TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 1, February 2020, pp. 30~36
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i1.13153

UWB THz plasmonic microstrip antenna based on graphene

Hussein A. Abdulnabi, Mushreq Abdulhussain Shuriji, Sadiq Ahmed
Department of Electrical Engineering, AL-Mustansiriyah University, Iraq

Article Info

Article history:

Received May 18, 2019
Revised Jul 6, 2019
Accepted Jul 18, 2019

Keywords:

Graphene
Microstrip
Plasmonic Surface plasmon polaritons (SPPs)
Terahertz

ABSTRACT

This paper proposes design and investigates of graphene based plasmonic microstrip antenna for terahertz high speed communication and application systems 0.1-20 THz. The proposed antenna structure composed of graphene-based rectangular patch and transmission line mounted on a grounded silicone dioxide substrate. SPP (Surface Plasmon Polariton) waves that appear in graphene at THz band is analyzed. The proposed antenna simulation was done by using numerical method CST program. The simulation results show the scattering parameter S11 less than -10 dB at frequency band (0.1-20) THz. Also, the presented antenna system has a good gain along the frequency band.

Corresponding Author:

Hussein Ali Abdulnabi,
Department of Electrical Engineering, AL- Mustansiriyah University,
Baghdad, Iraq.
Email: Hussein_ali682@yahoo.com

1. INTRODUCTION

Fully used of microwave spectrum in gigahertz by the wireless communication system and the requirement for higher bandwidth and higher bit rate in modern communication systems, lead the researcher to discover new and unused frequency spectrum. The researcher discover terahertz frequency band. The antenna is the major part of any wireless communication systems, so this paper proposed design of UWB antenna in terahertz band.

Graphene is the simplest one atom thickness material which has drawn very high interest in last decade because of its unique characteristic. Graphene is used in wide range of applications including mechanical, thermal, optical and electrical applications, [1-3]. Also, the graphene can be used in fabrication of high-speed field effect transistor [4] or Schottky diode [5]. The graphene plasmonic behavior can be used to miniaturization process for the antennas and other applications. The applied electrical potential is changed to tune the graphene's chemical potential which leads to change in the surface conductivity of the graphene [6, 7], thus numerous graphene based-devices like waveguides, absorbers, antennas, and polarizer's, filters have been designed for the bands microwave, terahertz and optical regimes [8-13].

Graphene can be defined by its surface conductivity σ (ω, μc, τ, T) which has very significant effect in SPP utilized in nano-antennas, nano-microwave components, etc. surface conductivity depends on some parameters which tuned of σ to get a tunable resonance frequency. These parameters are temperature T, frequency ω, chemical potential μc which is depend on the doping of the chemical carrier density and electric bias voltage) and relaxation time τ. These parameters result to a variable surface conductivity. Graphene can be used in low THz zone to support surface plasmon polariton fields.

Surface plasmon polaritons (SPPs) can be specified as electromagnetic (EM) waves. SPPs propagate along the interface of the dielectric-metal with an exponentially dropping field in two sides. SPPs are one of the most important promising modern techniques to overcome the conventional diffraction limitation of the optical devices and miniaturized devices [7, 8]. Hence, different plasmonic devices are suggested and investigated, such as antennas, filters for terahertz systems.

Graphene supports SPP waves at much lower frequencies in THz band in comparison with gold or silver [14-16]. SPP wave appeared in the noble metals at near infrared and visible frequency in the radio frequency spectrum. SPP waves are coupled to the surface electric charges particles at the limit between a noble metal (gold or silver) and the dielectric substrate [17, 18]. The graphene can be used as artificial magnetic conductor (AMC) [19-21] or radiating patch [22-25] in the design of antennas.

