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# Design and optimisation of microstrip bowtie antenna based on graphene material for terahertz applications

# *Terahertz uygulamaları için grafen malzemesine dayalı mikroşerit bowtie anten tasarımı ve optimizasyonu*

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# Design and Optimisation of Microstrip Bowtie Antenna Based on Graphene Material for Terahertz Applications

## *Highlights*

- *Microstrip Bowtie Antenna*
- *Future of Wireless Communication Systems*
- *Electrical Characteristics of Graphene*
- *Computer Simulation Technology*
- *THz- Based Inodoor Applications*

## *Graphical Abstract*

*In order to design, simulate, optimise, and analyse the proposed microstrip bowtie antenna the graphical illustration in the figure shown below is introduced.*

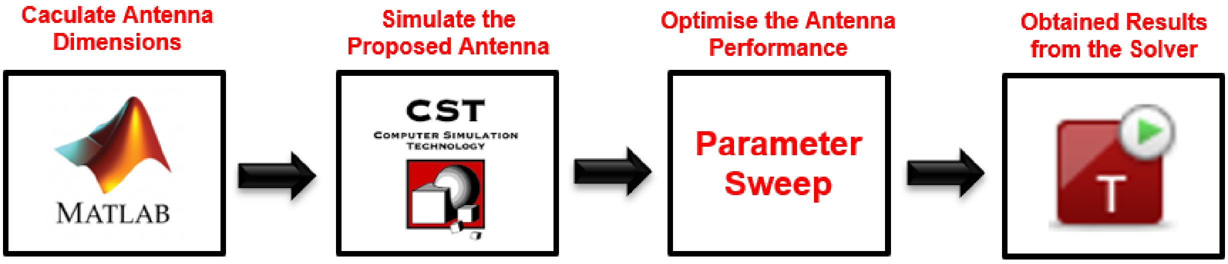


**Figure.** Graphical illustration for the proposed graphene-based microstrip bowtie antenna.

## *Aim*

*The main aim of this work is the study the performance of the graphene-based microstrip bowtie antenna in the high-frequency bands of the frequency spectrum (i.e., the THz regime).*

## *Design & Methodology*

*The proposed work is summarised by studying the graphene conductivity for the microstrip bowtie antenna in the THz bands based on computer simulation technology.*

## *Originality*

*This work's originality is summed by introducing a super-wide band (0.1-10 THz) microstrip bowtie antenna for the future of wireless communications like 6G and indoor applications.*

## *Findings*

*The electrical conductivity of metals is related to the antenna's functional frequency. The conductivity of some conductive materials decreases as frequency increases. In contrast, graphene has superconductivity, which becomes more dominant as frequency increases. This feature is used in the proposed antenna's design.*

## *Conclusion*

*Based on this work, it is possible to conclude that increasing the frequency used leads to an increase in the data rate. The proposed antenna can cover a wide bandwidth ranging from 0.1 to 10 THz by utilising graphene.*

## *Declaration of Ethical Standards*

*The authors certify that the preparation of this research was done in accordance with scientific research ethics and related laws.*

# Terahertz Uygulamaları için Grafen Malzemesine Dayalı Mikroşerit Bowtie Anten Tasarımı ve Optimizasyonu

***Araştırma Makalesi / Research Article***

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**ÖZ**

Kablosuz iletişim teknolojisindeki gelişmeler, elektromanyetik spektrumun Terahertz (THz) frekans bandı umut verici hale geliyor ve son zamanlarda araştırmacıların dikkatini tıbbi, kişisel ağlar için iç mekan iletişimi ve askeri uygulamalar gibi çeşitli uygulamalarda kullanmaya başladı. Bu frekans bandındaki ana konular, kompakt, yüksek performanslı bir anten tasarımının oluşturulması; bu frekans bandında olduğu gibi, frekans arttıkça iletim için malzeme özellikleri azalmakta ve dolayısıyla antenin performansı düşmektedir. Bu yazıda, grafen tabanlı bir papyon mikroşerit anten öneriyoruz, grafen malzemesinin THz frekans bandındaki performansı, Bilgisayar Simülasyon Teknolojisi (BST) yazılımının sonlu entegrasyonuna dayalı olarak analiz ediliyor. Alt kısmında tamamen bakır bir zemin düzlemi bulunan bir silikon dioksit substratı üzerine basılmış grafen bazlı papyon yaması. Önerilen grafen plazmonik papyon anten, 2-19 dBi aralığında iyi kazanç ile 0.1-10 THz bant frekansını kapsar.

