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Reconfigurable Monopole Antenna Using Graphene Material for Wireless Applications

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ABSTRACT

With the rapid advancement of wireless communication technology, the necessity for multi-band mobile devices is increasing. So the reconfigurable antenna is an excellent option for wireless communications. The reconfigurable antenna has favorable properties such as compact size, similar radiation performance, and less co-site interference as compared to traditional designs. This paper proposed and discusses a reconfigurable monopole antenna with dimensions $75\times75mm^2$ on an electromagnetic bandgap (EBG) using graphene material. Monopole antenna operates at 5 GHz, which is loaded by EBG, and the intended EBG provides a bandgap in the range of frequency from 4 to 9.8 GHz. A coaxial cable feeds the monopole antenna, which is connected to the inner wire. A single monopole denotes matching bandwidth from 4.6GHz to 5.3GHz, with a gain of 8 dBi, so as to candidate the antenna for 5G applications such as tracking and healthcare systems. Graphene material is used to achieve a reconfigurable beam between four monopole graphene antennas (A_1, A_2, A_3, A_4), which are concentric on a circle slot with four edges connected to monopoles feeding by coaxial cable on the EBG surface. The beam is switching toward the direction of biasing monopole in four different angles($+45^o$,0,-45^o,180^o). Four monopole antennas structure is proposed and offered 7.8 dBi constant gain in all four beam directions and the same reflection coefficient band.

Keywords: Reconfigurable antenna, Monopole antenna, EBG, Graphene.

I. Introduction

Antennas with reconfigurable radiation characteristics are widely applied in different wireless applications. Antennas with beam-switching capability allow transmitting directive beams with the same frequency in different directions to serve multiple applications. They have drawn interest in radar, smart tracking, satellite, navigation, and mobile systems, among other uses. Different smart systems use the switching of single or multiple beams to regulate the direction of the emitted beam, either mechanically or electronically [1]. Changing the frequency, polarization, or radiation properties of a monopole antenna allows it to be reconfigured. Many strategies that redistribute antenna currents and so alter the electromagnetic fields of the antenna's effective aperture are used to achieve this modification. Switches integrated into monopole antenna structure [2], varactor diodes [3], PIN diodes [4], or changing material characteristics such as using stretchable liquid metal monopole operating at 2.4 GHz [5], and material electric properties as plasma and graphene [6].

Different approaches are illustrated to achieve radiation pattern reconfigurability using graphene materials in 5G applications. Rectangular strips are connected to monopole and antenna start resonant from 3-7GHz [7], the antenna dimensions are $45\times50\times1.524\,mm^3$, with gain 2.5dBi. circular-shaped monopole antenna with ultra-wideband (UWB) performance is presented in [8]. The mentioned antenna consists of a circular patch radiator made of graphene films and a ground plane made by copper and graphene film. Antenna dimensions are 42×50 mm^2, and offered 2.5 dBi gain at 10.5GHz.

Graphene is an ultrathin sheet of carbon atoms arranged in a hexagonal structure with controlled conductivity [9]. It exhibits plasmatic behavior in THz frequencies with its surface impedance controlled via applying an electric field, doping, or laser source. Graphene-based surfaces with reconfigurable characteristics are introduced in [10], [11]. Changing radiation patterns is one of the most challenging areas of antenna reconfigurability [12]. Reconfigurability can significantly reduce the number of components, hardware complexity, and cost of communication systems, thus a reconfigurable antenna is a good candidate in wireless communication. A great introduction of reconfigurable antennas, with numerous examples, is given in [13].

This paper proposed antenna structure uses graphene material to obtain beam switching for four monopole antenna at different angles without changing in structure, by applying DC voltage on graphene material to switch on and applying 0 voltage to switch off.