The spectrum of terahertz waves is from about 0.1 THz to 10 THz which locate between microwave and infrared (IR) Spectra, and it has the same some characteristics with each of these bands. Like IR and microwave radiations, terahertz radiation propagates in a line of sight mode and is non-ionizing. THz waves are transparent to a large amount of non-conducting materials. Like microwave radiation, terahertz beam can transmit through several materials such as: cloths, cardboard, masonry, paper, wood, plastic and ceramics materials. The penetration depth is less than that of microwave radiation. Terahertz wave has limited penetration the clouds and fog and not penetrate water and metal. Terahertz antennas have many applications in recent years. Some applications are: terahertz pulsed imaging (TPI), pharmaceutical industries, molecular structure, in dermatology, medical imaging, oral healthcare, and high-speed indoor communication.

In this paper, we propose and analyze graphene-based plasmonic antenna with SPP wave behavior in THz band. The graphene is studied in section 2. In section 3 presents design of plasmonic graphene-based antenna. Simulation results are discussion are present in section 4.

2. GRAPHENE CONDUCTIVITY

As a 2D, the graphene configuration is two-dimensional structure has fantastic electrical characteristic due to its thickness is one atom only. The single-layer graphene surface conductivity is depending on its properties such as chemical potential, frequency, and relaxation time. Graphene material properties is dispersive and its value tuned by the changing the frequency and other factors. The one atom thickness of the graphene equivalent to a two-sided surface described by a surface conductivity, σ ($\boldsymbol{\omega}$, **μ**c, Γ, T) that is described by Kubo Forma [12]. It contains two parts inter-band and intra-band and the intra-band dominates in lower frequency band of interest (f < 5 THz) with electric voltage biasing on graphene film. The accuracy of the model is the sum of the two parts of the conductivity,

$$\sigma = \sigma_{intra} + \sigma_{inter} \tag{1}$$

$$\sigma_{intra}(\omega, \mu_c, \gamma, T) = \frac{e^2 k_B T \tau}{\pi \hbar^2} [\frac{\mu c}{k_B T} + 2\ln\left(e^{\frac{-\mu_c}{k_B T}} + 1\right)] \frac{1}{\omega - j2\gamma} \tag{2}$$

$$\sigma_{inter}(\omega, \mu_c, \gamma, T) = \frac{-je^2}{4\pi h} \ln\left(\frac{2|\mu_c| - (\omega - j2\gamma)h}{2|\mu_c| + (\omega - j2\gamma)h}\right. \tag{3}$$

where ω is the frequency in rad / s, γ is the scattering rate, μ_c is the Chemical potential (eV), T is the Temperature (K), e = Electron charge, ħ is the reduced Planck's constant, and k_B is the Boltzmann constant.

The chemical potential **μ**c is depend on the carrier density n (m^{-2})

$$\mu_c = \upsilon_f \hbar \sqrt{n\pi} \tag{4}$$

where $v_f = 1x\ 10^6$ represents the Fermi velocity of the graphene. The n value can be modified via by electric field effect.

$$n = \frac{\varepsilon_o \varepsilon V_b}{dq} \tag{5}$$

where ε_o is the free space permittivity of (F/m), V_b = voltage bias (V), d is the height of the dielectric material (m) and ε represent the dielectric material relative permittivity between the graphene sheet and back gate material.

The equation for the dispersion of the SPP present in (6):

$$\sqrt{n^2 - n_{eff}^2} + n^2\sqrt{n^2 - n_{eff}^2} + \frac{4\pi}{c}\sigma_\omega \sqrt{1 - n_{eff}^2}\sqrt{n^2 - n_{eff}^2} = 0 \tag{6}$$

where n_{eff} = complex propagation index, n = refraction index of substrate, $k_{SPP} = n_{eff} \times \omega/c$. Surface impedance of the graphene can be determined,

$$Z_{S=1/\sigma(\omega)} = R_S + j\,X_S \quad (7)$$

the propagation constant of SPP wave can be given by:

