Kurdistan Journal of Applied Research (KJAR)
Print-ISSN: 2411-7684 | Electronic-ISSN: 2411-7706

Website: Kjar.spu.edu.iq | Email: kjar@spu.edu.iq

Terahertz Microstrip Patch Antennas For The Surveillance Applications

Rashad Hassan Mahmud
Physics Department
College of Education
Salahaddin University
Erbil, Iraq
rashad.mahmud@su.edu.krd

Article Info

Volume 5 – Issue 1 – June 2020

DOI: 10.24017/science.2020.1.2

Article history:

Received: 13 February 2020
Accepted: 06 April 2020

Keywords:

Microstrip patch antenna, Terahertz frequency band, Multilayer technique, Large bandwidth, Surveillance applications.

ABSTRACT

This paper presents a new design of the microstrip patch antenna operated at the terahertz frequencies (700-850 GHz). The conventional microstrip patch antenna dimensions shrink to a few microns when operating at such terahertz frequencies. Thus, the design of the patch and its feeding network will be miniaturized extremely, and their fabrications would be extremely difficult. In this paper, the configuration of the proposed microstrip patch antenna is suited in a way that it can be modelled using multilayers structure. This multilayer structure facilitates the modeling, and considering its fabrication. The proposed microstrip antenna has been designed using three layers. The top layer is used to model the rectangular patch; while the second layer is for the substrate, and the bottom layer is for the ground plane. The physical dimensions of the layers and the fed-line are optimised using the microwave Computer Simulation Technology (CST) simulator in order to enhance the electrical parameters of the antenna such as antenna realised gain, bandwidth, total and radiation efficiencies, and radiation patterns. In addition to that, the impact of the physical dimensions of the rectangular patch on controlling the resonant frequency of the dominant mode (TM_{01}) have been investigated. Keeping the lower and higher propagating modes out of the frequency band of interest is another aspect which has been addressed in this paper. The antenna has been simulated, and its realised gain fluctuates from 6.4 dBi to 9.7 dBi over the operating frequency range (700-850 GHz). Also, it provides extremely large reflection coefficient bandwidth (S11) which it is below -10 dB over the entire operating

frequency band. The total efficiency is more than 75 %. Due to its simplicity and providing large bandwidth, the proposed antenna could be of interest in many security and surveillance applications.

1. INTRODUCTION

Terahertz frequencies band and terahertz communication components are being the subject to research in the last decades due to the demands for a large bandwidth not only in the fields of astronomy and science [1, 2], but also in security and surveillance applications [3]. Usually, multiple reflectors in the surveillance systems are employed when operating at low frequencies to detect hazard materials and explosives. Operating the system at terahertz frequencies could introduce some unique features to the system. For instance, the terahertz frequencies can penetrate different types of materials and belongings [4], and this could be beneficial for the system to scan the object. Also, the photo resolution is extremely high when "terahertz radiography" is used due to the inverse relation of resolution with the wavelength [4]. Figure 1 shows a terahertz photo taken for a closed box containing some plastic and metallic items. All the items can be recognized easily without opening the box. This property of terahertz frequencies could be useful in the airports and train stations to check the passenger bags and belongings without the need of opening.

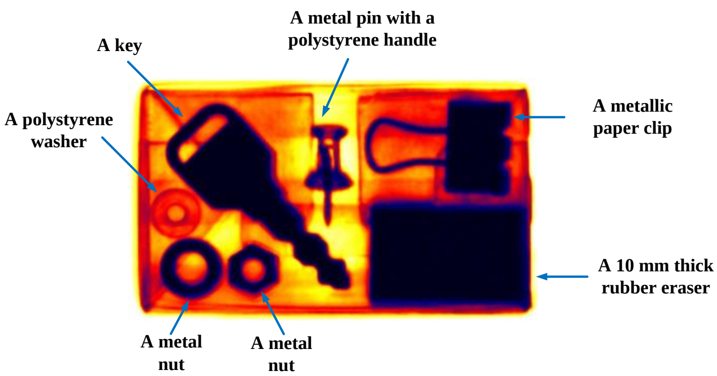


Figure 1: A closed cardboard box taken by terahertz radiography [4].

Another advantages of the terahertz frequencies and terahertz spectrum is the availability of a larger bandwidth as pointed out before. This could fulfill the demand of users of wireless systems to transmit or receive varieties of information simultaneously like texts, video, animations and so on [5]. The increasing of data rate capability of a system is another reason which encourage the researchers to focus on terahertz communication systems and its components [6-11].

When talking on a terahertz communication system, the first issue faces the researchers is the high value of free path loss [4] which degrades the transmission/reception of the signals over a long-distance communication coverage. Employing a high gain and wide bandwidth antenna could minimize the free space path loss issue [5].

