which is 100 times greater than that of silicon [11]. The term *terahertz* defines frequency range between 300 GHz to 3THz [12]. Also at some places the range considered between 100 GHz to 10 THz [13]. For working in terahertz range devices should be much compact and miniaturized. Thus Microstrip patch antennas are best suited for this condition. Conventional metallic patch antenna using copper patch has several disadvantages like less gain, very low power handling capacity, huge narrow bandwidth, etc. [14]. Also very high resonant frequency is needed for even reducing few micrometer size of metallic patch antenna. Such frequency cause channel attenuation due to which there is severe difficulty in implementation of nano devices.

Table 1 Brief Summary of Intrinsic Properties Of Graphene

Saturation Velocity (cm/Sec)	$4\text{-}5 \times 10^7$
Carrier mobility (cm^2/Vs)	> 100,000
Current density (A/cm^2)	~10^9
Thermal Conductivity (W/m-K)	4800
Optical opacity (%)	2.3% per layer
Young's modulus (Pa)	0.5-1 tera

Several intrinsic properties of graphene are shown in the Table-1 directs to the factor that graphene material is far very beneficial and great replacement of several metallic patch materials. The present research work shows exact mathematical calculation of conductivity of graphene material and clear analysis of several radiation parameters of GMPA using silicon dioxide as a substrate material which has dielectric constant Ɛr=3.9 at 6 Terahertz frequency band. [15]

II. NOVEL GRAPHENE PATCH ANTENNA

In several papers we see rectangular patch antenna with conducting material as a patch placed on substrate with a metallic ground and microstrip line feeding [16]. The transmission line having quarter wavelength is used to match the patch matching the load with characteristic impedance. We have taken a rectangular shaped patch having length " Lp", thickness of substrate 'silicon dioxide material' is "h" with dielectric constant "Ɛr" as shown in figure 1st . The Graphene based microstrip patch antenna 'GMPA' is designed with micro strip line feeding technique on SiO2 substrate to be operated at 6 Thz Frequency band.
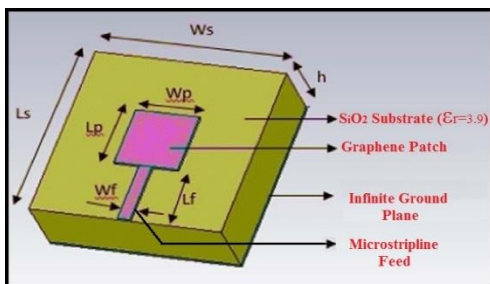

Fig 1- GMPA (Graphene Microstrip patch Antenna)

The length of following rectangular graphene patch antenna is " Lp" and calculated by equation 1st which shows solution to find out Graphene's surface conductivity. So we use following technique to find electrical conduction ability which is used for graphene sheets, also for resonant frequency "fr" the antenna is required with SPP dispersion relation.[17]

$$Lp = L + 2\partial l = \frac{\pi}{\beta} = \frac{v}{2fo} \qquad (1)$$

"L" is the length of antenna, ∂l is electrical fields penetration length which is outside the antenna β is the 'wave number' produced by Surface plasmon polaritons waves. Here we observe two things firstly graphene antenna resonates up to two orders of frequency which is much lower than metallic patches, secondly the pace of resonant frequency is slowly increase in graphene material as compared to several metallic nano patches as there is reduction in antenna size. The derivation of single layer graphene conductivity is done by Kubo formula which can be reduced when condition of ' $\mu_t \gg h\omega_c$' satisfies. Usually ' μ_T' is graphene material fermi level and ω_c is frequency shown in *equation 2* we see drude formulation here in its variable form. .

$$\sigma = \frac{2e^2\tau}{\pi h^2} K_b T_m \log\left(Cosh \frac{\mu_t}{2K_b T_m}\right) \frac{1}{1+\tau\omega_c J} \qquad (2)$$