$$k_{SPP} = k_0(n_{eff}) \quad (8)$$

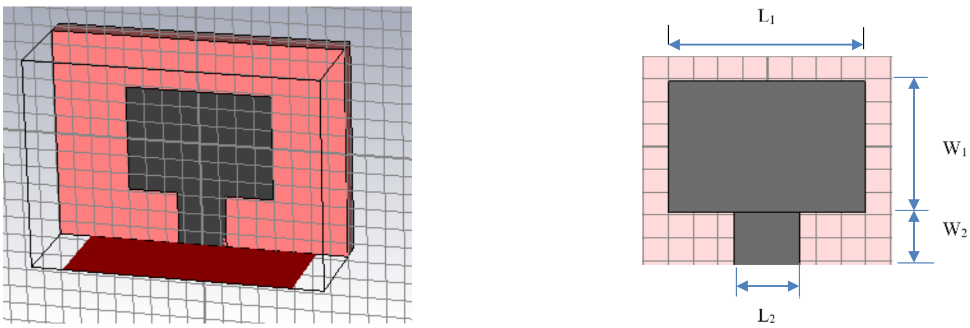
where $k_0 = 2\pi/\lambda_0$ is the wave number of the free space and n_{eff} represents the SPP modes complex effective index. The resonant length L_1 is half of surface plasmon polariton wavelength λ_{SPP}.

$$\lambda_{SPP} = 2\pi/\mathrm{Re}\,\{k_{SPP}\} \quad (9)$$

3. PLASMONIC GRAPHENE-BASED ANTENNA DESIGN

The plasmonic antennas provide higher wave vector than normal PEC antennas, thus the electrical size of the plasmonic nanoantenna is much more than the phsyiscal size. This is the major difference between plasmonic and classical metal antennas. The SSP characteristics apear in nobel metal such as gold and silver in optical resonances in the visible and near-infrared region due to the resonant response of their free electrons to the electric field of light. Metal materials, (gold or silver) is a non-plasmonic in the terahertz frequency band. While SPP behavior appears in graphene in low part of the terahertz band.

The proposed graphene plasmonic antenna is simulated by using CST software using waveguide port excitation. The substrate thickness is 25 nm of SiO_2 with $\varepsilon_r = 3.9$. The dielectric substrate is mounted between the graphene patch and ground plane. The thickness of the graphene is 0.34 nm. The structre of the designed antenna 3D & 2D is shown in Figure 1. Table 1 shows the dimensions of the proposed antenna.



(a) (b)

Figure 1. Plasmonic patch graphene-based antenna: (a) 3D, (b) 2D

Table 1. The dimensions of the microstrip antenna

L_1 (um)	L_2 (um)	W_1 (um)	W_2 (um)
158.93	52.6	115.06	57.53

4. RESULTS AND DISCUSSION

The graphene patch antenna is printed on the SiO_2 substrate material and ground plane. Figure 2 shows the reflection coefficients of the on graphene-based antenna for **μ**c = 0.5 in THz. This figure shows that the antenna operating frequency band from 0.1 to 20 THz and the resonant frequency is 3.5 THz. The simulation results reveal that S11 is about -48 dB at the center frequency. Figure 3 shows the gain of the proposed antenna at the frequency band (0.1-20) THz. The antenna has good gain at this frequency band. Gain at this frequency is equal to 7.53 dB. Radiation patterns of the based antenna at (F =0.55, 1, 2, 5.05, 8) THz is shown in Figures 4-9.