**Anahtar Kelimeler: Papyon mikroşerit anten, BST, grafen, yüzey plazmon polariton, terahertz antenleri.**

# Design and Optimisation of Microstrip Bowtie Antenna Based on Graphene Material for Terahertz Applications

**ABSTRACT**

The developments of the wireless communications technology, the Terahertz (THz) frequency band of the electromagnetic spectrum becomes promising and recently has the researchers' attention to be utilized in several applications such as medical, indoor communications for personal networks, and the military applications. The main issues in this frequency band are the construction of a compact, high-performance antenna design; as in this frequency band, the material properties for conduction decrease as the frequency increases, and therefore the performance of the antenna diminishes. In this paper, we propose a graphene-based bowtie microstrip antenna, the performance of the graphene material in the THz frequency band is analysed based on the finite integration of the Computer Simulation Technology (CST) software. The graphene-based bowtie patch printed on a silicon dioxide substrate with a fully copper ground plane printed on its bottom. The proposed graphene plasmonic bowtie antenna covers a range of 0.1-10 THz band frequency with good gain in the range of 2-19 dBi in the mentioned band.

**Keywords: Bowtie microstrip antenna, CST, graphene, surface plasmon polariton, terahertz antennas.**

## 1. INTRODUCTION

Modern wireless networks device requires multiple devices to operate in a wide frequency band, at the same time and this requires an ultra-wideband antenna operates in the unused frequency spectrum (terahertz band) for these multiple devices. The Electromagnetic Terahertz (THz) or sub-millimetre field recently has attracted the wide interest of the researchers in different fields like spectroscopy [1], imaging [2], [3] security [4], medical diagnosis [5] military applications, and indoor communications [6], and high-speed communication [7], [8]. The unused spectrum in the

THz regime provides broadband for communication with high-speed communication which can be utilized to transfer large data over a personal network. The ultra-massive multi-input multi-output technology was suggested to enlarge the utilization of the THz regime. The architecture of this technique requires a dense group of antennas organized in a tiny area, which can be done via the utilising the graphene antennas [9].

Graphene is a one-atom thickness of the carbon material which has received a great interest in the last years due to its ideal characteristic. Graphene is utilised in an extensive variety of utilisation including the mechanic,

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thermic, optic, and electric applications. The low profile and the lightweight behaviour of the graphene material make it applicable in the miniaturisation manner of the antennas and other purposes. Graphene material is characterised by the other materials by the tuneability of its surface conductivity; where the surface conductivity can be adjusted and changed by practising an electric field on the graphene flake. The graphene chemical potential varies with the applied voltage which in turn leads to a variation on the total surface conductivity of the graphene material. Consequently, diverse graphene based-devices have been designed such as waveguides, absorbers, antennas, polarizers, and filters for the microwave, terahertz and optical bands as well. The graphene Surface Plasmon Polariton (SPP) could be designated as an electromagnetic wave that propagates along with the combination of the dielectric-metal with an exponentially dropping field on the two parties. The SPP are one of the various significant hopeful modernised procedures to defeat the standard diffraction limit of the optical appliances and miniaturised tools. Hence, several plasmonic appliances are advised and studied, such as antennas, filters for THz applications. In the correlation with gold or silver, the graphene backings SPP waves at extremely small frequencies in the THz regime [10]-[12].

The SPP wave presents in the noble metals at the near-infrared and visible frequency of the radio frequency spectrum. SPP waves are linked with the surface electric charges particles at the limit among the noble metal (e.g., gold or silver) and the insulation substrate [13], [14].

