UWB Single Port Log Periodic Toothed Terahertz Antenna Design Based on Graphene Artificial Magnetic Conductor

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Abstract

In this work, a single port exponential tapered toothed log periodic antenna based on graphene artificial magnetic conductor (AMC) is suggested for ultra-wideband (1–10) THz operation. The resonance frequency of the proposed antenna can be tuned by changing the connected DC voltage which leads to variation in the chemical potential of the graphene. The radiating toothed log periodic antenna consists of gold patch placed on 25x25 graphene patches which act as an AMC surface unit. Exponential taper is used to satisfy impedance matching between the antenna and the feeder over the frequency range. The simulation results reveal that 90% of frequency range satisfies \( s_{11} < -10 \) dB when the chemical potential is 1 eV.

Keywords: Graphene, artificial magnetic conductor, terahertz antenna, toothed log periodic antenna, UWB antenna

1. Introduction

Graphene has been named the simplest complex material which has drawn increasing attention in recent years due to its unique properties and advantages. In fact, graphene is used in many fields including mechanical, thermal and electrical applications (Geim & Novoselov, 2007; Grigorenko, Polini & Novoselov, 2012). The surface conductivity of the graphene can be varied by changing the applied electrical potential (Sensale-Rodriguez, Yan, Liu, Jena & Xing, 2013; Low & Avouris, 2014), thus many graphene based-devices such as antennas, filters, absorbers, and polarizer's have been suggested for bands in microwave, terahertz and optical frequencies (Fallahi & Perruisseau-Carrier, 2012; Andryieuski, & Lavrinenko, 2013). Graphene-based THz and photonic antennas were also developed in (Wu, Tuncer, Naeem, Yang, Cole, Milne & Hao, 2014; Xu, Lu, Jiang & Dong, 2012) for different applications.

The graphene can be used to design THz antennas, as radiating part (Esquius-Morote, G’omez-D’iz & Perruisseau-Carrier, 2014; Tamagnone, G’omez-D’iz, Mosig & Perruisseau-Carrier, 2012), parasitic component, or high impedance surfaces (HIS) usually based on AMC configuration (Dragoman, Muller, Dragoman, Coccetti & Plana, 2010; Tamagnone, Gomez Diaz, Mosig & Perruisseau-Carrier, 2013). The AMC is a planar array of periodic surface which can improve the control of electromagnetic wave radiation. Thus this structure has been broadly utilized in the design of some types of antennas such as low profile leaky wave antenna operating at microwave regime with high efficiency and gain in correlation with conventional ground plane. Also adding active HIS (Huang, Wu, Tang & Mao, 2012) elements loaded with varactor diodes to the antennas enables them to beam steering and easy frequency tuning (Guzman-Quiros, Gomez-Tormero, Weily & Guo, 2012; Sievenpiper, Schaffner, Song, Loo & Tangonan, 2003). It is also possible to insert periodic graphene patches as antenna ground. A tunable terahertz antenna based on graphene AMC with relatively narrow bandwidth was presented in (Wang, Zhao, Hu & Zhang, 2013). In (Wang, Li, Zhao & Hu, 2013) many shapes of graphene-based AMC were studied and compared. The graphene biased reflective array was also applied for antenna configuration to get frequency tuning and beam reconfiguration (Esquius-Morote, G’omez-D’iz & Perruisseau-Carrier, 2014; Tamagnone, Gomez Diaz, Mosig & Perruisseau-Carrier, 2013).

In this work, a single port novel tunable UWB antenna depending on AMC array is proposed. The antenna has...
log periodic toothed shape with exponential tapered transmission line implemented over graphene patche array which acts as an AMC. The applied voltage is used to tune this antenna in order to wide its bandwidth.

2. Background

2.1 Graphene Conductivity

The graphene can displayed as an infinitesimally flimsy surface which is portrayed by surface conductivity $\sigma_s (\omega, \tau, \mu_c, T)$. The graphene conductivity Drude model in intraband can be written by (Wang, Zhao, Hu & Zhang, 2013)

$$\sigma_s (\omega) = \frac{e^2 k_b T \tau}{(1 + j \omega \tau) \hbar^2} \left[ \frac{\mu_c}{k_b T} + 2 \ln \left( e^{\frac{\mu_c}{k_b T}} + 1 \right) \right]$$

(1)

Where $\tau$ is the scattering time, $\omega$ is the angular frequency, $\mu_c$ is the chemical potential in eV, which can be changed by chemical doping process or by using DC voltage, $e$ is the electron charge, $T$ is the absolute temperature, $k_B$ is Boltzmann constant, and $\hbar$ is reduced Planck’s constant.