II. Electromagnetic Bandgap (EBG) unit cell structure

Electromagnetic bandgap (EBG) structures are periodic structures that exhibit special properties in a band of

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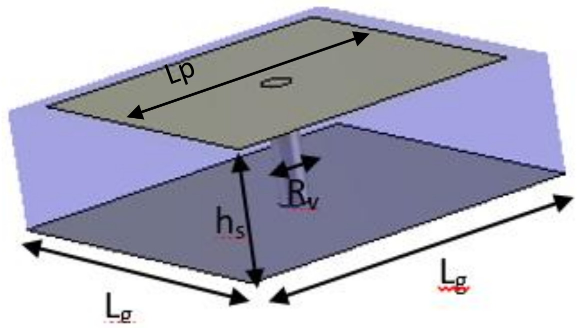
frequencies called the bandgap. The special properties include very high surface impedance and reflecting an incident wave, normally incident on the EBG surface with a near 0^{o} reflection-phase. The phase of the reflection coefficient measured at the surface of the EBG structure is defined as the reflection phase. EBG is realized by etching periodic mushroom-like square patches on a dielectric board, via connecting the patches to the ground plane as shown in Fig. 1 (a). The proposed unit cell has ground plane dimensions l_g = 9.37mm, substrate with h_s=3mm and ε_{rs}=2.2, square patch with l_p= 7.5mm, via radius(R_v) = 0.375mm. The dispersion diagram of the EBG unit-cell element is presented using the Floquet mode infinite integration technique (FIT) program and is plotted in Fig. 1 (b). The phase of S_{11} versus frequency for the unit-cell element is depicted in Fig.1(c). The bandwidth is varied from 4.3 GHz to 5.6 GHz and 0 phase is at resonant frequency 5GHz. The designed unit-cell element has a stop-band extended from 4 to 9.8 GHz which includes the impedance matching bandwidth of the monopole antenna as will discuss in the next section.



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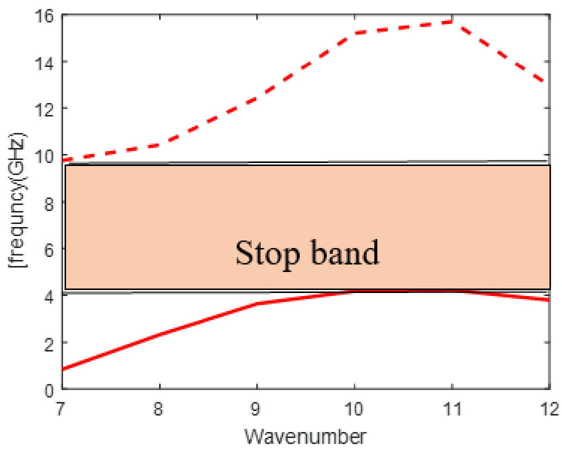

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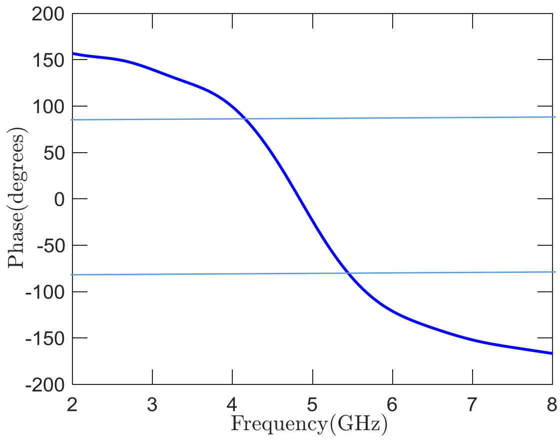
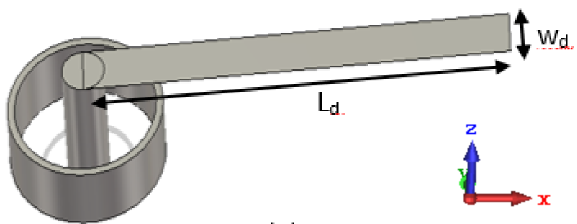


(c)

Figure 1. (a) EBG unit-cell performance (b) Dispersion diagram (c) Phase diagram.

