High bandwidth triple-band Microstrip Patch Antenna for THz Application

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ABSTRACT *To meet demands of the future realization, new progresses in communication systems require a low-cost, light-weight, low-profile, and high-performance antenna. In this paper triple-band microstrip patch antennas (MPAs) is proposed and designed for THz applications. The proposed antenna has the dimensions of 56.8x 66.8x 5pm3, uses Quartz-glass as a substrate material with a loss tangent =0 and thickness of 5 pm Partial ground technique is implemented to improve the return loss and bandwidth of proposed antenna. This obtains bandwidth of 140, 700 and 410 GHz with return loss of -19.3, -29.2 and - 22.5 dB at resonant frequencies 2.5 THz, 4 THz, and 5.4 THz respectively. The proposed antenna has been fed by means of microstrip feed line having impedance of 50 Ω. The results of antenna designed are suitable for THz applications. Higher Frequency Structural Simulator (HFSS v13) tool is used to simulate the proposed antenna*.

INDEX TERMS

terahertz, MPA, triple-band

1. INTRODUCTIONS

The number of users and their services in the wireless communication are expected to grow rapidly in response to consumer demands [1]. The data transmission speed would continue to increase as higher frequencies of microwave spectrum are exploited, and future generations of communication will need speeds of 10-100Gbps to meet the increasing demand [2]. To satisfy this speed demand, the exploitation of the terahertz band is going to be crucial [2]. This band ranges from 100 GHz to 10 THz and between microwave and mid-infrared spectrum [3]. THz waves combine the advantages of light and mm-waves. Compare to mm-waves, the usable frequency band is wider than Mm- waves, also, the beam is directional and very narrow, the confidentiality is higher and anti-interference performance is better [4]. Additional terahertz advantages such as higher speed, very high resolution, wider bandwidth, and size miniaturization of devices make the terahertz band is discovering applications in the domain of agriculture [6], wireless network-on-chip (WNoC) [5], medical biological and applications [7] and metal characterization [8].

Miniaturized antennas which able to transmit and receive at high data rates, broad bandwidth, low transmission power, and high spatial resolution are needed for THz frequencies [9]. So there are many types of antennas such as wideband horn antenna [10], leaky-wave antenna [11], Yagi-Uda antenna [12], bow-tie antenna [13], log-periodic antenna [14], and MEMS antenna [15] have been developed for terahertz band applications. However, despite these benefits of THz advantages, THz has drawbacks, including absorption when transmitted in space. Furthermore, due to their small sizes, most THz antennas, such as previous types, suffer from low fabrication precision and high loss, as well as a complication in structure design in high THz frequencies. Also, the performance and efficient of THz antennas does have a direct impact on the overall system's quality, chiefly the gain and bandwidth of the antennas [4]. therefore, design MPA with wide bandwidth, high gain, and simplicity in the structure are needed to overcome previous problems.

The triple-band MPA is preferable in most wireless network applications because of its attractive benefits such as reduced cost and system complexity using a single element antenna for different operating frequencies. This antenna has a great interest in 6G wireless network applications due to the capabilities of providing high data rate and capacity that meet a variation of services and application in the sixth generation [16].

Several research papers have been published on single and triple-band microstrip antenna for THz wireless communications [21-24]. In [21] a single and compact sized antenna operating at THz band is proposed. The gain and return loss of this antenna are both lower, but the bandwidth is wide. According to works [22-23], the designed antenna is good in all terms off gain and bandwidth and return loss.

For THz wireless applications, a dual-band microstrip patch antenna is proposed in this work. The proposed antenna is simple in structure, better gain, and efficient bandwidth as compared with reference antennas. Table 2 shows the comparison between the above works with the proposed antenna

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2. Proposed Patch Antenna

The compact size of the microstrip patch antenna structure with both the bottom and top plane is represented in Fig.1. with their dimensions. The substrate material of the proposed antenna is quartz-glass (=3.78) with the smallest value of loss tangent (a = 0) and thickness of 5 ^m, and the copper is used as the perfect conductor of the radiated patch and partial ground with 1 ^m in thickness. The overall thickness of the proposed antenna is 7 ^m. The feed line method is chosen for the proposed design. The width of the feed line to achieve the matching with 50 Q transmission line impedance is 2.5 ^m with length of 15.6 ^m. 26.8 and 36.8 ^m represent the length and the width of the proposed patch antenna design, respectively. The dimensions of substrate material are 56.8 ^m *66.8 pm for length and width respectively. The dimensions of the proposed antenna are illustrated in Table 1.