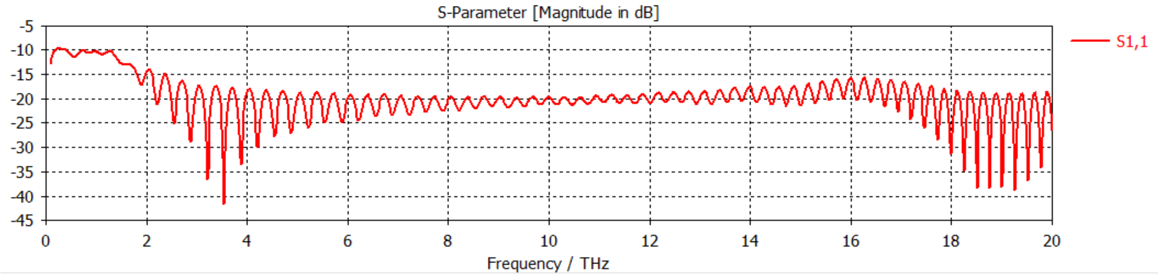


Figure 2. Return loss for graphene antenna

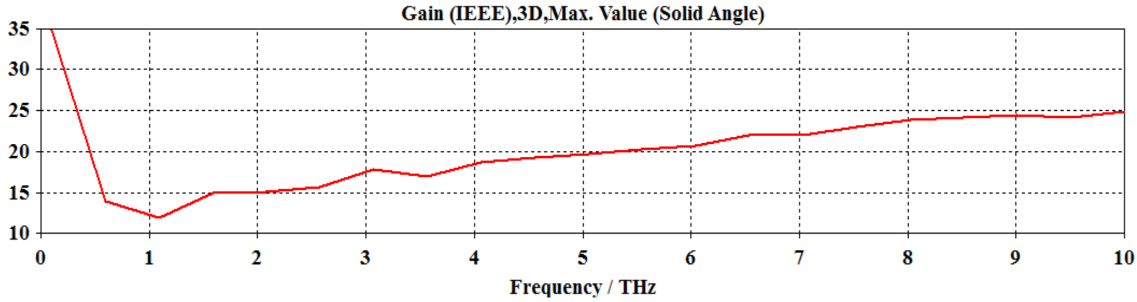


Figure 3. Gain of the proposed antenna

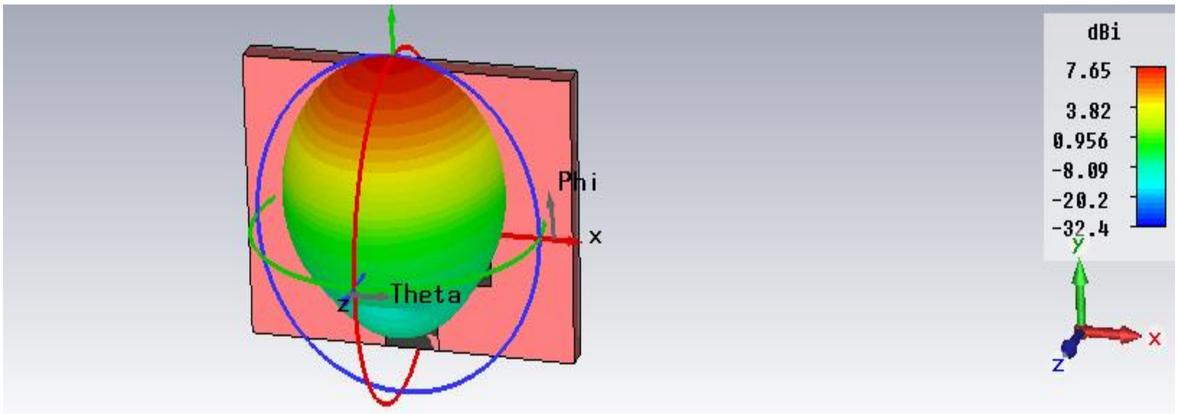


Figure 4. Radiation pattern of the antenna at 0.55 THz

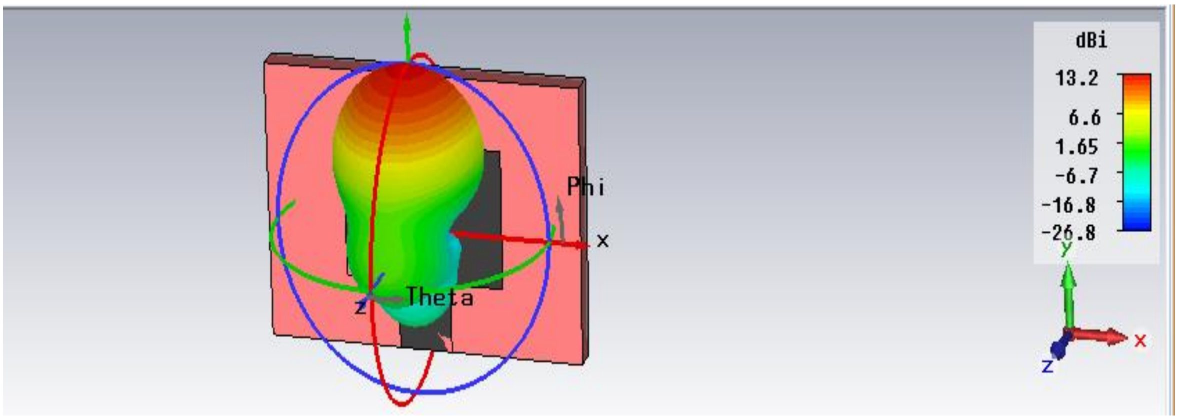


Figure 5. Radiation pattern of the antenna at 1 THz

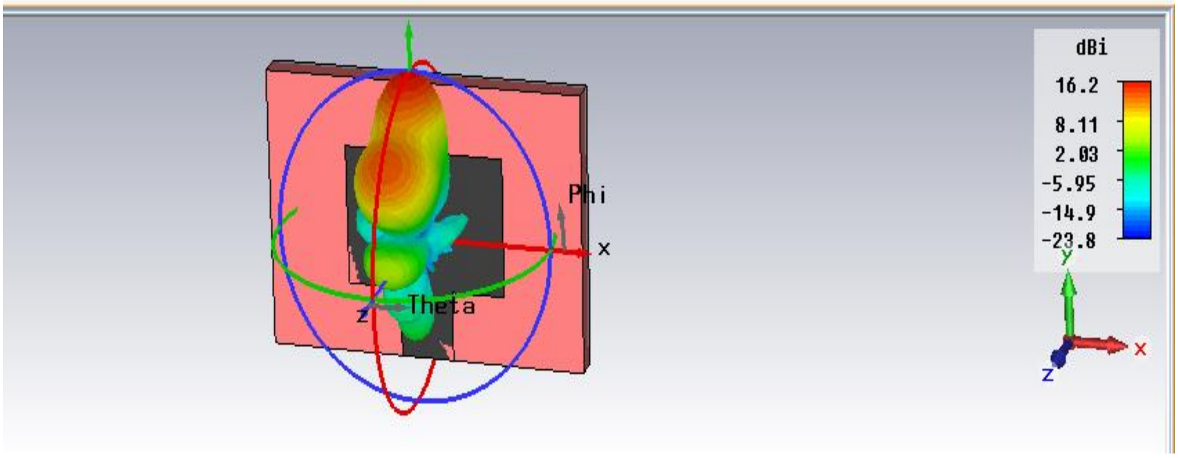


Figure 6. The radiation pattern of the antenna at 2 THz

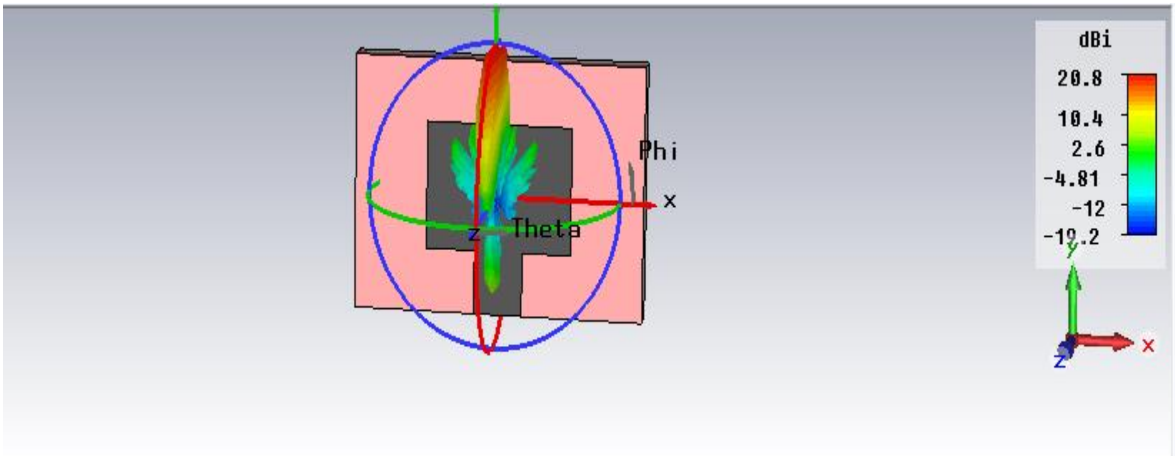


Figure 7. The radiation patterns of the antenna at 5.05 THz

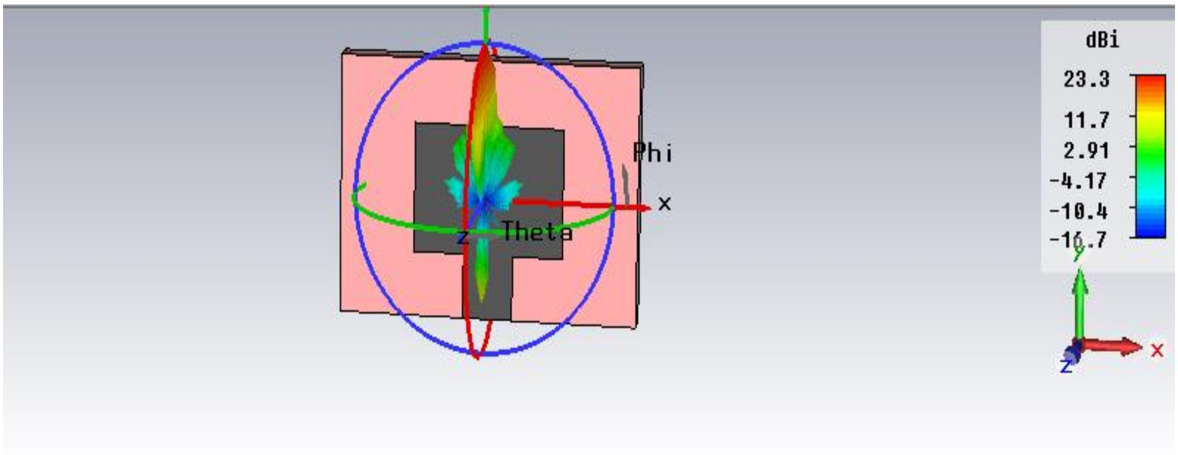


Figure 8. The radiation patterns of the antenna at 8 THz

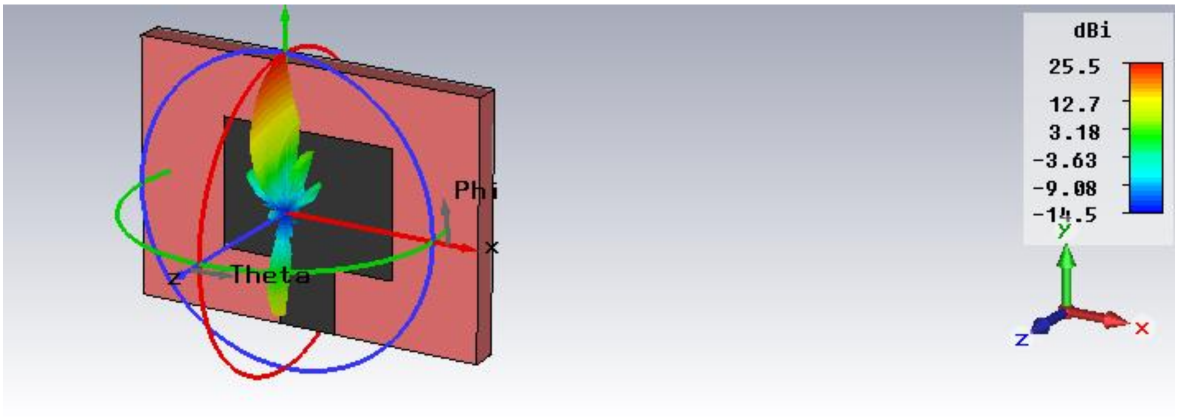


Figure 9. The radiation patterns of the antenna at 10 THz

5. CONCLUSION

This work presents the plasmonic graphene-based antenna, with their main performance are demonstrated in full wave simulations. Graphene supports SPP waves in the lower THz region of the electromagnetic spectrum but