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Dual Graphene Patch Antenna For Ka Band Satellite Applications

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Introduction

Satellite links present very promising techniques to develop many wireless services and this increasing demand for telecommunication services requires us to discover and exploit a new technique that has the criteria of ability to respond and low cost. Antennas have a very important part in the satellite system, which requires us to develop and optimize the operation of these devices.

The traditional planar metallic antenna has several problems such as loss, low bandwidth, and poor radiation performance, moreover, it requires more power to operate at high frequency band (Balans, 2012). Actually, the limitations caused by a metal antenna are minimized by the use of graphene (Castro Neto, Guinea, Peres, Novoselov, & Geim, 2009; Geim & Novoselov, 2009). Grapheme presents an innovative activity since it has a unique structure where the electrons are capable of moving with minimal resistance. This allows electron motion much faster speed than metal, which proposes to implement graphene for satellite applications.

This work presents an introduction to the use of graphene in space technology (Kausar, Rafique, & Muhammad, 2017; Monne, Jewel, Wang, & Chen, 2018) where a rectangular microstrip patch antenna using graphene as the radiating patch is designed by the CST studio (Rütschlin & Tilmann, 2015) on a Rogers RT5880 substrate (Khan & Nema, 2012) to resonate at two resonant frequencies in the Ka band. This is presented as an advantage to use this antenna for transmission and reception for satellite communication systems. By variation on substrate thickenness, an antenna characteristic such as return loss, VSWR, gain, and radiation patterns will be presented to study the response of the proposed antenna in the millimetric bands. See Figure 1.

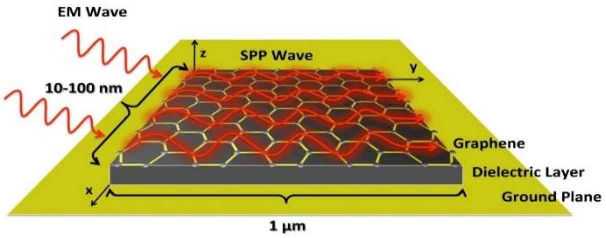

Figure 1. Surface plasmon polariton (SPP) formed on the surface of tiny antennas fabricated from graphene. Adapted from “Graphene-Based Nano-Antennas for Electromagnetic Nanocommunications in the Terahertz Band,” by J. M. Jornet, and I. F. Akyildiz, 2010, *Proceedings of the Fourth European Conference on Antennas and Propagation (EuCAP).*

Graphene mmwaves Characteristics

To model the propagation in graphene, it is necessary to study the conductivity in graphene where the Kubo formula is the most used formula to characterize the conductivity as a function of frequency (Gusynin, Sharapov, & Carbotte, 2006; Qin, Chen, Xie, Xu, & Shi, 2016). The formula of conductivity in graphene without counting the magnetic field is as follows:

$$\sigma(i\omega, \mu_c, \Gamma, T) = -j\frac{q_e^2(\omega+2j\Gamma)}{\pi\hbar^2}\left[\frac{q_e^2}{(\omega+2j\Gamma)^2}\int_0^\infty E\left(\frac{\partial f(E)}{\partial E}-\frac{\partial f(-E)}{\partial E}\right)dE - \int_0^\infty \frac{f(-E)-f(E)}{(\omega+2j\Gamma)^2-\left(\frac{4E}{h}\right)^2}dE\right] \quad (1)$$

Where;

ω is radian frequency,

T is temperature(Kelvin)

μ_c is is the chemical potential of graphene(ev) , controlled by variation of a gate voltage

Γ is the electron scattering rate, related to the relaxation time $\tau = {}^{1}/_{2\Gamma}$

q_e is electron charge,

$\hbar = {}^{h}/_{2\pi}$ is the reduced Planck constant or Dirac constant

$f(E) = \left(e\left[\frac{(E-|\mu_c|)}{K_B T}\right]\right)^{-1}$ is Fermi distribution function ; K_B=1.3806 × 10^{-23} J/K is Boltzmann constant.