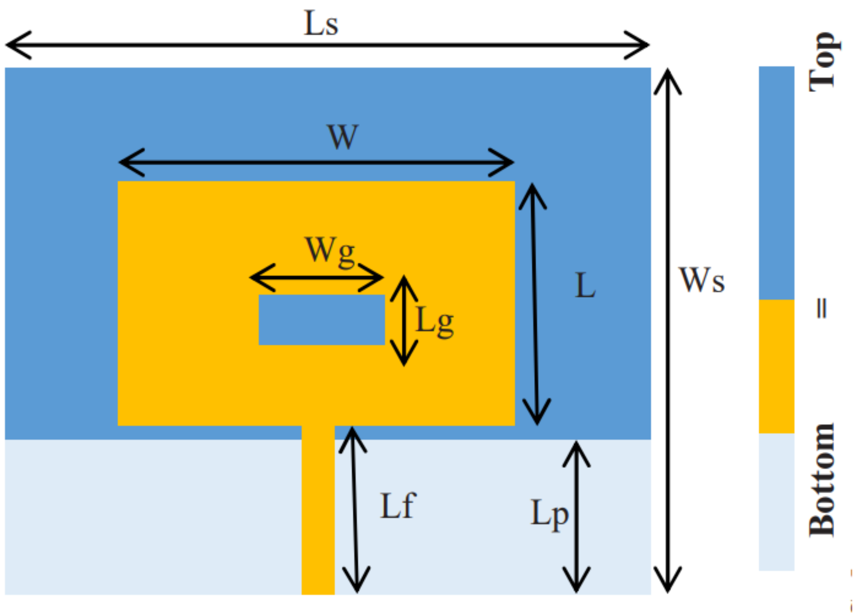

Figure 1. Top view of proposed Microstrip Antenna

Figure 2. Side view proposed Microstrip Antenna

TABLE 1. Dimensions Of Designed Patch Antenna

	Parameter	Dimension
Design	Resonant Frequency	2.5, 4, 5.4 THz
	Dielectric constant	3.78
Rectangular patch	Length of patch (L)	26.8 μm
	Width of patch (W)	36.8 μm
	Patch / Feed thickness (t)	1 μm
Feed	Feed length (Lf)	15.6 μm
	Feed width (wf)	2.5 μm

Substrate plane	Length of plane(Ls)	56.8 μm
	Substrate Thickness (hs)	5 μm
Gap	Width of plane (Ws)	66.8 μm
	Length of gap (Lg)	6 μm
Partial ground	Width of gap (wg)	15 μm
	Length (Lp)	14.8 μm

3. METHODOLOGY OF DESIGN

For the proposed design, the HFSS simulator is used to design the antenna and show the simulated results. The design was done in some steps. The transmission line model with its basic equations is used to determine the dimension of the proposed design. The dimensions are about length and width of radiated patch and thickness, width and length of substrate material. The design equations [17-20] are stated in the following:

$$h = \frac{0.0606\lambda}{\epsilon_r} \quad (1)$$

$$W = \frac{c}{2f_r}\left(\sqrt{\frac{2}{\epsilon_r+1}}\right) \quad (2)$$

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left\{1 + 12\frac{h}{W}\right\}^{-0.5} \quad (3)$$

$$L = L_{eff} - 2\Delta L \quad (4)$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} \quad (5)$$