T_m is temperature, τ is scattering time, K_b is Boltzmann constant, and *e* in the above eqn shows charge on electron. The condition $\mu_c \gg h\omega$ is usually satisfied at low electromagnetic frequencies as we see μ_c> 0.05 eV. At room temperature, equation (2) Thus we get the conductivity curves shown in Fig. 2, where different values of μ_c are assumed. [18]

While reaching near to Thz frequency band we see surface conductivity has a different nature, for this reason allowing the

beginning of surface plasmons polaritons at resuced level which is lesser than traditional materials at the Thz range. Plasmons for 'GMPA' facilitate hidden cover to electromagnetic power at small wavelength balance and is capable to be stand with increment of standing voltage, offering an information because on a metal–dielectric line. Reaching closer to the terahertz frequency the surface conductivity has a drastically distinctive nature, for this reason permitting the beginning of surface plasmons polaritons at range lower than given obtained values. We see 'Plasmons' of graphene enable thoughtful cover of EM supply at high range frequency band. Thus managed by using software simulation and several formulations.
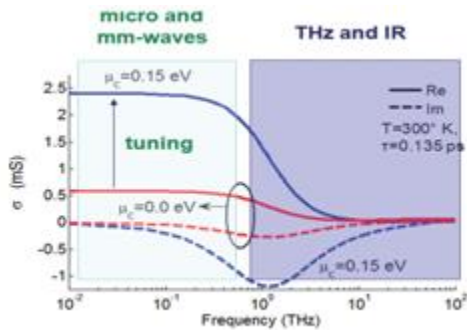

Figure 2- Surface Conductivity Curve Microwave and Terahertz waves

In metallic antenna usually there is wave propagation nearly equal to speed thus it has optical resonance while as we researched graphene material patch antenna resonates at less speed than speed of light ie 'c' thus is is highly recommended for higher band communication purpose specially at Terahertz band. The novel graphene antenna is designed to be resonated at 06 Thz and shows several radiation properties. For SPP graphene materials provide best results for its propagation. Waves generated and guided along interface of metal dielectric as it is superimposed by high frequency radiations. [19] The effective mode index of SPP waves shows transverse magnetic nature of graphene layer is given by equation 3

$$n_{eff}(w) = \sqrt{1 - \frac{4\mu_o}{\varepsilon_o \sigma(\omega)^2}} \qquad (3)$$

Here $\sigma(\omega)$ graphene conductivity, ε_o is permittivity and μ_o is permeability of free space. Further study of graphene is done by Kubo formula as we saw previously in eqn 2 also for good propagation of surface plasmons polaritons wave in graphene patch this formula is used to obtain conductivity in optical regime [20]. There are two processes by which optical wave absorption in graphene can be studied firstly intraband carrier transitions and secondly interband carrier transitions shown in equation 4

$$\sigma(\omega) = \sigma_{intra}(\omega) + \sigma_{inter}(\omega) \qquad (4)$$

Here ω is photons angular frequency. The surface conductivity of graphene has two parts namely intra and inter bands.

III. SOFTWARE SIMLATION TOOLS USED

HFSS 18

Introduced in early 90's HFSS is a software simulation tool used to design several types of microwave devices including antennas of several types and complex 3D geometrical structures. The H.F.S.S is basically a 'High Frequency Structural Simulator' which uses a numerical simulation method called Finite Element Method 'FEM'. In this technique the whole design structure is divided into many smaller sub-sections which we call finite elements. HFSS uses 'tetrahedra' as finite elements and all its collection called a 'mesh'.
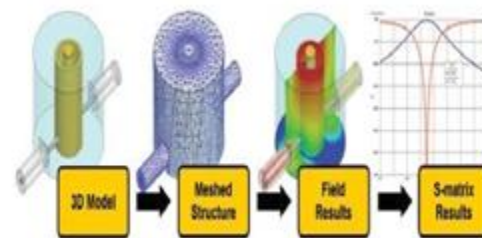
Fig 3-   Shows modeling and designing overview of HFSS software

A. Salient Features of HFSS Tool

- It creates fully parameterized cross segment arranging models having 2D and 3D architecture.