not the infrared band. The designed antenna bandwidth is about 0.1-20 THz. Furthermore, the simulation results reveal that the gain of the antenna is about 12-25 dB at this frequency band. The obtained gain is high which makes the antenna promising for communication systems.

ACKNOWLEDGEMENTS

The authors would like to thank the college of Engineering at AL-Mustansiriyah university, Baghdad, Iraq, https://uomustansiriyah.edu.iq/ for their support in preparing this paper.

REFERENCES

[1] A. K. Geim and K. S. Novoselov, "The rise of graphene," *Nature Mat.*, vol. 6, no. 3, pp. 183–191, Apr 2007.
[2] A. N. Grigorenko, M. Polini, and K. S. Novoselov. Graphene plasmonics, *Nature Photon.*, 2012, 487, pp. 749–758.
[3] B. Sensale-Rodr´ıguez, R. Yan, L. Liu, D. Jena, and H. G. Xing. "Graphene for reconfigurable terahertz optoelectronics, " *Proc. IEEE*, vol. 101, no. 7, pp. 1705–1716, Jul 2013.
[4] M. A. Ismail, K. M. M. Zaini, M. I. Syono, "Graphene field-effect transistor simulation with TCAD on top-gate dielectric influences", *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 17, no. 4, pp. 1845-1852, Aug 2019.
[5] S. F. Abd Rahman, N. A. Salleh, M. S. Zainal Abidin, A. Nawabjan, "Humidity effect on electrical properties of graphene oxide back-to-back Schottky diode", *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 17, no.5, pp. 2427-2433, October 2019.
[6] Seyed Arash Naghdehforushha, Gholamreza Moradi, "Plasmonic patch antenna based on graphene with tunable terahertz band communications," *Optik - International Journal for Light and Electron Optics*, vol. 158, pp. 617–622, Apr 2018.
[7] Seyed Arash Naghdehforushha, Gholamreza Moradi, "High directivity plasmonic graphene-based patch array antennas with tunable THz band communications," *Optik - International Journal for Light and Electron Optics*, vol. 168, pp. 440–445, Apr 2018.
[8] F. Rano, "Graphene terahertz plasmon oscillators," *IEEE Transactions on Nanotechnology*, vol. 7, no. 1, pp. 91–99, Jan 2008.
[9] J. T. Kim and C. G. Choi, "Graphene-based polymer waveguide polarizer," *Optics Express*, vol. 29, no. 4, pp. 3556–3562, Feb 2012.
[10] B. Gulbahar and O. B. Akan, "A communication theoretical modeling of single-layer graphene photodetectors and efficient multireceiver diversity combing," *IEEE Transactions on Nanotechnology*, vol. 11, no. 3, pp. 601–610, May 2012.
[11] B. Z. Xu, C. Q. Gu, Z. Li, and Z. Y. Niu, "A novel structure for tunable terahertz absorber based on grapheme," *Optics Express*, vol. 21, no. 20, pp. 23803–23811, Oct 2013.
[12] A. Andryieuski and A. V. Lavrinenko, "Graphene metamaterials based tunable terahertz absorber: Effective surface conductivity approach," *Optics Express*, vol. 21, no. 7, pp. 9144–9155, Apr 2013.
[13] B. Wu, H. M. Tuncer, M. Naeem, B. Yang, M. T. Cole, W. I. Milne, and Y. Hao, "Experimental demonstration of a transparent graphene millimeter wave absorber with 28% fractional bandwidth at 140 GHz," *Scientific Reports*, vol. 4, no. 4130, Feb 2014.