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (6)$$

$$L_s = L + 6h \quad (7)$$

$$W_s = W + 6h \quad (8)$$

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

$$\lambda_g = \frac{\lambda}{\sqrt{\epsilon_{reff}}} \quad (10)$$

Where:
h: substrate thickness
λ: Wavelength
ϵ_r: Dielectric constant
ϵ_{reff}: effective Dielectric constant
W: width of the patch
L: length of the patch
L_{eff}: effective length of the patch
L_s: substrate length
W_s : substrate width

To improve the results of the proposed antenna some techniques must be used in the design. The partial ground is used in this design to the return loss and bandwidth parameters enhancement. Fig.3 show the return loss and bandwidth before using The partial ground and the effect of the partial ground is introduced in results analysis section. As the improvement of the bandwidth and return loss is required, the improvement of the gain is also required. The gap technique is presented in this design to achieve a good result of gain for the THz antenna. The gap is not make clear effect on reflection coefficient. Fig.4 show the results of reflection coefficient before the gap and fig.5 in the result section is show the result after using the gap. To get the final results, the gap along the patch is made then decreasing in the length and width of the gap with the same ratio of the patch until reach to the good results. The gap is located at the center of the patch with length and width as introduced in the previous section.

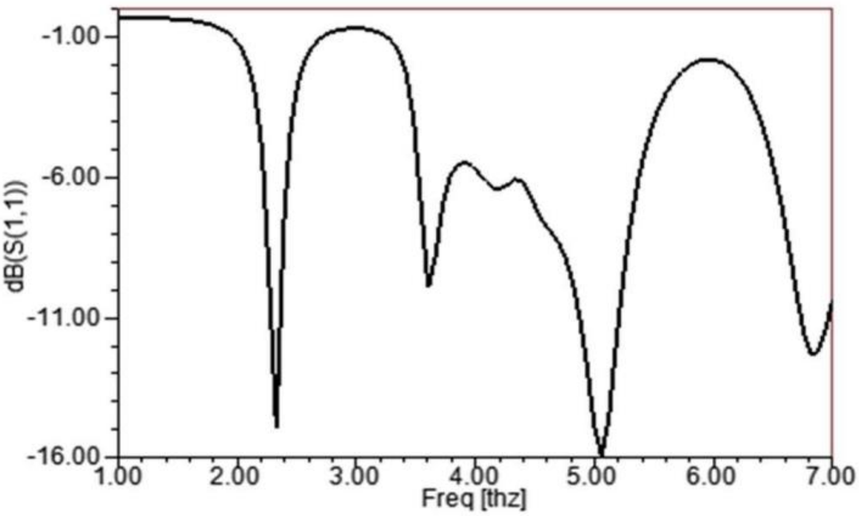

Figure 3. **Return Loss (S11) in dB of the proposed design before partial ground**

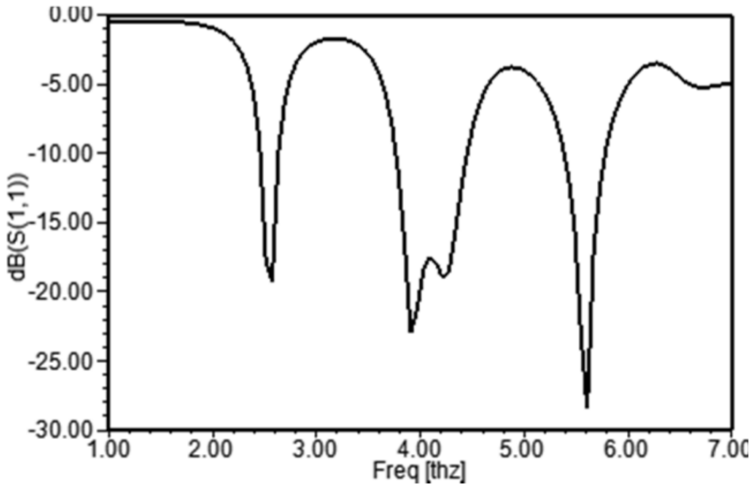

Figure 4. **Return Loss (S11) in dB of the proposed design before gap**

4. RESULTS ANALYSIS

The simulated results from HFSS software are introduced in this section. As shown in Fig.4 and Fig.5, the proposed antenna works in three bands which their center frequencies are 2.5, 4 and 5.4 THz with return loss -19.3, -29.2 and -22.5 dB respectively. The total bandwidth is 1250 GHz which is divided into 140, 700 and 410 GHz for 2.5, 4 and 5.4 THz bands respectively.