In the antenna design, the graphene material could be utilized as an Artificial Magnetic Conductor (AMC), radiating elements, hybrid-metal as a radiating patch in microwave regime, or in the energy harvesting microstrip antenna, underwater communication system, and in the design of photonic device. Also, the graphene can be utilised to develop the meta-material to enhance the antenna performance [13]-[21].

In general, conductive materials lose their conduction properties at very high frequencies, so they sometimes behave like semiconductors or their conductivity decreases significantly. Graphene has a superior conductivity for the electric current, especially at very high frequencies (e.g., THz regime). Furthermore, as the $\mu_c$increases, its conductivity changes and increases, which is related to the DC voltage applied to the graphene flake. In this article, a novel for a graphene-based bow-tie antenna is presented and analysed for the THz band. The proposed antenna design is able to cover the frequency range of roughly about 0.1-10 THz. The proposed antenna is designed and simulated at the graphene chemical potential $\mu_c = 1$ because it is sufficient to cover the entire THz band in this work.

## 2. PROPOSED ANTENNA DESIGN

In this section, the fundamental steps of the design and simulation of the proposed antennas will be presented and discussed as well.

### 2.1 Microstrip Bowtie Antenna design

The base design of the Microstrip Bowtie Antenna (MBA) will be discussed in this subsection. The first step of the base design of the MBA summarised by the selection of the fundamental antenna parameters such as operating frequency band, substrate type, and input impedance, as demonstrated in Table 1. The structure of the MBA with its dimensions is illustrated in Figure 1.

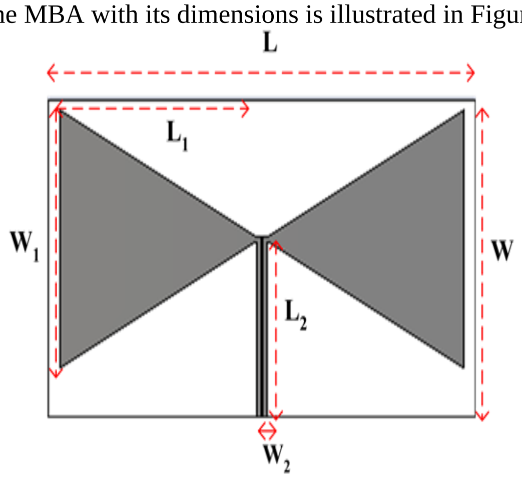



**Figure 1.** Dimensions description for the MBA.

**Table 1.** Fundamental Antenna Parameters

| Parameter | Description |
|---|---|
| Operating frequency ($\boldsymbol{f_r}$) | 7 THz |
| Input impedance ($\boldsymbol{R_{in}}$) | 50Ω |
| Substrate type | Silicon Dioxide with a dispersive Dielectric constant $\varepsilon_r$= 3.7 and Loss tangent $\delta$=0.002 |
| Graphene sheet thickness | 10 nm |

The second step of the MBA design procedure is the calculation of the patch and substrate dimensions by utilising the set of the following Equations [22], [23]:

$$f_r = \frac{ck_{mn}}{2\pi\sqrt{\varepsilon_r}} \quad (1)$$

$$f_r = \frac{2c\sqrt{m^2+mn+n^2}}{3a\sqrt{\varepsilon_r}} \quad (2)$$

$$f_{10} = \frac{2c}{2f_r\sqrt{\varepsilon_r}} \quad (3)$$

$$a_{eff} = a + \frac{h}{\sqrt{\varepsilon_r}} \quad (4)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{4\sqrt{1+\frac{12h}{a}}} \quad (5)$$