The graphene surface impedance can be expressed as

$$Z_s (\omega) = \frac{1}{\sigma_s (\omega)}$$

(2)

2.2 Graphene-Based AMC

The graphene is used as an AMC unit cell which consists of a periodic of square patches with dimension $D$ and the gap between adjacent patches is $g$ as in Figure 1 (Wang, Zhao, Hu & Zhang, 2013).

The patch array at terahertz band surface impedance can be written as (Wang, Li, Zhao & Hu, 2013)

$$Z_g = j \left( \frac{D}{D - g} \frac{1}{\omega C_g} \right) = \frac{1}{j \omega C_{eff}(\omega)}$$

(3a)

where $C_g$ represents the capacitance between adjacent graphene patches

$$C_{eff} = \frac{1}{\pi} \varepsilon_r (\varepsilon_r + 1) D \ln[\csc \left( \frac{\pi g}{2 D} \right)]$$

(3b)

Here $\varepsilon_r$ is the permittivity of free space, $\varepsilon_r$ is the substrate relative permittivity, and $C_{eff}$ is the capacity for the background and patch geometry.

Figure 1. Graphene-based artificial magnetic conductor (Wang, Li, Zhao & Hu, 2013)

The circuit model representing the equivalent circuit of graphene patches array mounted on grounded substrate is shown in Figure 2 (Wang, Zhao, Hu & Zhang, 2013).
2.3 Log Periodic Antenna

Log periodic antenna (LPA) is still interesting although many decades passed. It provides frequency independence properties for the antenna over wide band of frequency. In fact, theoretically log periodic antenna is a class of antennas for which pattern and impedance independent on frequency for unlimited band of frequencies. The impedance and pattern of LPA structures is shaped so that repeat periodically in relation with the frequency logarithm, as in Figure 3.

\[
\tau = \frac{R_{N+1}}{R_N}
\]

(4)

\[
\delta = \frac{r_N}{R_N}
\]

(5)

where \(R_N\) and \(r_N\) are the distance from the center of the antenna to the outer and inner radiuses of the tooth \(N\) respectively, \(\tau\) is the ratio between two outer radiuses of successive teeth, and \(\delta\) is the ratio between inner radius to the outer radius for any tooth. The structure shape and scaling factor \(\tau\) can be used such that the changing of the impedance and pattern over each period is small, the result being an extremely wideband antenna. The feeding of the two parts of the antenna is at the vertices either by a coaxial line or by a balanced two-wire line. The upper and lower frequency limits are achieved when the shortest and longest teeth, respectively, are around 0.25 wavelength long.

2.4 Impedance Matching
Tapered line is used in this work to increase the matching between the antenna and the feeder. Typically the characteristic impedance of the transmission line is 50Ω, while the input impedance of the proposed wideband antenna is 200Ω. Thus an exponential line taper is used to match the 50Ω of the feeder to the 200Ω of the antenna, as shown in Figure 4. The exponential line is characterized by (Pozar, 2011)

$$Z(z) = Z_0 e^{az} \text{ for } 0 \leq z \leq L$$

where $Z_0 = Z(0)$ and

$$a = \frac{1}{L} \ln\left(\frac{Z_L}{Z_0}\right)$$

Here $Z(L)$ is the characteristic impedance of the transmission line at distance $L$, i.e., $Z_L = Z(L)$.

3. Proposed Antenna Model

In our work, the proposed log periodic toothed antenna has a structure of $\alpha = 120^\circ$, $\beta = 45^\circ$, where $\alpha$ is the tooth angle, $\beta$ is the bow angle and $\tau = \sigma^2 = 0.5$, as shown in Figure 5a.

This proposed antenna is based on AMC and composed of 25 x 25 array of periodic square conductive graphene sheets. A log periodic toothed antenna from gold material is placed on the graphene-depend AMC ground plane, as shown in Figure 5b. A grounded SiO₂ material of thickness 10 μm is representing the AMC substrate. A silicon wafer of thickness 300 μm is used under the substrate. A50 nm from polycrystalline silicon material is placed above the quartz is thick layer and Al₂O₃ of 10 nm-thick film in sequence, (Wang, Zhao, Hu & Zhang, 2013). The AMC unit consists of 25 x25 graphene square shape patches with $g = 1\mu m$ and $D = 9\mu m$. The graphene patches are connected by a 60 nm-wide graphene to keep all AMC units at the same μ, when a DC voltage is connected between the polycrystalline silicon and the AMC. A 2 μm-thick SiO₂ material is placed on the graphene AMC, and the gold antenna is placed on SiO₂ layer (Wang, Zhao, Hu & Zhang, 2013).