For graphene the value of the relaxation time τ = 10^{-13} s,

The intraband term is hence obtained as Eq. (2) (Gusynin, Sharapov, & Carbotte, 2006).

The first segment of the conductivity formula take the intraband electron transition part ,and the second segment present interband electron transition.

$$\sigma(intra) = -j\frac{q_e^2(\omega+2j\Gamma)}{\pi\hbar^2(\omega+2j\tau)}\left(\frac{\mu_c}{K_B T}+2ln\left(e^{-\left({}^{\mu_c}/_{K_B T}\right)}+1\right)\right) \quad (2)$$

Intra-band electrons induce absorption or dissipation of energy which will be presented by the real part of the previous expression(Hanson, 2008).

The simplified expression when taking $\mu_c = 0ev$ (zero electrostatic biasing conditions) and T=300 K (the room temperature) is given as:

$$\sigma(intra) = j\,\frac{q_e^2 K_B T}{\pi \hbar^2(\omega)}(2lin(2)) \tag{3}$$

interband contribution can be simplified, in the case when :$K_B T \ll |\mu_c|$

$$\sigma(inter) \approx \frac{-jq_e^2}{4\pi\hbar^2}\, ln\left(\frac{2|\mu_c|-(\omega-j2\Gamma)\hbar}{2|\mu_c|+(\omega-j2\Gamma)\hbar}\right) \tag{4}$$

Once calculated, the surface conductivity we can be converted to volumetric conductivity to model the antenna since the graphene has the finite thickness. The volumetric conductivity can be obtained by dividing surface equation (2) conductivity on thickness of graphene and is:

$$\sigma(intra, V) = \frac{\sigma(intra, S)}{\Delta(patch\ \text{thickness})} \tag{5}$$

Graphene Ka-Band Antenna Design

The disadvantages of the conventional patch antenna such as narrow bandwidth, low gain, and losses make the use of this type of antenna difficult especially for high frequencies. In addition, the decrease the antenna dimensions of a few micrometers causes a great attenuation with a difficulty of manufacture and implementations in wireless communication systems of nanometric dimensions. As a result, the graphene antenna can resonate at higher frequencies for the same dimensions as a metal patch antenna (Jornet & Akyildiz, 2010).

This section presents the simulation with finite element method (FEM) used by frequency domain solver in CST studio for microstrip line fed square shaped graphene patch antenna. The graphene patch antenna is designed on Rogers RT5880 substrate with permittivity of 2.2 for operating in the Ka band in dual frequency. See Figure 2.

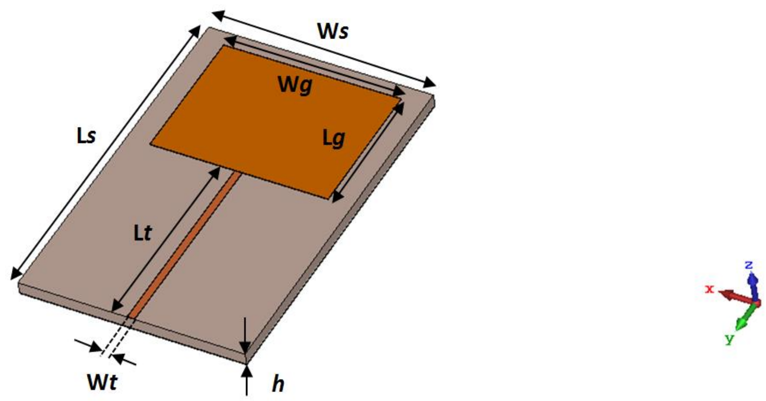

Figure 2.Graphene patch antenna designed in CST studio.

After calculation of patch antenna parameters and feeding, the dimensions are shown in the Table1.