$$f_{mn} = f_{10}\sqrt{m^2+mn+n^2} \quad (6)$$

$$\lambda_o = \frac{c}{f} \quad (7)$$

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_{eff}}} \quad (8)$$

$$L_1 = \frac{\lambda_g}{4} \quad (9)$$

$$\frac{w}{d}=\frac{8e^{A}}{e^{2A}-2} \qquad for\ \frac{w}{d}<2 \tag{10}$$

$$\frac{w}{d}=\frac{2}{\pi}\left\{B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1)+0.39-\left(\frac{0.61}{\varepsilon_r}\right)\right]\right\} \tag{11}$$

$$for\ \frac{w}{d}>2$$

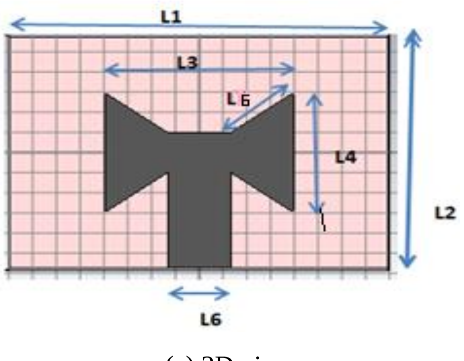
$$A=\frac{z_o}{60}\sqrt{\frac{\varepsilon_r+1}{2}}+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right) \tag{12}$$

$$B=\frac{377\pi}{2z_o\sqrt{\varepsilon_r}} \tag{13}$$

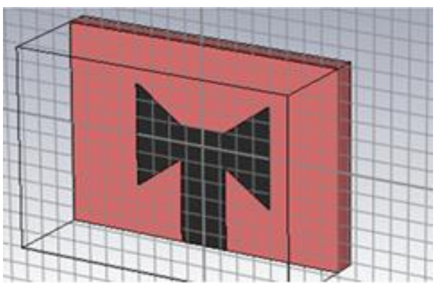
Where $f_r$ referred to the frequency of the resonance, $k_{mn}$ represents the mode of the resonance at $m$ and $n$ numbers, $c$ is referring to the speed of light which equals $3*10^8\ m/s$, and $a$ is the length of the side the bow tie strip. The L1, L2, W1, and W2 are the matching network parameters which illustrated in Figure 1.

## 3. GRAPHENE-BASED MBA DESIGN

The graphene material has variable properties related to the operating frequency and the applied voltage on the graphene flake so that the previous equations don't match with the graphene-based MBA, especially in the THz regime. To simulate the graphene-based MBA, the optimisation process on the antenna dimensions should be carried out via the trial and error until the best result is obtained. Figure 2 and Table 2, respectively, illustrate the simulated graphene-based MBA within the CST software and the optimised MBA dimensions.




(a) 2D view



(b) side view

**Figure 2.** Graphene-based MBA in the CST

**Table 2.** Optimised Graphene-Based MBA Dimensions

| Dimension | Optimised value(μm) |
|---|---|
| **L1** | 317.86 |
| **L2** | 230.12 |
| **L3** | 153.41 |
| **L4** | 115.06 |
| **L5** | 52.6 |
| **L6** | 63.38 |

The graphene surface conductivity is a function of temperature, chemical potential, frequency, and scattering rate. Thus, the graphene has an abnormal as well as dispersive characteristics that can be represented by utilising the Kubo's formula to model and calculate the graphene conductivity. Generally, the graphene material comprises of two principal parts, which are termed as the inter-band and the intra-band; the first band has an effective effect on the total conductivity for the frequencies below 5 THz while the effect of the second band appears in the frequencies above the previously mentioned band, the graphene conductivity can be modelled in the CST software by using the following Equations [24], [25]:

$$\sigma = \sigma_{intra} + \sigma_{inter} \tag{14}$$

$$\sigma_{intra} = -j\frac{q_e^2 k_B}{\pi \hbar^2 (w-j2\Gamma)} x \left[\frac{\mu_C}{k_B T} + 2ln\left(e^{-\mu_c/(k_b T)}+1\right)\right] \tag{15}$$

$$\sigma_{inter}(\omega,\mu_c,\gamma,T)=\frac{-je^2}{4\pi h}\ln\left(\frac{2|\mu_c|-(\omega-j2\gamma)h}{2|\mu_c|+(\omega-j2\gamma)h}\right), \tag{16}$$

$$Zs = \frac{1}{\sigma_s} \tag{17}$$

Where σ is the graphene material conductivity, $\omega$ is the angular frequency in rad/sec, $\gamma$ is the scattering rate in $s^{-1}$, $\mu_c$ chemical potential in eV, $T$ is the temperature in Kelvin, e is Electron charge in coulomb, ħ is the reduced Planck's constant, and $K_B$ is the Boltzmann constant.

