# Study of a Metallic Antenna Backed by Graphene-Based Reflector

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***Abstract*-In order to improve the performance of traditional metal dipole antennas with poor gain and narrow bandwidth, this paper presents a novel metallic dipole antenna backed by a tunable graphene-based reflector. By applying a single layer graphene sheet to the bottom of substrate, the novel antenna has greater reconfigurability, higher gain compared to the normal metal dipole antenna. Moreover, the antenna shows enhanced radiation efficiency and good tunability due to the unique electronic properties of graphene. These interesting characteristics make new applications possible in wireless communication where dynamic radiation controls are required.**

## I. Introduction

With the rapid development of wireless communication technology, the increasing number of users and growing demand of data rates become the problems in mobile communication system [1]. The working frequency of current communication system is located at microwave band, which could only provide limited spectrum resources and might lead to frequency interference within adjacent frequency bands. To solve this problem, two main methods could be used. One of the methods is to use higher frequency band like millimeter wave band which could dramatically extend the spectrum resources [2]. However, this would be a sophisticated process to upgrade whole communication system with millimeter wave devices. Another way is to develop multi-band antenna by sufficiently utilizing the current available frequency resources. Usually, multi-band antenna can be fulfilled by designing a single antenna with multiple resonance frequency. This antenna system have simple structure, stable performance, high efficiency [3]. But the design and production process of this antenna is complex, in addition the mass production cost is high.

In this context, researchers having been focusing on using graphene in antennas [4]. Graphene is a honeycomb crystal structure composed of carbon atoms, and the atoms are connected by covalent bonds [5]. Due to its unique two-dimensional structure, graphene has excellent electronic, mechanical and optical properties [6]. It can work in a wide frequency range from microwave band to optical band. Specially, the conductivity of graphene is frequency-independent ant it can be controlled by bias voltage [7]. This allows graphene-based antennas to be tunable by changing the gate voltage. Several papers were published to report tunable antenna with graphene as radiator instead of metal [8]. It should be noted that, in microwave band, graphene's conductivity is not better than metal. However, the tunability of graphene still can be utilized as a reconfigurable reflection plane in traditional metal antenna [9]. With this feature, the characteristic of multi-band can be achieved using graphene in metal antenna without additional structure or other processes.

In this paper, dipole antenna working at 35-45GHz are focused on. A single layer graphene sheet is utilized as a reflector at the bottom of the metallic dipole antenna. The DC-controlled characteristic such as tunability, reconfigurability, and gain are investigated with simulation.

## II. Surface Conductivity Model of Graphene

For its ultra-thin (one atom) thickness, the electrical of grapheme could be described by the surface electrical conductivity $\sigma$ which is related to chemical potential $\mu_c$, temperature $T$, frequency $\omega$ and scattering rate $\Gamma$. Based on the Kubo formula, the surface conductivity of graphene can be expressed as [10]:

$$\sigma(\omega,\mu_c,\Gamma,T)=\frac{je^2(\omega-j2\Gamma)}{\pi\hbar^2}\Big[\frac{1}{(\omega-j2\Gamma)^2}\int_0^\infty\varepsilon\Big(\frac{\partial f_d(\varepsilon)}{\partial\varepsilon}-\frac{\partial f_d(-\varepsilon)}{\partial\varepsilon}\Big)\mathrm{d}\varepsilon-\int_0^\infty\frac{f_d(-\varepsilon)-f_d(\varepsilon)}{(\omega-j2\Gamma)^2-4(\varepsilon/\hbar)^2}\mathrm{d}\varepsilon\Big] \quad (1)$$

Where e is the electron charge, $\hbar=h/2\pi$ denotes the reduced Planck constant, $f_d(\varepsilon)=(e^{(\varepsilon-\mu_c)/k_BT}+1)^{-1}$ is the Fermi Dirac distribution, $k_B$ is Boltzmann constant and $\varepsilon$ represents the energy of the electron. Assuming there is no external magnetic field, the surface conductivity in the formula (1) is isotropic, the first term is the intra band surface conductivity, and the second term is the inter band surface conductivity. In this paper, as the operating frequency is relatively low, the inter band contribution can be neglected. Therefore, the surface conductivity of graphene can be approximated to [11]:

$$\sigma_s=\sigma_{\text{intra}}(\omega,\mu_c,\Gamma,T)=-j\frac{e^2k_BT}{\pi\hbar^2(\omega-j2\Gamma)}\times\Big(\frac{\mu_c}{k_BT}+2\ln(e^{-\mu_c/(k_BT)}+1)\Big) \quad (2)$$