- It has intense drawing abilities to influence improved outline to structure.

- Its field understanding motor has great precision subordinate driven versatile arrangements.

- With its most capable processor for extraordinary knowledge into electrical execution.

- Advanced materials in its new version HFSS 18.

- It registers s-parameters and full-wave fields for any subjectively molded 3D structures.

- Its wideband frequency sweep has very fast action..

- Consist model with Library-including winding inductors, half, quarter, or octet symmetry designs.

IV. Graphene Modeling and Conductivity Formulation

The antenna modeling is done by using by 2 Dimensional surface conductivity formulation as derive in equation 5

$$\sigma(\omega_c, \mu_c, \tau, T_m) = -J\frac{q_e^2 K_b T_m}{\pi h^2(\omega - 2jT_m)} \times \{\frac{\mu_c}{K_b T_m} + 2\ln(e^{\frac{-\mu_c}{K_b T_m}} + 1)\}$$

(5)

Where ' ω_c is angular frequency, 'T_m' is scattering rate also called TR timing, 'μ_c' is its chemical potential 'h' is plank constant and 'K_b' is Boltzmann constant and in reduced state. The intraband relation gives higher accuracy for low Thz frequencies. When considered $\mu_c = 0ev$ at room temperature of approx 300K we get following simplified equation

$$\sigma(intra) = J\frac{q_e^2 K_b T}{\pi h^2(\omega)}[2\ln(2)]$$

(6)

$$\sigma_{inter}(\omega) = \frac{e^2}{4h}[H\{\frac{\omega}{2}\} + i\frac{4\omega}{\pi}\int_0^\infty \frac{H(\varepsilon) - H(\frac{\omega}{2})}{\omega^2 - 4e^2}d\varepsilon]$$

(7)

Unit electron charge is 'e' and 'h' denotes plank constant with 'μ_c' as chemical potential 'T_m' is rate of scattering and 'K_b' is Boltzmann constant.
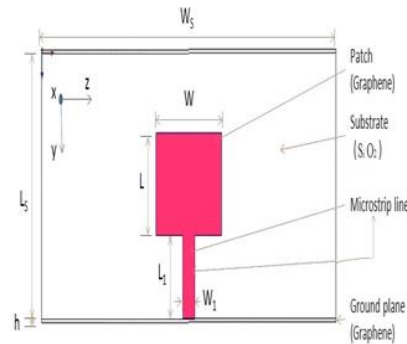

Fig- 4 Graphene Patch Antenna Design with Microstrip line Feeding

The above figure demonstrates the design overview of novel "Graphene Microstrip Patch Antenna"- GMPA. It has rectangular patch made with graphene material having 'L' and 'W' namely as GMPA'S length and width, L_{11} is length and and W_{11} is width of microstrip line feeding. L_s and W_s as length and width of substrate. Here 'SiO2' is used as substrate material. 'h' is the height, also called thickness of substrate used. Graphene material is also used as infinite ground plane of antenna .

Design Parameters	Dimensions	
Length & Width of Rectangular Patch	L x W	10.71 µm x 14.87 µm
Substrate's width, length and thickness	L_S x W_S x h	27.9 µm x 66.67 µm x 1.8 µm
Silicon Dioxide as Dielectric constant	ε_r	3.9
Microstrip line length and width	L_1 x W_1	8.595 µm x 2.664 µm
Substrate Thickness	'h' or 't'	1.8 µm

Table 2   Parameters of Novel 'GMPA' designing

Table 2 demonstrates the different values for designing 'Novel GMPA' using graphene as its patch and having rectangular architecture of length L = 10.71 µm and width W=14.87 µm along with micro-stripline feeding. Substrate used is silicon dioxide (SiO2) having dielectric constant 'ε_r = 3.9' and having thickness 'h = 1.8 µm'.

Feeding is given by simple microstrip line of dimension L_1= 8.595 µm and W_1= 2.664 µm as its length and width.