## 4. OBTAINED RESULTS AND DISCUSSION

In this part of the article, the obtained results from the CST solver for the designed graphene-based MBA will be presented, discussed, and explained. Generally, the bandwidth of the generic antenna can be defined as the range over which the antenna functions properly. The bandwidth of the antenna is usually calculated from the $S_{11}$ plot at $S_{11}=-10$ dB. This criterion implies that only 10% of the supplied power is returned back to the source and the rest is received by the antenna, as illustrated in Figures 3 and 4, respectively. It is clear that from the previous figures the $S_{11}$ is less than -10 dB and

$VSWR$ less than 2 over the entire frequency band of 0.1-10 THz. According to the studies that have been made in the literature the microstrip antennas have a poor gain because it is affected by the substrate properties. Figures 5 and 6, respectively, presented the simulated broadband antenna gain; and the 3D gain results at frequencies 1, 2, 4, 8, and 10 THz as well. Finally, Figure 7 illustrates the current distribution over the simulated antenna.

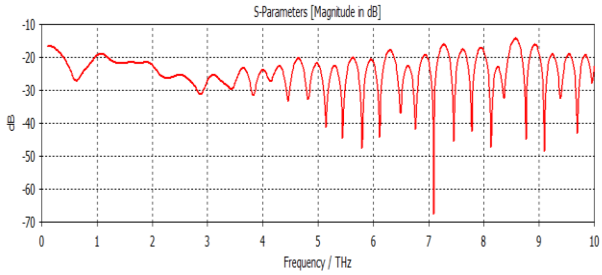



**Figure 3.** Scattering parameter for the proposed MBA

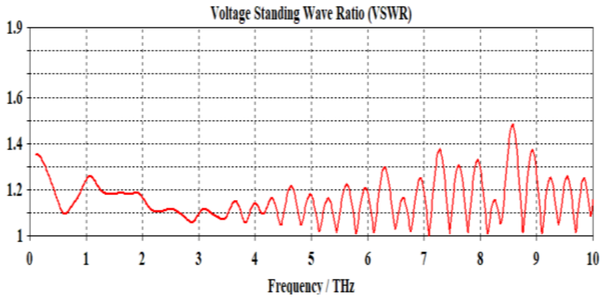



**Figure 4.** $VSWR$ for the proposed MBA

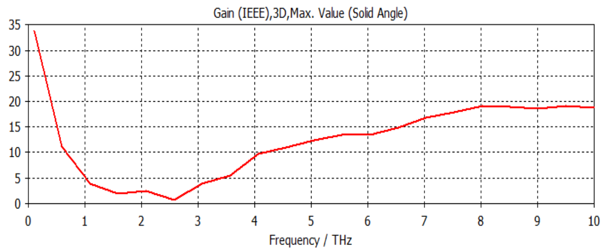
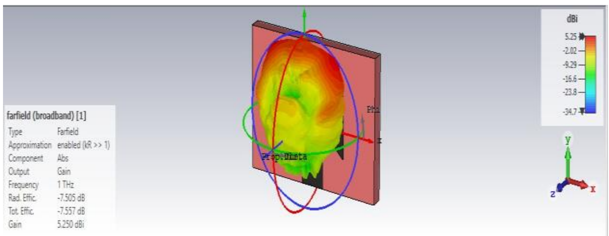
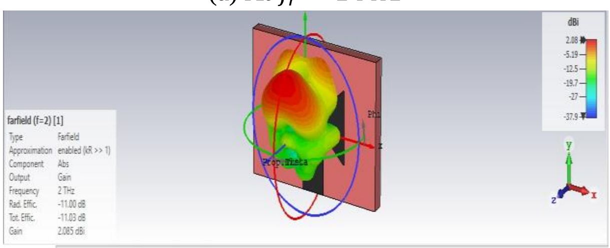