The surface impedance of grapheme can be expressed as:

$$Z_S=1/\sigma_s(\omega)=\mathrm{R}_S+\mathrm{j}X_S \quad (3)$$

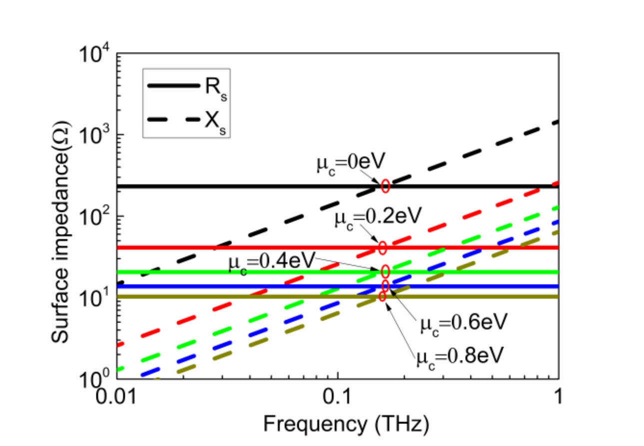


Figure 1. Surface impedance against frequency at different $\mu_c$

Fig. 1 shows the surface impedance of grapheme against frequency at different $\mu_c$ .It can be seen, after 0.2THz , the imaginary part of the surface impedance of graphene is larger than the real part, and the difference gradually increases. This is the reason why the SPP wave [12] can propagate on a graphene surface. Moreover, with the increase of frequency, the resistance value remains almost a constant, whilst reactance value increases. That is to say in the terahertz frequency range, the loss of graphene could hardly change with frequency, but the inductance intensity increases with frequency.

## III. Radiation Characteristics Of A Metal Dipole On A Graphene-Based Composite Dielectric Substrate

To realize reconfigurable radiation, the electrical properties of graphene are used, and a proposed graphene-loaded dipole antenna structure is shown in Fig. 2a. Gold dipole antenna is placed on a high resistivity silicon substrate which is used to grow $SiO_2$ and graphene. Graphene is used as a reflector as detailed in Fig. 2b. In order to study the effect of graphene, the resonance frequency and the far field radiation characteristics are simulated respectively. In addition, to further explore the tunability performance, according to the analysis in section 2, the change of bias at both ends of the graphene can lead to the variation of surface impedance, so it can achieve the purpose of tuning the antenna performance.

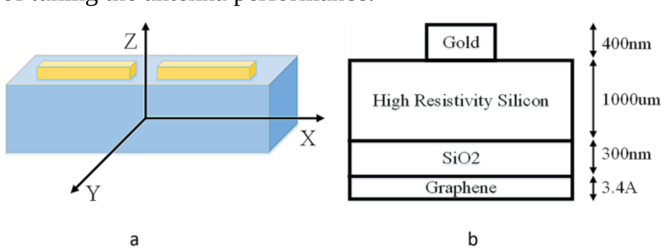


Figure 2. (a) Schematic diagram of antenna simulation: arm length is 750um, width is 120um and the gap 80um; (b) antenna side material map

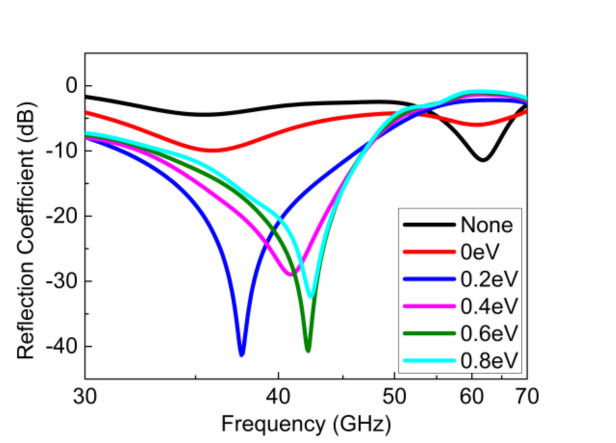


Figure 3. The reflection coefficients of the graphene antenna

Using the commercial electromagnetic simulation software CST Microwave Studio, a series of simulations are carried out. Fig. 3 demonstrates the relationship between the reflection coefficient ($|S_{11}|$) and antenna operating frequency. As mentioned, graphene layer without bias voltage tuning or doping can be regarded as a lossy dielectric plate due to the high surface impedance. Therefore, there will be no obvious improvement of radiation efficiency when using graphene with chemical potential of 0eV as the reflector. Also, it can be observed that the chemical potential changing of graphene brings reconfigurability of antenna operating frequency ranging from 35GHz to 45GHz. To be more specific, the resonant frequency of the antenna increases with the boost of the voltage (from 0eV to 0.6eV) applied on the graphene sheet. In addition, there is no significant difference of antenna resonant frequencies between chemical potential of 0.8eV and 0.6eV, as shown in Fig. 3. So the chemical potential should be chosen appropriately for effectively tuning the antenna.