III. Monopole antenna structure

Monopole antenna is one half dipole antenna, it is attracted when the smaller antenna is needed [14] in wireless applications. The proposed antenna dimensions are L_d×w_d =18×1.8 mm and simulated in free space as shown in Fig.2(a). The resonant frequency band is 4.7GHz-5.3GHz as shown in Fig.2 (b). Gain is reached to 1.95dBi at 4.8GHz, Fig 3 shows 3-D and 2-D far failed patterns.



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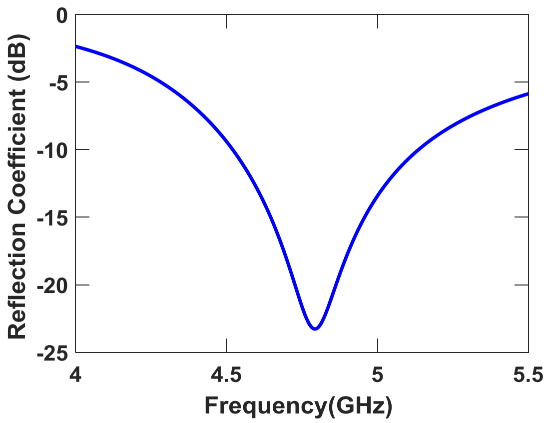

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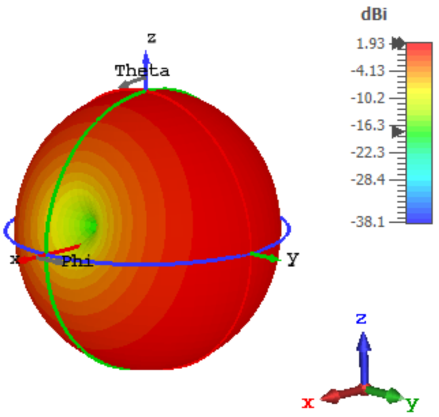
Figure 2. (a) monopole antenna in free space, (b) Reflection coefficient.



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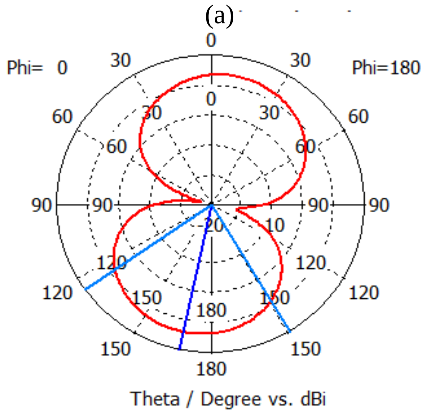
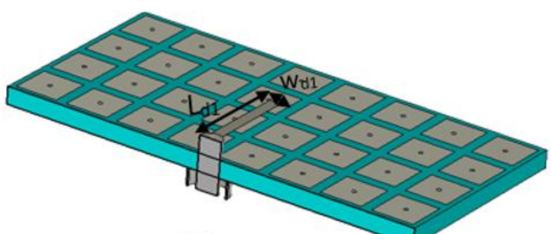


(b)

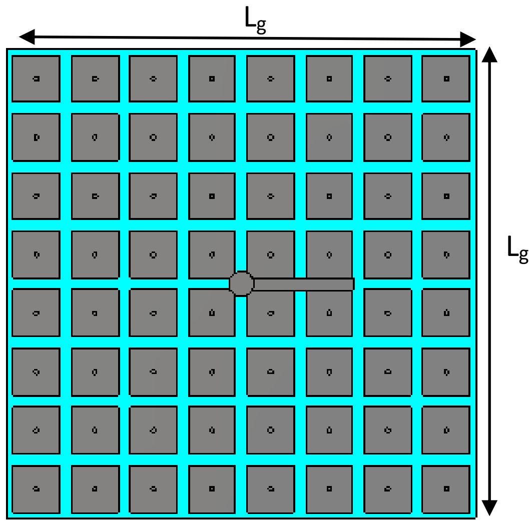
Figure 3. Radiation pattern (a). The 3D gain pattern (b) The 2D gain pattern in the y-z plane.