Table 1
Dimensions of the graphene patch antenna

Parameters	Dimensions (*mm*)
Patch length (Lg)	8.72667
Patch width (Wg)	11.86
Substrate length (Ls)	22.28667
Substrate width (Ws)	15
Substrate height (h)	1.588
Microstrip feed length (Lt)	12.56
Microstrip feed width (Wt)	0.5
Patch height	1e-005

The comparison shown in Figure 3 shows that for the same dimensions of the patch of the metallic antenna; the resonance of the antenna is shifted towards the high frequencies for a graphene patch antenna and this due to the unique properties of graphene.

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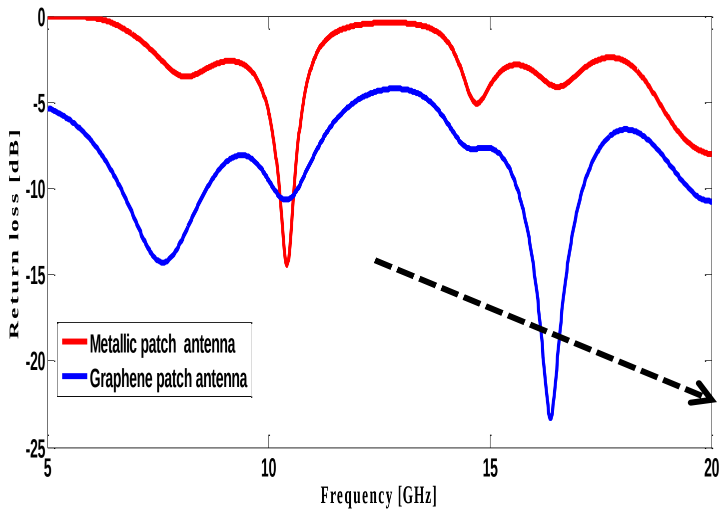

Figure 3. Return loss comparision between metellic and graphne patch.

The comparison shown in Figure 3 further shows that for the same dimensions of the metallic patch antenna, the resonance of the graphene-based antenna is shifted towards a lower frequency of two orders of magnitude frequencies for a metal-based patch antenna. This is due to the unique properties of graphene, as shown by equation 6. In equation 6, the graphene layer allows surface plasmon polariton propagation (SPP). Since a variation in the chemical pontontiel induces wave appearance SPP at the interface with the dielectric layer, the edges of the patch reflect the SPP waves because the air-dielectric interface does not support the SPP wave and the patch can resonate.

The resonant frequency of the graphene patch antenna is calculated is based on the condition of resonance of the antenna combined conventional patch by the SPP wave dispersion relation and it is given by (Llatser, Kremers, Cabellos-Aparicion, & Alarcón, 2012):

$$L_p = L + 2\delta L = \frac{\pi}{\beta} = \frac{\vartheta}{2f_0} \quad (6)$$

L:antenna length

δL : penetration length of the electric field outside the antenna

β : the wave number of SPP waves.

Substrate Variation Effect Study

In this section, the radiation characteristics of Ka band graphene patch antenna are analysed by a variation in substrate heights keeping in view the dual band mode and secure data transfer requirements in the satellite communication systems (Mishra, Kuchhal, & Kumar, 2015). The ease of manufacture of patch antennas makes it possible to make a parametric study for the different heights of commercially available Rogers RT 5880 substrate and for a chemical potential equal to μ_c= 0 ev.

Using the parameters of the patch antenna based on the graph indicate in Table 1, Figure 4 shows the return loss curve for the different substrate heights, and Figure 5 represents the corresponding VSWR values. For a height *h* =1.575 *mm*, it is observed that for resonance frequency f_1 = 20.365 GHz and f_2= 31.285 GHz, we can use two frequencies for satellite communication application where the return losses reaching minimum values of -11.31 dB and -13.33 dB for the frequencies 20.365 GHz and 30.97 GHz respectively.