![Figure 4. Variation of the characteristic impedance along the exponential taper](image)

(a) Top view (b) side view

![Figure 5. Proposed AMC-based antenna structure](image)
4. Simulation Results and Discussion

Simulation results are obtained using CST Studio ver.2014 for many values of chemical potential $\mu_C$. Results related to $\mu_C = 0.1eV$ and $1eV$ are given in this section, while the results relate to other values of $\mu_C$ are given in the Appendix. Figure 6a shows the scattering parameter $S_{11}$ in dB of the proposed antenna for $\mu_C = 0.1eV$. The operating bandwidth extends from (1.0 - 2.8) THz, at which $S_{11} < -10$ dB, while Figure 6b shows the broadband gain of the proposed antenna when $\mu_C = 0.1eV$. The antenna has gain $\geq 5$ dB for the entire frequency band (6.1 - 10) THz.

Figure 6. Proposed antenna characteristics when $\mu_C = 0.1eV$.

Figure 7a shows the scattering parameter $S_{11}$ in dB of the proposed antenna for $\mu_C = 1eV$. The operating bandwidth extends from (2.4 - 8.3) THz and from (9 - 10) THz. Further, there are resonance frequencies at (1, 1.5, and 2) THz at which $S_{11} < -10$ dB.

Figure 7b shows the broadband gain of the proposed antenna for $\mu_C = 1eV$. It has very good gain between -2 and 10 dB for the entire frequency band.
Figure 7. Proposed antenna characteristics when $\mu_c = 1eV$

Figure 8 summarize the frequency bands at different values of chemical potential $\mu_c = (0.1 - 1)eV$. The cumulative bandwidth, calculated as the sum of the bandwidths of different bands at which $S_1|< -10dB$, is mentioned in Table (1).

![Gain spectrum](image)

(b) Gain spectrum

**Figure 8. Frequency bands for different values of chemical potential $\mu_c = (0.1 - 1)eV$**

**Table 1. Variation of the cumulative bandwidth with $\mu_c$**

<table>
<thead>
<tr>
<th>Chemical potential $\mu_c$(eV)</th>
<th>Cumulative bandwidth (THz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>1.80</td>
</tr>
<tr>
<td>0.2</td>
<td>2.50</td>
</tr>
<tr>
<td>0.3</td>
<td>6.45</td>
</tr>
<tr>
<td>0.4</td>
<td>6.80</td>
</tr>
<tr>
<td>0.5</td>
<td>6.90</td>
</tr>
<tr>
<td>0.6</td>
<td>6.92</td>
</tr>
<tr>
<td>0.7</td>
<td>7.20</td>
</tr>
<tr>
<td>0.8</td>
<td>7.20</td>
</tr>
</tbody>
</table>
5. Conclusions
In our work, a tunable antenna based on graphene as artificial magnetic conductor has been designed to achieve UWB operating frequency band, (1 – 10)THz at which $S_{11} < -10$ dB. The antenna itself has been formed as log periodic toothed antenna whereas exponential transmission line taper is used to increase the matching between the antenna and the feeder. The simulation results reveal that the antenna cumulative bandwidth increases by increasing the chemical potential. The highest cumulative bandwidth of $S_{11} < -10$dB of the proposed antenna is equal to 6.86 THz at $\mu_c = 1eV$.

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References


Appendix

This Appendix presents related to the spectrum of the scattering parameter S11 and the gain for the proposed antenna when μc varies from 0.2 eV to 1 eV at step of 0.1 eV

![S-Parameter Magnitude in dB](image)

(a) Antenna scattering parameter S11

Frequency / THz

S11
Figure A1. Antenna scattering parameter $S_{11}$ (a) and antenna gain (b) when $\mu_c=0.2$ eV

Figure A2. Antenna scattering parameter $S_{11}$ (a) and antenna gain (b) when $\mu_c=0.3$ eV
Figure A3. Antenna scattering parameter $S_{11}$ (a) and antenna gain (b) when $\mu_c=0.4$ eV

Figure A4. Antenna scattering parameter $S_{11}$ (a) and antenna gain (b) when $\mu_c=0.5$ eV
Figure A5. Antenna scattering parameter $S_{11}$ (a) and antenna gain (b) when $\mu_c=0.6 \text{ eV}$

(b) Antenna gain

Figure A6. Antenna scattering parameter $S_{11}$ (a) and antenna gain (b) when $\mu_c=0.7 \text{ eV}$

(b) Antenna gain
Figure A7. Antenna scattering parameter $S_{11}$ (a) and antenna gain (b) when $\mu_c=0.8$ eV

Figure A8. Antenna scattering parameter $S_{11}$ (a) and antenna gain (b) when $\mu_c=0.9$ Ev

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