IV. Monopole antenna on EBG surface

As presented in the previous section, monopole antenna has 1.95dBi gain in free space. EBG surface has been successfully used as a ground plane for monopole antenna to radiate efficiently with low profile configuration [15]. The ground plane size is $l_g \times l_g$=75x75 mm^2, including 8×8 EBG cells. The patch width of the EBG cell is 7.5 mm, the gap width is 1.5 mm, and the vias' radius is 0.375 mm. The substrate thickness is 3 mm and the dielectric constant is 2.94. A 1.5 mm wide strip wire is used in the FDTD on the CST simulation programmer and its height over the ground plane is also 3 mm as shown in fig.4. Monopole dimensions become $l_{d1} \times w_{d1}$=12.5×0.6mm^2 to guarantee to match between monopole and ground plane. The resonance frequency band is 4.7GHz-5.3GHz as shown in fig.5(a), gain enhanced to 8dBi as shown in Fig.5(b).

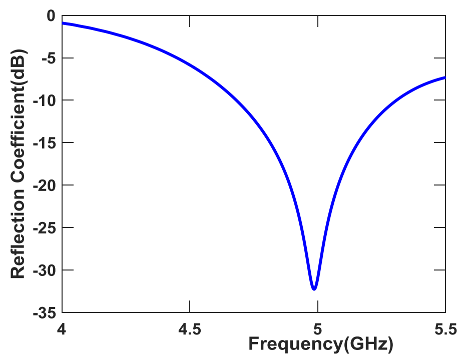


(a)

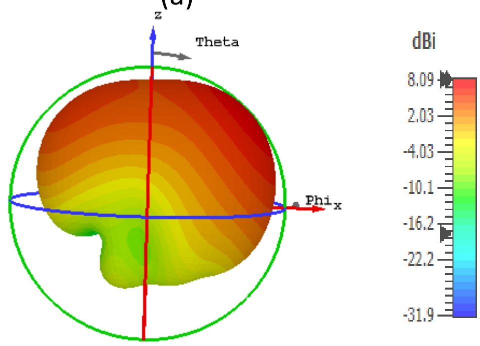


(b)

Figure 4. Monopole antenna structure on EBG surface.



(a)



(b)

Figure 5. (a) Reflection coefficient, (b) 3D gain pattern.

V. Reconfigurable four monopoles antenna structure

The reconfigurable monopole is designed using graphene material instead of copper material of monopole antenna. The graphene strips control the polarization of the radiated wave through its tunable frequency dependent conductivity σ. It is calculated from Kubo formula is given by [16]:

$$\sigma(\omega) = \sigma_{intra}(\omega) + \sigma_{inter}(\omega) \quad (1)$$

where $\sigma_{intra}(\omega)$ is the intra-band term given by:

$$\sigma_{\text{intra}}(\omega) \approx -j\frac{q_e^2 k_B \mathrm{T}}{\pi\hbar(\omega - j2\Gamma)} \times \left(\frac{\mu_c}{k_B \mathrm{T}} + 2\ln\left(e^{-\mu_c/k_B\mathrm{T}} + 1\right)\right) \quad (2)$$

and $\sigma_{inter}(\omega)$ is the inter-band term given by:

$$\sigma_{\text{inter}}(\omega) \approx -j\frac{q_e^2}{4\pi\hbar}\ln\left(\frac{2|\mu_c| - (\omega - j\tau^{-1})\hbar}{2|\mu_c| + (\omega - j\tau^{-1})\hbar}\right) \quad (3)$$