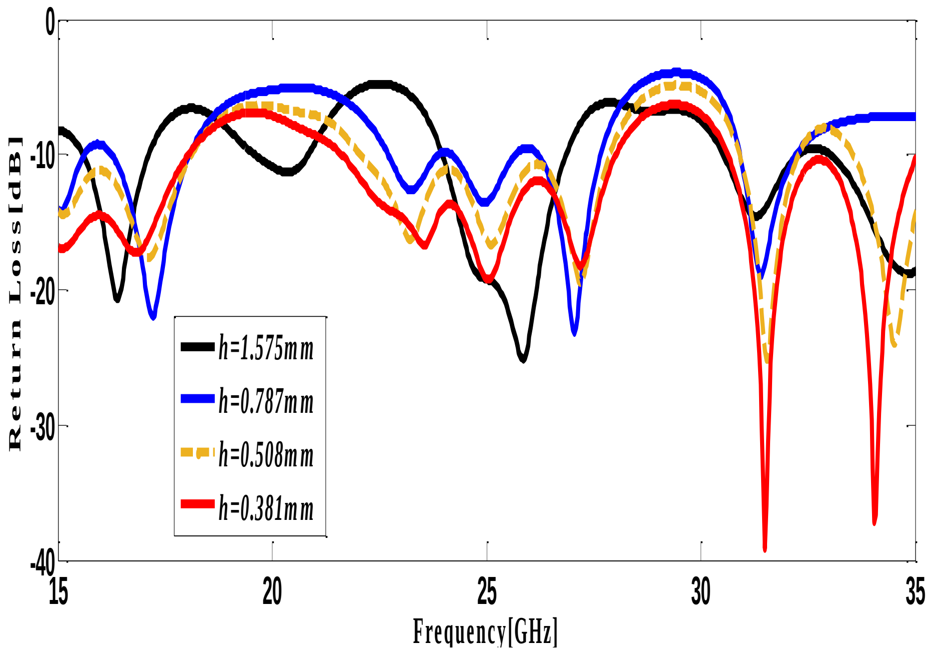

Figure 4. Return loss curves, (a) *h* = 0.381*mm*, (b) *h* = 0.508 *mm*, (c) *h* = 0.787 *mm*, (d) and (e) *h* = 1.575 *mm*.

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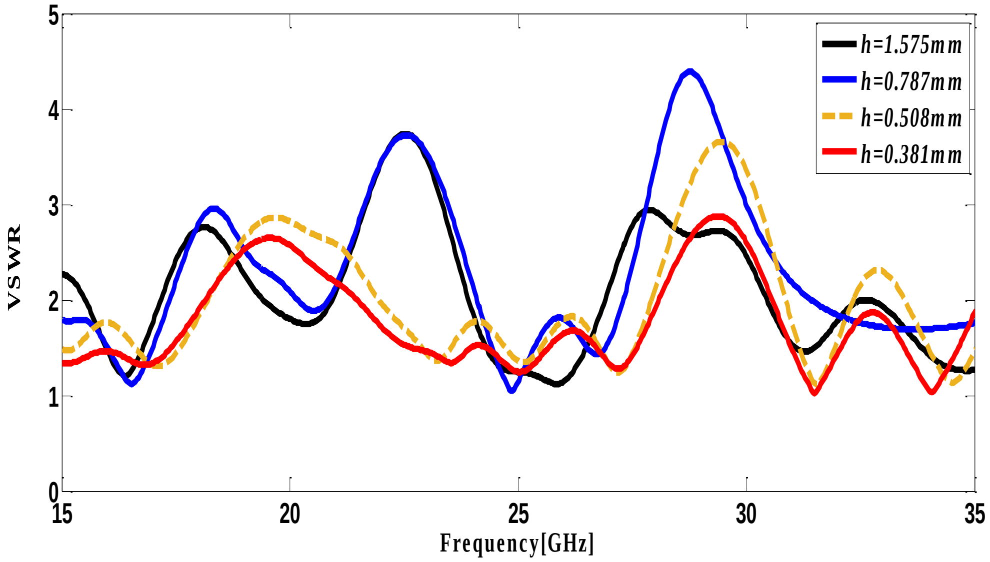