The substrate is made of silicon dioxide material having length L_S= 27.9 µm, Width W_S= 66.67 µm and height h=1.8 µm.
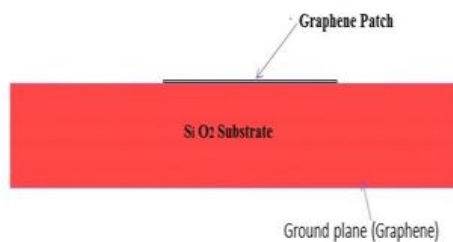
Fig- 5 Graphene Patch Antenna Cross Sectional View

Measured Parameters	Patch Antenna	
	With Copper	With Graphene
1. Overall S_{11} at 6 THz	-39.37	-48.75
2. Frequency	5.66 – 6.43	
3. Impedance bandwidth	12.83%	

Table 3 Several Measured Parameters

Fig 5 shows cross sectional 3D view of 'GMPA' along with substrate material and ground plane.

The substrate which is used here is Silicon Dioxide having dielectric constant of 3.9, it is also most efficient substrate material in present era having good radiation mapping quality.

Design Parameters	Conventional Metallic Patch Antennas			Proposed graphene Patch Antenna Comparison with Copper Patch	
Ref.	[21]	[22]	[12]	Graphene	Copper
{fr} Resonant frequency (GHz)	2.2	2150	1425	6000 (6 Thz)	
Gain (dB)	1	1.89	1.65	5.60	4.20
Directivity (dB)	-	-	-	7.56	7.56
Radiation efficiency (%)	68	41.59	43	37.17	36.27
Return Loss	-	-	-	-48.75	-39.37

Table- 4 Comparative Analysis of Several Conventional Metallic Patches along with Copper and Graphene Patch Results

The following tables demonstrates comparative results of several parameters. Main comparative parameter is return loss which is very basic parameter of microstrip patch antenna design. We get return loss of -39.37 db with copper patch and -48.75db with our novel graphene patch showing decrement of 9.38db which is quite good decrease in return loss when graphene patch is taken . It shows impedance bandwidth of 12.83% with good gain of 5.60dbi with graphene patch in comparison with 4.20dbi of copper. Thus there is enhancement of 1.40dbi. The radiation efficiency is slightly decreased.

V. RESULT AND DISCUSSION

The antenna is parameterized and simulated on FEM based simulation software HFSS several results are obtained. The parameters of traditional copper patch antenna are compared with novel proposed graphene patch antenna minutely. When we take copper material as a patch we got return loss of -39.37db at approx 6Thz frequency. Comparing result with Graphene patch shows tremendous return loss of -48.75 db at 6Thz. Thus there is an decrement in return loss of 9.38 db, which is quite good comparative result .
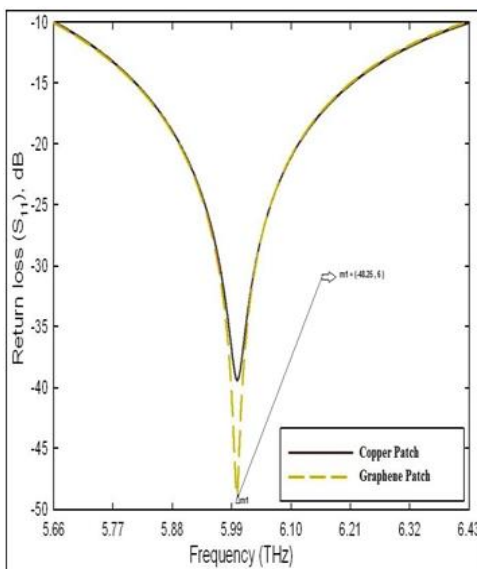
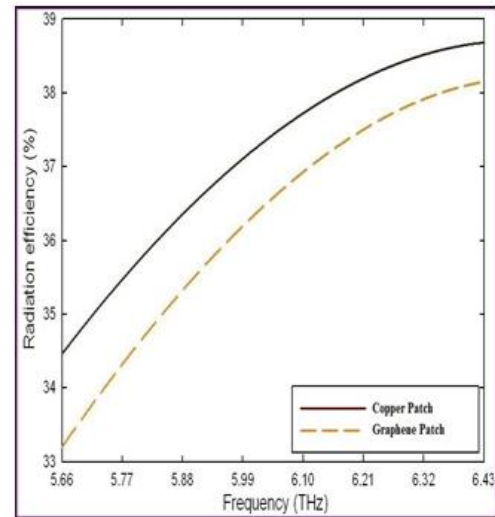**Fig- 6** Return Loss Comparative Graph of Copper and Graphene Patch Parameters