Fig.6 illustrates the gain for three bands. As shown in the figure, the maximum gain is achieved in the band 5.4 THz with a value of 6.8 dB. The other bands 2.5 and 4 THz has gain with value 6.1 and 6.3 dB respectively. The gain is improved to these values by using gap tech as introduced in the methodology section. Fig.7 shows the results of the radiation pattern of three bands for the E-plane and H-plane. The comparative analysis of the proposed antenna with previous works is introduced in Table 2.

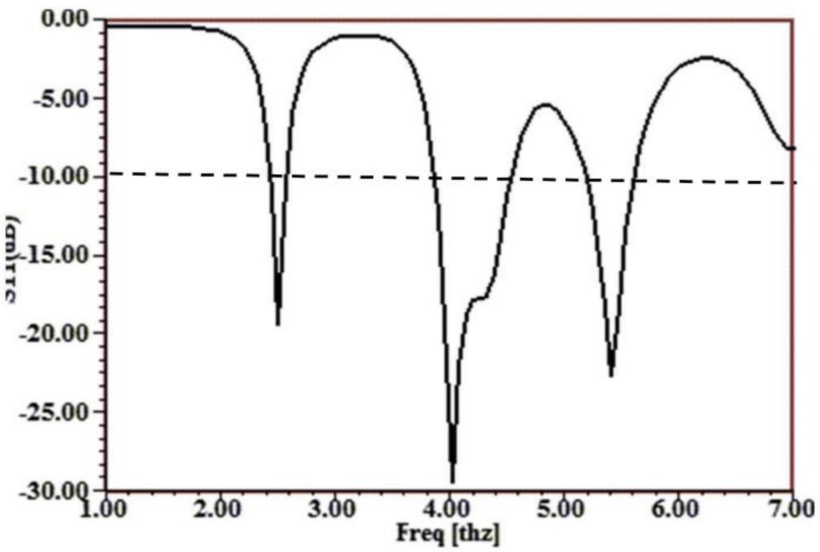

Figure 5. **Return Loss (S11) in dB of the proposed design**

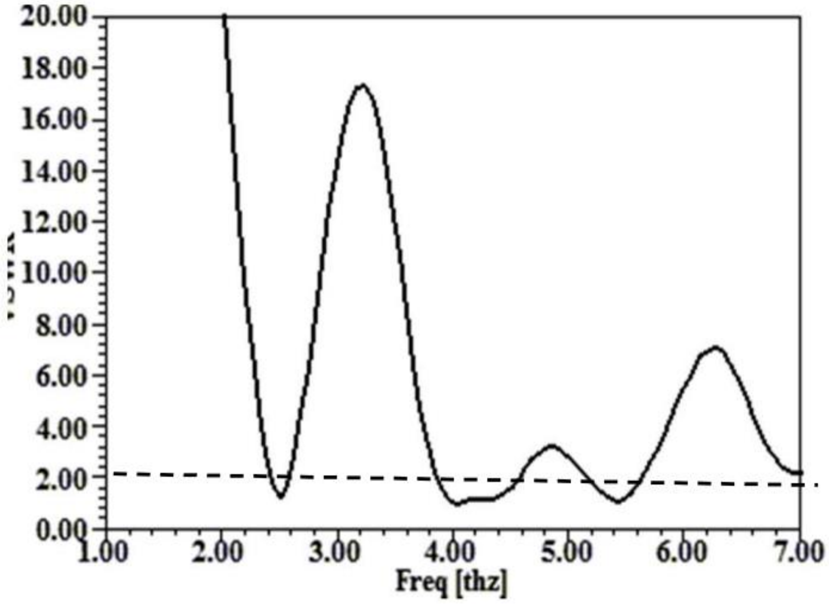

Figure 6. **VSWR of the proposed design**

TABLE 2. DIMENSIONS OF DESIGNED PATCH ANTENNA

Frequency (THz)	**S11(dB)**	**Bandwidth (GHz)**	**M. Gain** (dB)
2.6	- 27	145.4	2.8
5.491	- 48.8	231.3	4.06
7.32	- 50.7	371	6.33
0.5,0.85,1.65	-	1250	2.2,3.4,5.72
2.5,4,5.4	-	1250	6.1,6.33.6.9

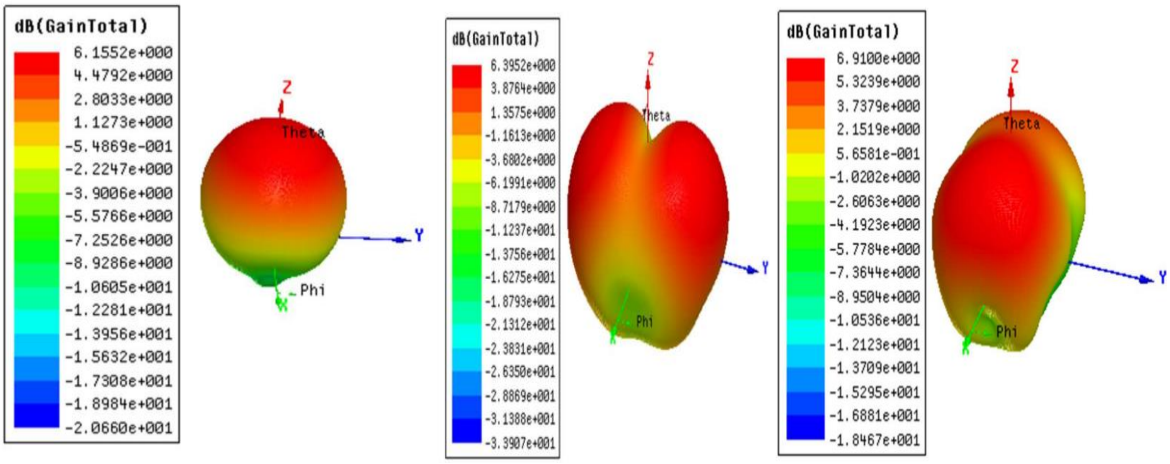