To analyze the effect of graphene, the far field performance of this antenna is simulated. Fig. 4a and Fig. 4b show the antenna gain of H-plane and E-plane. Figure 4c shows the different gain values that under different bias. Fig. 4d shows the radiation pattern of the antenna (3D pattern) when the bias voltage is 0.2eV. The maximum gain increase from the original 1.627 dB to 2.652 dB. It should be noted that the conductivity of graphene in the natural state is poor, so when the bias voltage is 0V, the maximum gain is a relatively small, only -2dB or so. In that case, considering both results from section 2 and 3, we then could select the appropriate bias value for different application scenarios.

## IV. Conclusion

In this paper, a new type of metal dipole antenna backed by graphene-based reflector is proposed and analyzed. The graphene-based reflector is used to improve the performance of the traditional metal dipole which shows the disadvantages of poor directivity, narrow band and so on. Because graphene shows good conductivity in microwave band, which is to enhance the resonant characteristics of the antenna. It is

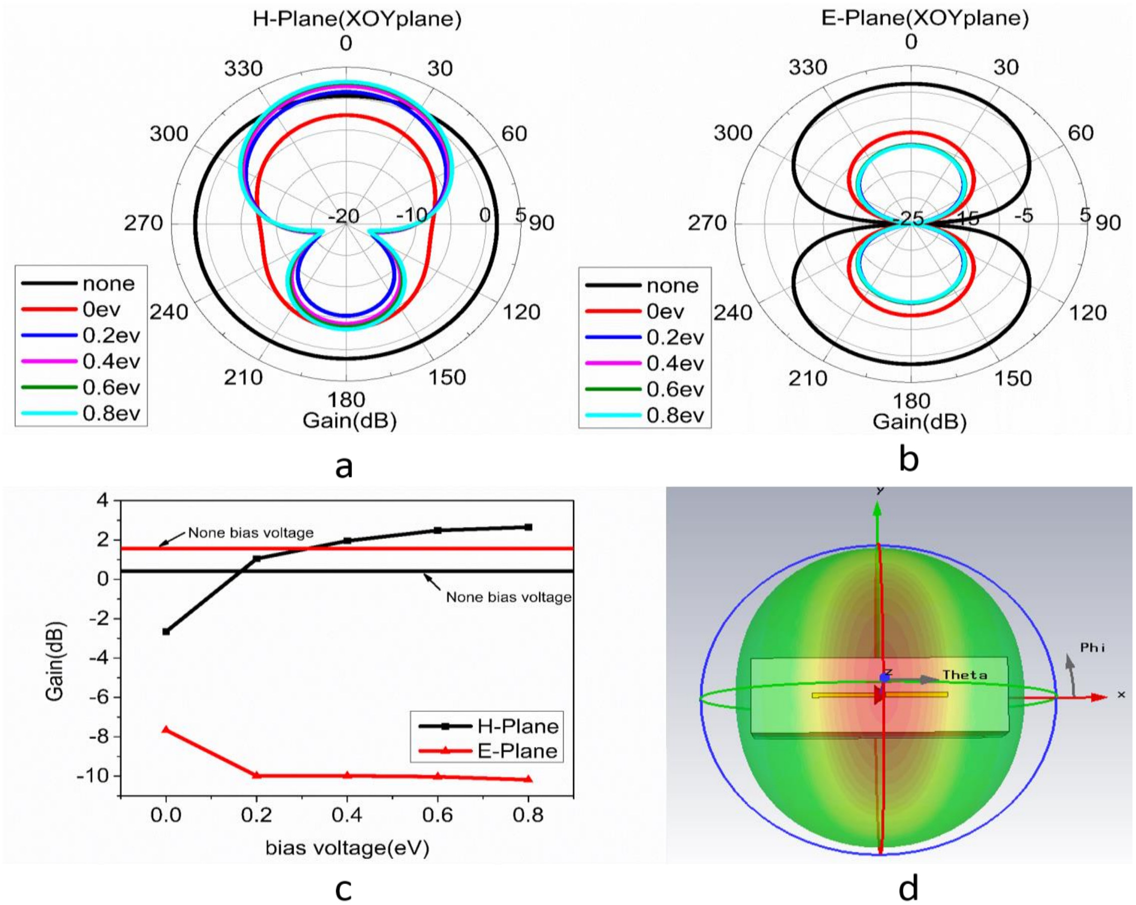


Figure 4. Gain of graphene antenna (a) H-plane; (b) E-plane; (c) The maximum gain(0°) under different bias; (d) The radiation pattern of the antenna (bias voltage=0.2eV)

proved that graphene can be used as a reflector to force the electromagnetic wave radiates into the upper space instead of substrate, and then it also could improve the radiation efficiency of metal dipole antenna. In addition, although the graphene has poor conductivity in the natural state, through artificially tuning the bias voltage of the reflector, the scattering parameters of antenna can be controlled. Thereby the purpose of optimizing the radiation performance of the traditional antenna can be reached. This novel antenna design shows a new way to tune metal antenna by introducing a graphene-based reflector and it can be envisioned as a potential technique in future reconfigurable mobile communication field in the future.

## ACKNOWLEDGMENT

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