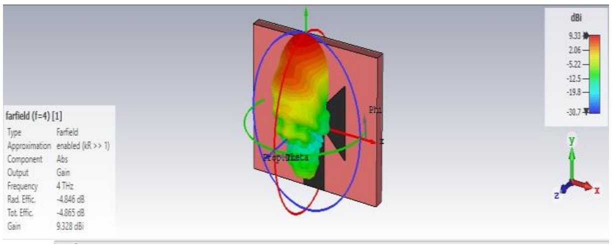

**Figure 5.** Broadband gain results for the simulated antenna



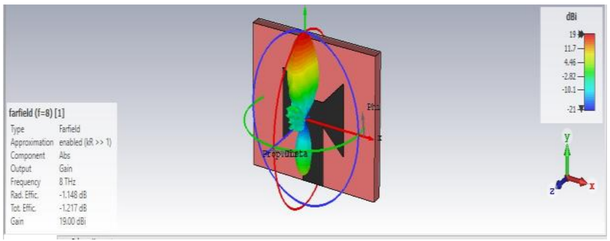
(a) At $f_r = 1\,THz$



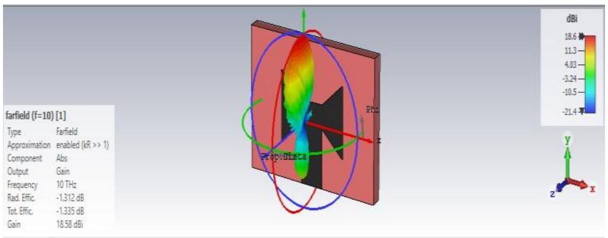
(b) At $f_r = 2\,THz$



(c) At $f_r = 4\,THz$



(d) At $f_r = 8\,THz$



(e) At $f_r = 10\,THz$

**Figure 6.** 3D gain results for the simulated antenna

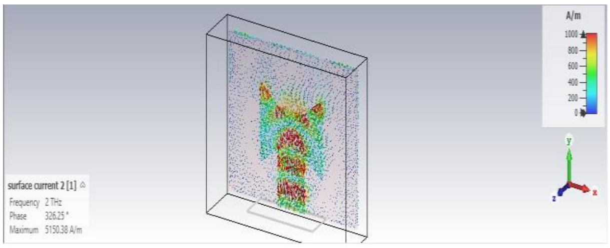


**Figure 7.** Current distribution over the simulated antenna

## 5. CONCLUSION

In this paper, a novel of a plasmonic graphene-based MBA plasmonic THz antenna has been presented. The graphene material backing the SPP waves at the lower THz regime of the electromagnetic while the metals support SSP waves at higher frequencies this property makes the simulated antenna able to operate among a very large band. The designed antenna comprises of a graphene bowtie patch, silicon dioxide substrate, and a full copper ground plane. The proposed MBA was designed, simulated, and optimised by utilising the finite integration technique that is supported by the CST software. The obtained result for the proposed graphene-based MBA was at the chemical potential is equal to 1; the bandwidth was about 0.1-10 THz and the antenna gain 31.7 to 18.7 dBi at the mentioned bandwidth.

## DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

## AUTHORS' CONTRIBUTIONS

**Hamzah M. Marhoon:** The author wrote the paper, compiled it, typeset and carried out the presentation process at the conference.

**Hussein A. Abdulnabi:** The author has carried out the process of antenna design and simulation in the CST software. Also, he has done mathematical modelling for the simulated antenna.

**Yasin Yousif Al-Aboosi:** The author has made the antenna optimisation process and organised the final version of the paper.

## CONFLICT OF INTEREST

The authors declare that is no conflict of interest in this study.

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