Figure 7. **total gain (a) 2.5 THz, (b) 4 THz and (c) 5.4 THz frequencies**

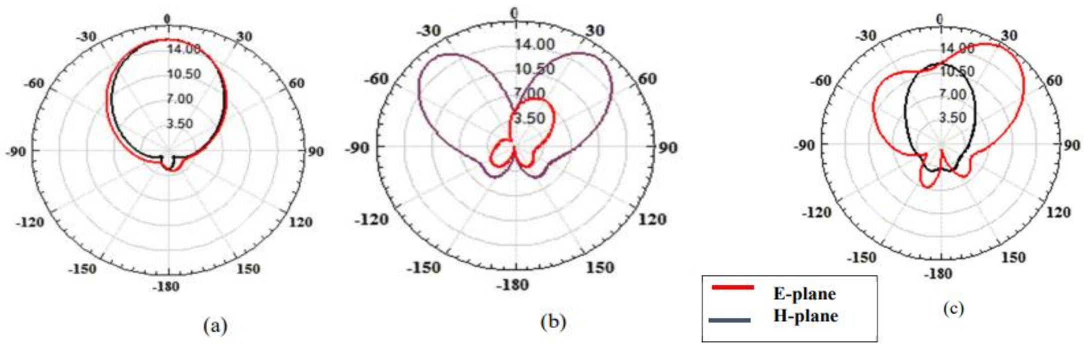

Figure 8. **Radiation pattern of E-plane and H-plane (a) 2.5THz, (b) 4THz and (c) 5.4 THz frequencies**

5. CONCLUSIONS

Design a directional microstrip patch antenna with high gain is one of challenges in THz communication. So in this paper, a simple structure, dual-band and compact microstrip patch antenna is presented. The simulated results of the proposed design are also presented. The partial ground technique is implemented to the performance improvement of the antenna in term of return loss and bandwidth. In addition, the improvement of the gain results is achieved by the gap which located at the center of the patch. Medical applications, communications and space communication in the THz frequency band this antenna suitable for. Therefore, The proposed antenna is applicable to 6G antennas for nano-scale THz applications.