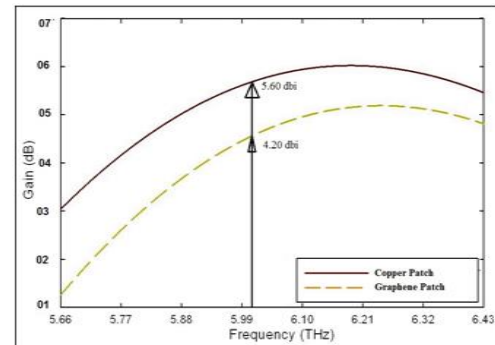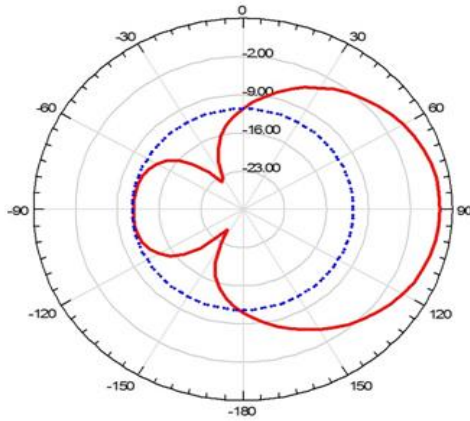**Fig- 7** Radition Efficiency of Patch Antenna With Copper and Graphene as a Patch Material
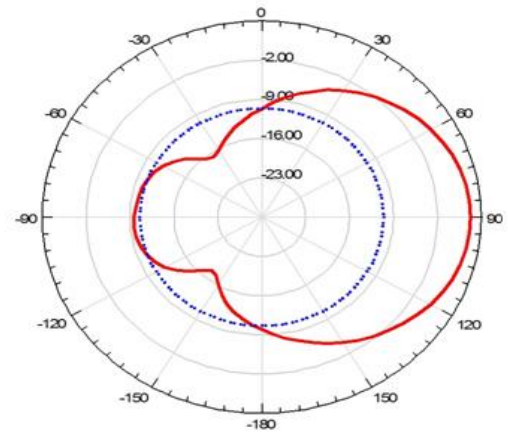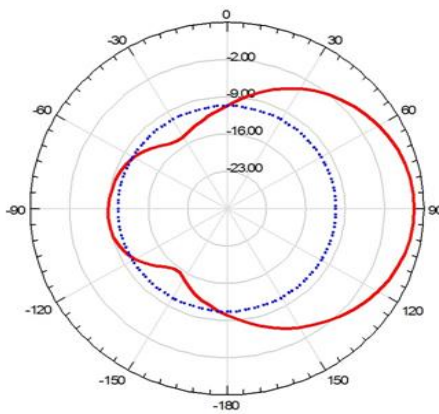