Figure 5. VSWR.a) *h* = 0.381*mm*, (b) *h* = 0.508 *mm*, (c) *h* = 0.787 *mm*, (d) and (e) *h* = 1.575 *mm*

The value of the VSWR for the height *h* = 1.575 *mm* is also interesting since we have values less than 2 especially for the frequencies 20.365 GHz and 30.97 GHz where we obtained 1.75 and 1.55 respectively, which allows us to use these frequencies as a uplink and dowlink frequency for a Ka band satellite link. See Tables 2 & 3.

Table 2

Antenna parameters for diffrents substrats heights for secleted frequency f=20.365 GHz

Substrat heights (mm)	S_{11}(dB)	VSWR	Gain(dBi)
0.381	-9.67	1.98	0.03
0.508	-7.48	2.46	0.5
0.787	-10.07	1.9	3.04
1.575	-11.31	1.75	4.14

Table 3

Antenna parameters for diffrents substarte heights for secleted frequency f=30.97 GHz

Substrate heights (mm)	S_{11}(dB)	VSWR	Gain (dBi)
0.381	-15.61	1.4	2.36
0.508	-10.43	1.86	2.64
0.787	-8.53	2.2	5.01
1.575	-13.33	1.55	6.95

The variation of the gain as a function of the frequency for a height of the substrate h = 1.575 mm will be presented in Figure 6. The gain will reach a maximum value of 6.95 dBi for the frequency of 23.97 GHz.

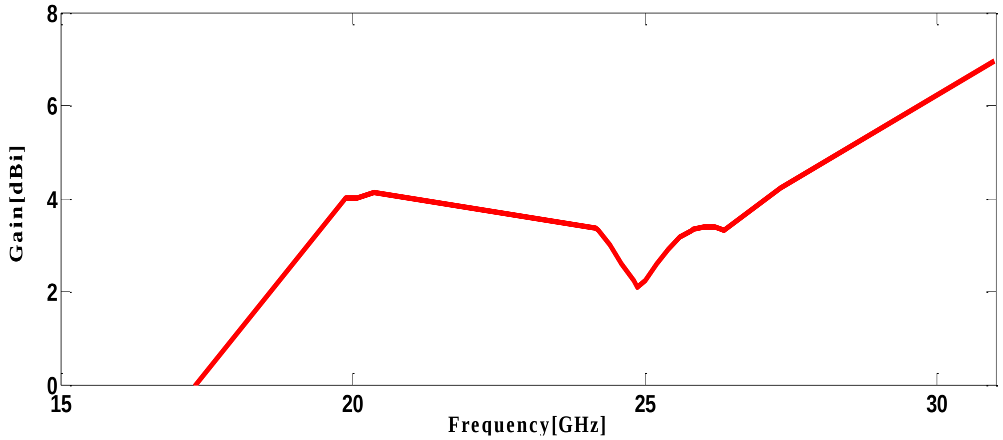
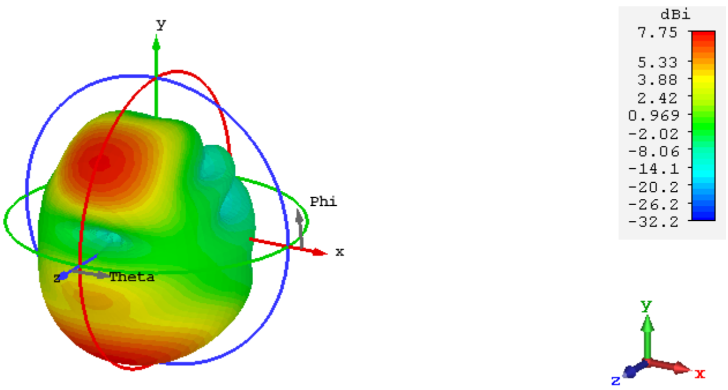
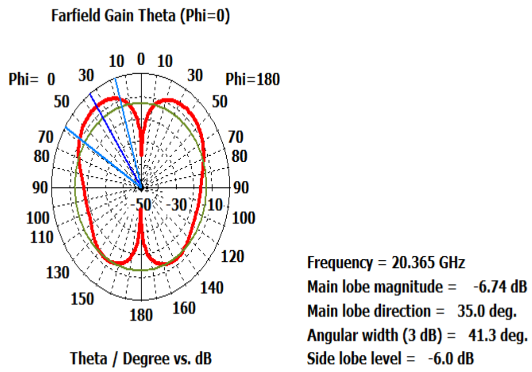