REFERENCES

[1] Song, Ho-Jin, and Tadao Nagatsuma. "Present and future of terahertz communications." IEEE transactions on terahertz science and technology 1.1 (2011): 256-263.

[2] Koenig, S., Lopez-Diaz, D., Antes, J., Boes, F., Henneberger, R., Leuther, A., Tessmann, A., Schmogrow, R., Hillerkuss, D., & Palmer, R. (2013). Wireless sub-THz communication system with high data rate. Nature Photonics, 7(12), 977-981.

[3] Akyildiz, I. F., Jornet, J. M., & Han, C. (2014). Terahertz band: Next frontier for wireless communications. Physical Communication, 12, 16-32.

[4] He, Y., Chen, Y., Zhang, L., Wong, S.-W., & Chen, Z. N. (2020). An overview of terahertz antennas. China Communications, 17(7), 124165.

[5] Li, B., Long, Y., Liu, H., & Zhao, C. (2018). Research progress on Terahertz technology and its application in agriculture. Transactions of the Chinese Society of Agricultural Engineering, 34(2), 1-9.

[6] Deb, S., Ganguly, A., Pande, P. P., Belzer, B., & Heo, D. (2012). Wireless NoC as interconnection backbone for multicore chips: Promises and challenges. IEEE Journal on Emerging and Selected Topics in Circuits and Systems, 2(2), 228-239.

[7] Nishizawa, J., Sasaki, T., Suto, K., Yamada, T., Tanabe, T., Tanno, T., Sawai, T., & Miura, Y. (2005). THz imaging of nucleobases and cancerous tissue using a GaP THz-wave generator. Optics Communications, 244(1-6), 469-474.

[8] Naftaly, M., Foulds, A. P., Miles, R. E., & Davies, A. G. (2005). Terahertz transmission spectroscopy of nonpolar materials and relationship with composition and properties. International Journal of Infrared and Millimeter Waves, 26(1), 55-64.

[9] Khan, M. A. K., Ullah, M. I., Kabir, R., & Alim, M. A. (2020). High- Performance Graphene Patch Antenna with Superstrate Cover for Terahertz Band Application. Plasmonics, 15, 1719-1727.

[10] Gonzalez, A., Kaneko, K., Kojima, T., Asayama, S., & Uzawa, Y. (2016). Terahertz Corrugated Horns (1.25${\hbox {--}} $1.57 THz): Design, Gaussian Modeling, and Measurements. IEEE Transactions on Terahertz Science and Technology, 7(1), 42-52.

[11] Mak, K.-M., So, K.-K., Lai, H.-W., & Luk, K.-M. (2017). A magnetoelectric dipole leaky-wave antenna for millimeter-wave application. IEEE Transactions on Antennas and Propagation, 65(12), 6395-6402.

[12] Han, K., Nguyen, T. K., Park, I., & Han, H. (2010). Terahertz Yagi- Uda antenna for high input resistance. Journal of Infrared, Millimeter, and Terahertz Waves, 31(4), 441-454.

[13] Alharbi, K. H., Khalid, A., Ofiare, A., Wang, J., & Wasige, E. (2016). Diced and grounded broadband bow-tie antenna with tuning stub for resonant tunnelling diode terahertz oscillators. IET Microwaves, Antennas & Propagation, 11(3), 310-316.

[14] Abdulnabi, H. A., Hussein, R. T., & Fyath, R. S. (2017). 0.1-10 thz single port log periodic antenna design based on hilbert graphene artificial magnetic conductor. ARPN Journal of Engineering and Applied Sciences, 12(4).