Fig-8 Gain with Copper Patch and with Graphene Patchs
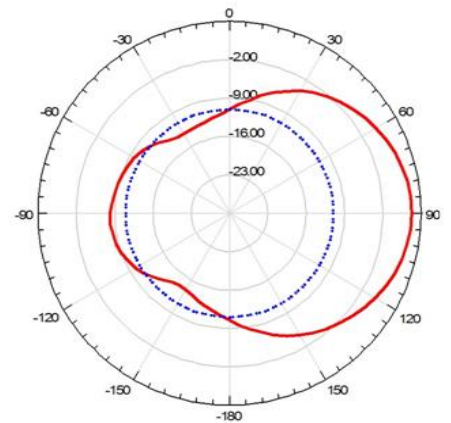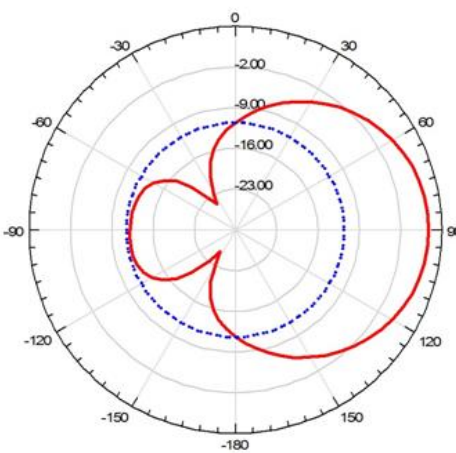
(A) 4.67

(B) 6
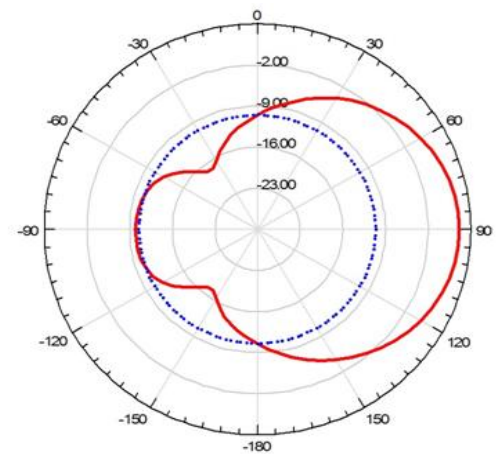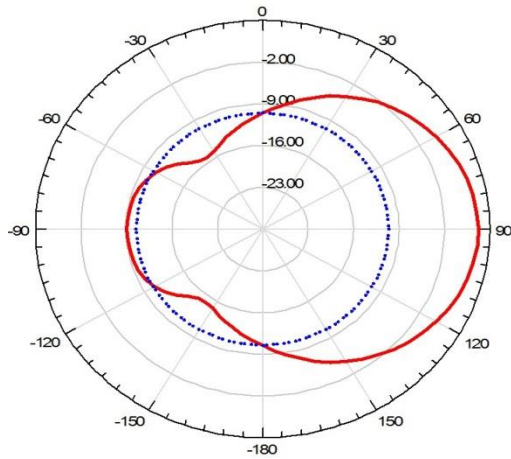

(C) 6.33

(D) 6.55

Fig 9- Red solid line and Blue dash line shows E&H-plane screening radiation patterns of the 'Copper Patch Antenna' at Terahertz Frequency Band
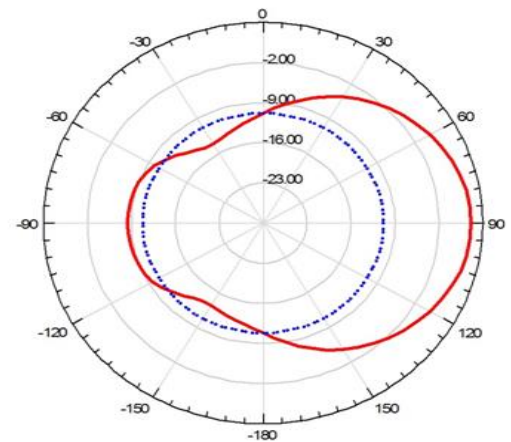

(A) 4.67

(B) 6

(C) 6.33

(D) 6.55

Fig- 10 Red solid line and Blue dash line shows E&H-plane screening radiation patterns of the 'GMPA' at Terahertz Frequency Band

VI. CONCLUSION

Thus finally we conclude that "GMPA" is not only novel but has drastic characteristic enhancement as compared with copper and other metallic patches. It gives more bandwidth, gain, less return loss in its comparison. It is best suites at higher frequency basically at Terahertz band. By its use we can get much electrical efficient patch antenna at nano scale design.

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