Figure 6. Gain variations for substrate height h=1.575 *mm.*

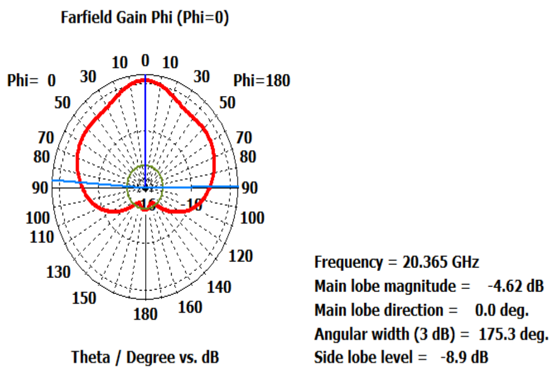
Figures 7 and 8 show the 3D radiation patterns for substrate thickness of 1.575 mm and and antenna parameters cited in table 1 and 2D antenna patern for theta and phi for *f*=20365 GHz and *f*=30.97 GHz.



(a)

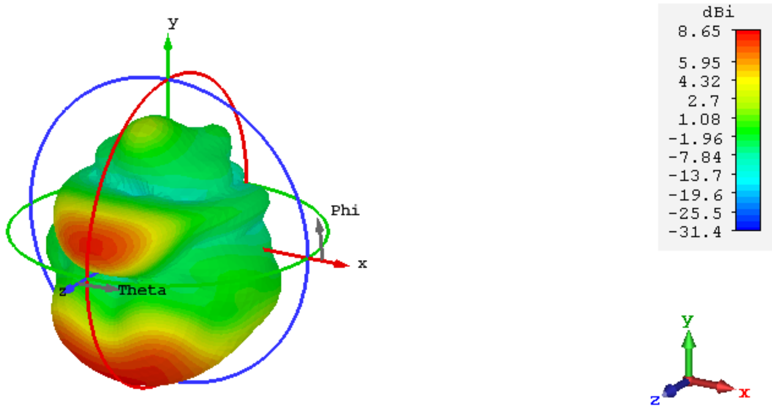


(b)

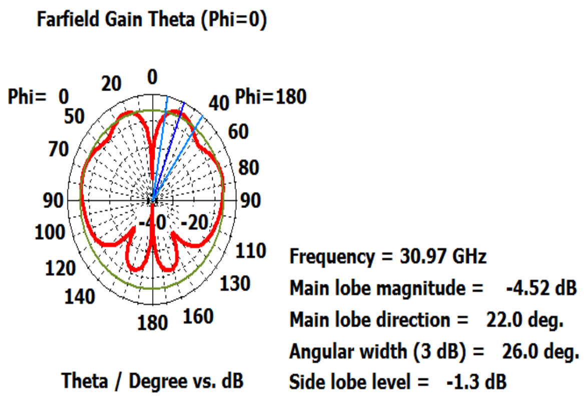


(c)

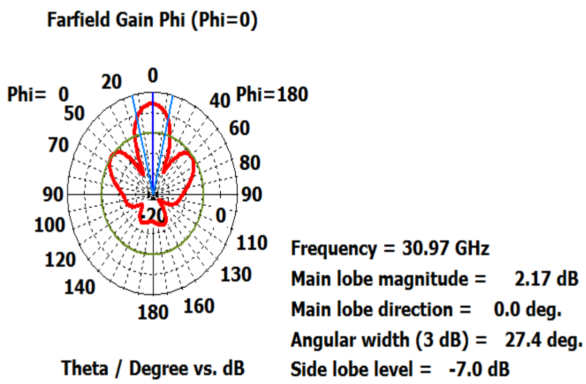
*Figure 7. (*a) 3D radiation pattern at f=20.635 GHz. (b,c) Theta plane and Phi plane pattern at f=20.365 GHz.