[15] Guo, L., Huang, F., & Tang, X. (2014). A novel integrated MEMS helix antenna for terahertz applications. Optik, 125(1), 101-103.

[16] Rappaport, T. S., Heath Jr, R. W., Daniels, R. C., & Murdock, J. N. (2015). Millimeter wave wireless communications. Pearson Education.

[17] Nandalal, V., Kumar, V. A., Sumalatha, M. S., & Manikandan, T.

[18] (2019). Performance Evolution of Reconfigurable Antenna Using Contact and Non Contact Feeding Technique. 2019 3rd International Conference on Electronics,Communication and Aerospace

[19] Technology (ICECA), 952-954.

[20] Al-hetar, A. M., & Aqlan, E. A. (2021 March). High Performance & Compact Size Of Microstrip Antenna For 5G application. In 2021 international conference of Technology, Science and Adminisration (ICTSA) (pp. 1-3). IEEE.

[21] Nandalal, V., Kumar, V. A., Sumalatha, M. S., & Manikandan, T.

[22] (2019). Performance Evolution of Reconfigurable Antenna Using Contact and Non Contact Feeding Technique. 2019 3rd International Conference on Electronics,Communication and Aerospace

[23] Technology (ICECA), 952-954.

[24] Sarkar, B. D., Shankar, S., Thakur, A., & Chaurasiya, H. (2015). Resonant frequency determination of rectangular patch antenna using Neural Network. 2015 1st International Conference on Next Generation Computing Technologies (NGCT), 915-917.

[25] George, J. N., & Madhan, M. G. (2017). Analysis of single band and dual band graphene based patch antenna for terahertz region. Physica E: Low-Dimensional Systems and Nanostructures, 94, 126-131.

[26] Khan, M. A. K., Shaem, T. A., & Alim, M. A. (2019). Analysis of graphene based miniaturized terahertz patch antennas for single band and dual band operation. Optik, 194, 163012.

[27] Khan, M. A. K., Shaem, T. A., & Alim, M. A. (2020). Graphene patch antennas with different substrate shapes and materials. Optik, 202, 163700.

[28] Davoudabadifarahani, H., & Ghalamkari, B. (2019). High efficiency miniaturized microstrip patch antenna for wideband terahertz communications applications. Optik, 194, 163118

[29] Shaddad, R. Q., Saif, E. M., Saif, H. M., Mohammed, Z. Y., & Farhan, A. H. (2021, August). Channel Estimation for Intelligent Reflecting Surface in 6G Wireless Network via Deep Learning Technique. In 2021 1st International Conference on Emerging Smart Technologies and Applications (eSmarTA) (pp. 1-5). IEEE

[30] Black, E., Katko, A., &Ilic-Savoia, A. Breaking Down mmWave Barriers with Holographic Beam Forming (R). MICROWAVE JOURNAL, 63(2), 22-34 (2020)

[31] Ohira, T., Suzuki, Y., Ogawa, H., & Kamitsuna, K. (1997). Megalithic microwave signal processing for phased-array beamforming and steering. IEEE transactions on microwave theory and techniques, 45(12), 2324-2332

[32] Mokal, M. V., Gagare, P. S., & Labade, D. R. (2017). Analysis of Micro strip patch Antenna Using Coaxial feed and Micro strip line feed for Wireless Application. IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) e-ISSN, 2278-2834

[33] Zhang, X., Zhang, Q., Chen, C., Chen, W., Liu, B., & Cai, J. (2018, November). Design of Holographic Metasurface for Antenna Beam Steering Based on Liquid Crystal Technology. In 2018 Asia-Pacific Microwave Conference (APMC) (pp. 1372-1374). IEEE.

[34] Yurduseven, O., Marks, D. L., Fromenteze, T. & Smith, D. R. Dynamically reconfgurable holographic metasurface aperture for a mills-cross monochromatic microwave camera. Opt. Express 26, 5281–5291 (2018)