where τ is the transport relaxation time, T is the temperature, ω is the operating angular frequency, the scattering rate $\Gamma=1/2\tau$ represents loss mechanism, and μ_c is the chemical potential. j is the imaginary unit, q_e is the electron charge, =h/2 is the reduced Planck's constant, K_B is the Boltzmann's constant, is the transport relaxation time, T is tl temperature. The conductivity of graphene may l effectively controlled using a perpendicular bias electr field, a DC voltage, and a laser beam. The comple structure is consisting of four monopole antennas (A_1, A A_3, A_4) concentric on a circle slot with four edges connecte to monopoles feeding by coaxial cable on the EBG surfa as shown in Fig.6. The reflection coefficient of fo reconfigurable monopole antennas is presented in Fig.7. Tl antennas resonate at 4.98 GHz with a 12% bandwidth. The antenna operating method depends on the applied voltage on graphene monopole antenna, one of these monopoles have applied voltage (biasing) μ_c=1 eV, which has green color acts as a conductor while the other monopole has zero voltage (off) μ_c=0 eV to be an isolator dielectric material in red color. As shown in Fig.8 antenna (A_1) is biased by the applied voltage and acts as a conductor, while other monopoles are acted as a dielectric.

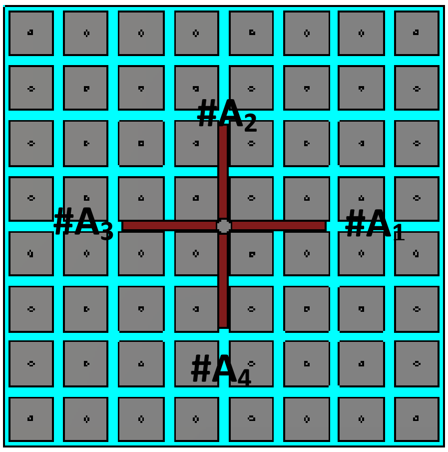


Figure 6. Reconfigurable monopole antenna structure on EBG surface.

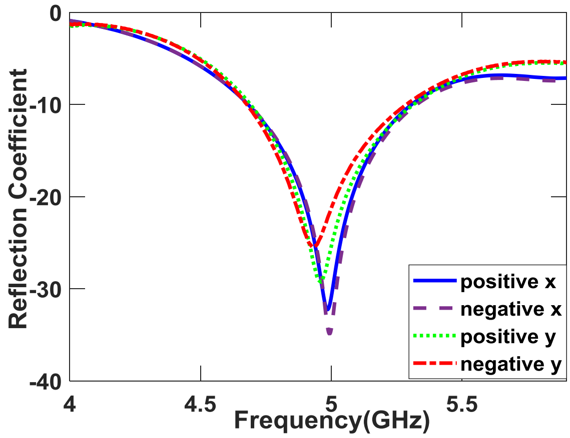


Figure 7. Reflection coefficient of four monopole antennas.

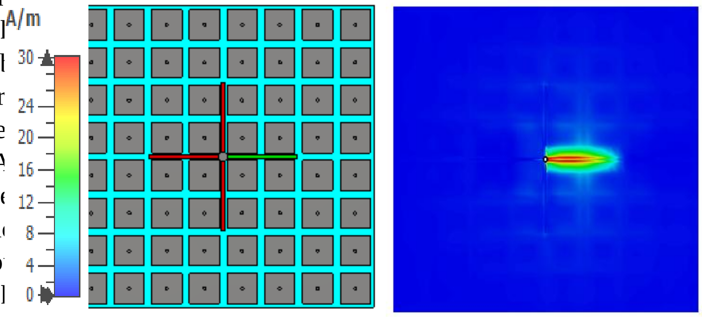


Figure 8. Monopole (A_1) working Structure and its field distribution.