(a)



(b)



(c)

Figure 8. 3D radiation pattern at f=30.97 GHz. (b,c) Theta plane and Phi plane pattern at f=30.97 GHz

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It is well noted that for a frequency *f* = 30.97 GHz the gain has a very high value with a concentration of energy in the direction of PHI where the main lobe opening is 27.4 degrees.

Conclusion

The dual graphene patch antenna obtenaid in this work helps us to use a single antenna for two ways communication links in Ka band application especially for satellite application. The designed graphene patch antenna element has a very high gain that can be set up for an antenna array to increase the gain to sufficient satellite link budget.

References

Balanis, C. A. (2012). *Antenna theory analysis and design*. New York, NY:Wiley.

Castro Neto, A. H., Guinea, F., Peres, N. M. R., Novoselov, K. S., & Geim, A. K. (2009). The electronic properties of graphene. *Reviews Of Modern Physics*, *81*(1), 109-162.

Geim, A., & Novoselov, K. (2007). The rise of graphene. *Nature Materials*, *6*(3), 183–191.

Gusynin, V. P., Sharapov, S. G., & Carbotte, J. P. (2006). Magneto-optical conductivity in graphene. *Journal of Physics Condensed Matter*, *19*(2), 026222.

Hanson, G. W. (2008). Dyadic Green's functions and guided surface waves for a surface conductivity model of graphene. *Journal of Applied Physics*, *103*(6), 064302.

Jornet, J. M., & Akyildiz, I. F.(2010). Graphene-based nano-antennas for electromagnetic nanocommunications in the terahertz band. *Proceedings of the Fourth European Conference on Antennas and Propagation (EuCAP)*, Barcelona, Spain. Retreived from https://ieeexplore.ieee.org/document/5505569

Kausar, A., Rafique, I., & Muhammad, B. (2017). Aerospace application of polymer nanocomposite with carbon nanotube, graphite, graphene oxide, and Nanoclay. *Polymer-Plastics Technology and Engineering*, *56*(13),1438-1456.

Khan, A., & Nema, R. (2012). Analysis of five different dielectric substrates on microstrip patch antenna. *International Journal of Computer Applications*, *55*(18), 6-12.

Llatser, I., Kremers, C., Cabellos-Aparicion, A., & Alarcón, E. (2012). Comparison of the resonant frequency in graphene and metallic nano-antennas. *The Fifth International Workshop on Theoretical and Computational Nano-Photonics*. doi: 10.1063/1.4750123

Mishra, R., Kuchhal, P., & Kumar, A. (2015). Effect of height of the substrate and width of the patch on the performance characteristics of microstrip antenna. *International Journal of Electrical and Computer Engineering*, *5*(6), 1441-1445.

Monne, M. A., Jewel, M. U., Wang, Z., & Chen, M. Y. (2018).Graphene based 3D printed single patch antenna. *Proceedings of the Low-Dimensional Materials and Devices conference*, San Diego, CA: 107250C. https://doi.org/10.1117/12.2323546

Qin, X., Chen, J., Xie, C., Xu, N., & Shi, J.(2016). A tunable THz dipole antenna based on graphene. *IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP).* Chengdu, China. 1-3.

Rütschlin, M., & Tilmann,W. (2015). State of the art antenna simulation with CST STUDIO SUIT. *Proceedings of the 9th European Conference on Antennas and Propagation (EuCAP)* in Lisbon, Portugal 2015.