[14] George W. Hanson, "Dyadic Green's functions and guided surface waves for a surface conductivity model of graphene," *Journal of Applied Physics*, vol. 103, no. 6, 2008.
[15] Jornet, C. Han, TeraNets: ultra-roadband communication networks in the terahertz band, *IEEE Wireless Communications*, vol. 21, no. 4, pp. 130–135, 2014.
[16] Seyed Ehsan Hosseininejad, Nader Komjani, Mahmoud Talafi Noghani, "A comparison of graphene and noble metals as conductors for plasmonicone-dimensional waveguides," *IEEE Transactions on Nanotechnology*, vol. 14 no. 5, pp. 829–836, 2015.
[17] Rasha H. Mahdi, R. S. Fyath, "Performance Analysis of Planar Nanocavities-Based Wavelength Demultiplexer for Optical Communication Systems," *International Journal of Computers & Technology*, vol. 11, no. 5, 2013.
[18] Rasha H. Mahdi, R. S. Fyath, "Analytical Framework to Investigate the Performance of WDM Cascade Demultiplexer," *International Journal of Optics and Applications*, vol. 4, no. 3, pp. 92-100, 2014.
[19] Hussein A. Abdulnabi, Refat T. Hussein & Raad S. Fyath, "UWB Single Port Log Periodic Toothed Terahertz Antenna Design Based on Graphene Artificial Magnetic Conductor," *Modern Applied Science*, vol. 11, no. 3, pp. 86-97, 2017
[20] Hussein A. Abdulnabi, Refat T. Hussein and Raad S. Fyath, "0.1-10 THz Single Port Log Periodic antenna design based on Hilbert Graphene Artificial Magnetic Conductor," *ARPN Journal of Engineering and Applied Sciences*, vol. 12, no. 4, 2017.
[21] Hussein A. Abdulnabi, Refat T. Hussein, "Zigzag Edges Toothed Log Periodic Terahertz Antenna Design Based on Graphene Hilbert Curve AMC", *2018 Third Scientific Conference of Electrical Engineering (SCEE)*, 2018.
[22] Hussein A. Abdulnabi, Yasin Yousif Al-Aboosi, "Design of Tunable Multiband Hybrid Graphene Metal Antenna in Microwave Regime," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 12, no. 3, pp. 401-408, 2018.
[23] Sasmita Dash, Amalendu Patnaik, "Graphene Plasmonic Bowtie Antenna for UWB THz Application," *2018 Twenty Fourth National Conference on Communications (NCC)*, 2018.
[24] Sasmita Dash, Amalendu Patnaik, Brajesh K. Kaushik, "Performance enhancement of grapheme plasmonic nanoantennas for THz communication," *IET Microwaves, Antennas & Propagation*, vol. 13, no. 1, 2018.
[25] Seyed Ehsan Hosseininejad, Mohammad Neshat Reza Faraji-Dana, Max Lemme, Peter Haring Bolívar, Albert Cabellos-Aparicio, Eduard Alarcón, Sergi Abadal, "Reconfigurable THz Plasmonic Antenna Based on Few-Layer Graphene with High Radiation Efficiency," *Nanomaterials (Basel)*, vol. 8, no. 8, 2018.