Gain is reached to 7.82 dBi at 4.99GHz and beam points to +45^0, Fig. 9 shows 3-D far failed pattern.

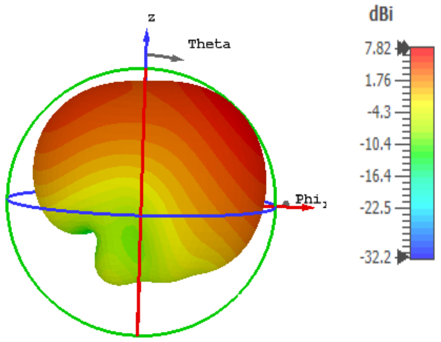


Figure 9. 3D Far failed pattern at 4.99GHz.

When voltage is applied in monopole in the positive y-direction (A_2), as illustrated in Fig.10, one slot has zero voltage (off) μ_c=1 eV and serves as a conductor, while the other slot has zero voltage (off) μ_c=0 eV and acts as an isolator dielectric material in red color. Gain is reached to 7.82 dBi at 4.99GHz and beam points to 0^0, Fig. 11 shows 3-D pattern direction.

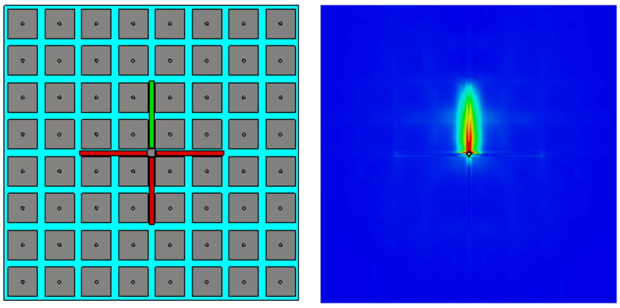


Figure 10. Monopole (A_2) working Structure and its field distribution.

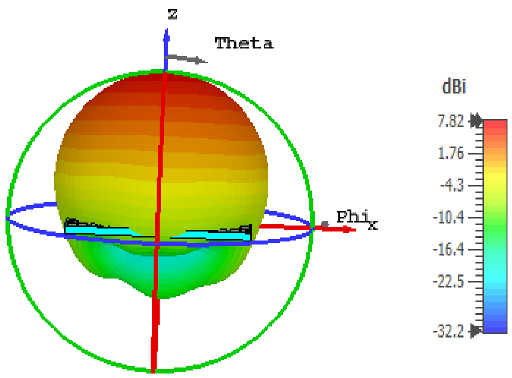


Figure 11. 3D Far failed pattern at 4.99GHz.

When voltage is applied in monopole in negative x-direction (A_3), as illustrated in Fig.12, one slot has a voltage (on) μ_c=1 eV and serves as a conductor, while the other slot has zero voltage (off) μ_c=0 eV and acts as an isolator dielectric material in red color. Gain is reached to 7.82 dBi at 4.99GHz and beam points to 180^0, Fig. 13 shows 3-D pattern direction.

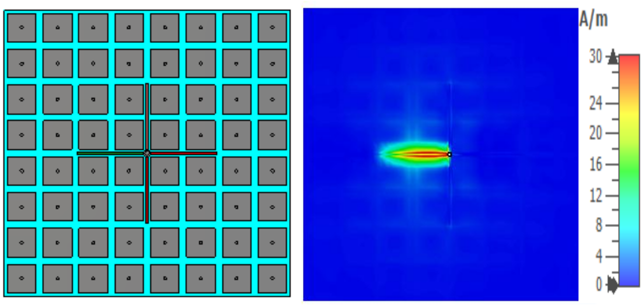


Figure 12. Monopole (A_3) working Structure and its field distribution.

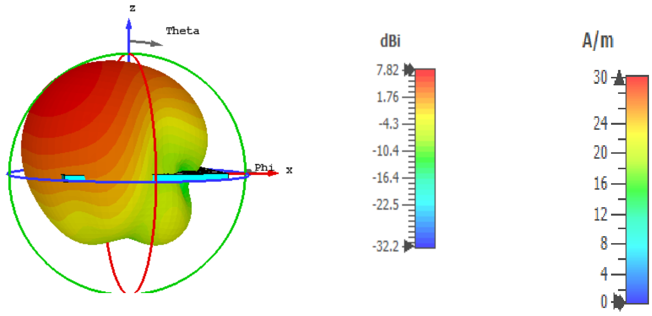


Figure 13. 3D Far failed pattern at 4.99GHz.

The last configuration, when voltage is applied in monopole in the negative y-direction (A_4), as illustrated in Fig.14, one slot has zero voltage (off) μ_c=1 eV and serves as a conductor, while the other slot has zero voltage (off) μ_c=0 eV and acts as an isolator dielectric material in red color. Gain is reached to 7.82 dBi at 4.99GHz and beam points to -45^0, Fig. 15 shows 3-D pattern direction.

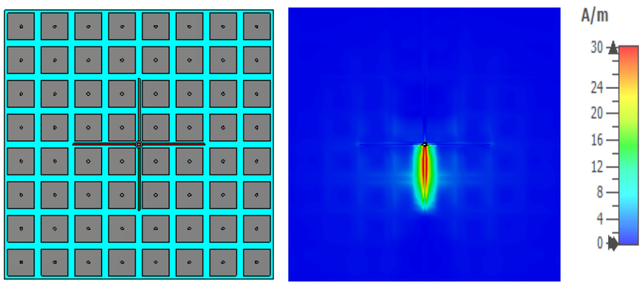


Figure 14.Monopole (A_4) working Structure and its field distribution.

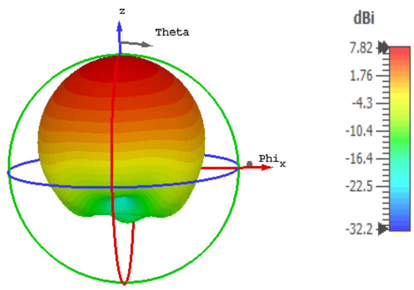


Figure 15. 3D Far failed pattern at 4.99GHz.

Reconfigurable monopole is ordinarily used to reduce antenna size and can use in many different applications, Table (I) shows a comparison between the proposed antenna structure and reconfigurable antennas in literature references [15-20].

Table (I) Reconfigurable monopole antenna in comparison with antennas in literature.

References	Antenna Type	Antenna Size (mm^2)	Reconfiguration Type	Reconfiguration Method	Gain (dBi)	Frequency (GHz)
[17]	Monopole	60 × 30	Frequency	PIN-Diode	1.1, 2.6, 3 3.4	1.8, 2.4, 3.5, 5.2
[18]	Monopole	28 × 28	Frequency	PIN-Diode	3.8	3–12
[19]	Notched Monopole	28 × 25	Frequency	PIN-Diode	4.0	4.2-7.2
[20]	Monopole	88 × 114	Frequency/Polarization	Varactor Diode	Not mentioned	1.03-1.54
[21]	Dipole	0.085 ×0.085	Radiation Pattern	Graphene	4.11	1.15×10^3
[7]	Monopole	50×45	Radiation Pattern	Graphene	2.5	3-7
This work	Monopole	75 × 75	Radiation Pattern	Graphene	8	4.6 - 5.3

VII. Conclusion

In this paper, a reconfigurable monopole antenna for wireless application has been presented. The single monopole antenna design provides 8 dBi gain in the frequency range 4.6 - 5.3 GHz, an antenna is loaded by 7×7 EBG to improve the antenna gain. Four monopole antennas are proposed using graphene materials, which deliver to change radiation pattern
in different four directions (positive and negative x, positive and negative y) with gain 7.82 dBi. The reflection coefficient of each monopole separately working is the same in the frequency range.

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