There are several limitations regarding the high gain antenna designs when operating at terahertz frequencies. One of the limitations is the physical dimensions which will be minimized extremely. Thus, the design of an antenna, which can be fabricable with the presence technique, would be a challenge. There are several techniques presented in the literature in order to facilitate and fabricate the design of terahertz antennas. The silicon micromachining was utilized in [12] to design and fabricate a travelling wave rectangular waveguide antenna at 23-245 GHz. Also, the metal deposition process was used in the fabrication of a corrugated rectangular waveguide at frequencies 130-180 GHz [13]. A reconfigurable loop antenna operated at terahertz frequencies was designed using the graphene metal approach [14]. There is another technique with high precision for the design of terahertz components, which is named micromachined SU-8 layers technique. Many terahertz components were designed and made using that technique [15-19]. Also, we used the SU-8 layer technique to design a travelling wave slotted waveguide antenna [15], and an 8×8 planar array slotted waveguide antennas [20] which were both operated at 220-325 GHz. More details regarding the SU-8 layer technique is given in the following.

The SU-8 is a kind of polymer which is bulky and act as insulator. In order to use SU-8 layers in the fabrication of any terahertz components like an antenna, they are to be coated by a conductor like silver or gold as detailed in [15, 18]. Based on the previous designs [15, 20], the SU-8 layer technique can confidently be used to make any terahertz antennas with dimensional errors of only a few microns and introducing very low losses. Several kinds of antennas that could be suitable to model and fabricate by means of the micromachined SU-8 layer technique. In this paper, a microstrip patch antenna is configured in a way that can be modelled according to the multilayer technique for the first time.

This paper is organized as follows. The proposed microstrip patch antenna layout, which is arranged in the light of the multilayer, is presented in Section 2. The impacts of the physical parameters on electrical performances are analyzed in Section 2. The CST Optimizations have been conducted for some of the physical dimensions of the antenna in order to achieve the goals which are defined in Section 3. Comparisons between the electrical properties of the proposed microstrip patch antenna and some antennas presented in the literature are shown in Section 4 for more clarification. It is then followed by a conclusion in Section 5.

2. DESIGN METHOD AND LAYOUT

Conventionally, a microstrip patch antenna consists of three layers. The top layer is used to make the rectangular patch out of it, the second layer is the substrate layer to hold the rectangular, and the third layer is to make the ground plane. The dimensions of the microstrip patch antenna are defined in terms of wavelength (λ). For the proposed terahertz microstrip patch antenna, the operating centre frequency is chosen to be 770 GHz. Usually the microstrip patch layer has a thickness (t) which is much smaller than the wavelength. However, because of the higher operation frequency here, the (t) value becomes so small. Thus, the (t) value is increased and is chosen to be 0.04 mm in order to avoid the design and fabrication limitations as shown in Figure 2.

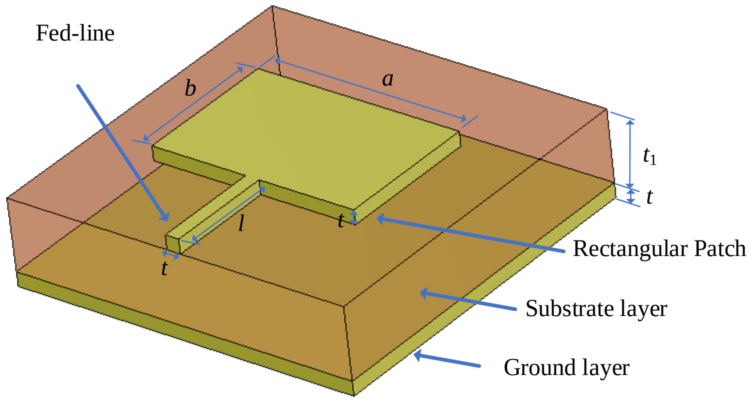


Figure 2: The configuration of the proposed microstrip patch antenna which is modelled using the CST simulator. Substrate is made from Rogers RT6006 with ε_r=6.15. Dimensions in mm are as follows. Patch dimensions; a = 0.6 and b = 0.4. patch and fed-line thickness; t = 0.04. Fed-line length; l = 0.3. Substrate thickness; t_1 = 0.2.

The material used in the CST for the ground layer and patch is perfect electrical conductor (PEC). The PEC material is later changed to sliver material so as to demonstrate its impact on the electrical performances. This will be addressed in Section 3. Using the patch antenna cavity model [21], the resonant frequency of the propagating modes (TM_{mn}) in the microstrip can be determined using the following expression.

$$f_{mn} = \frac{c}{2\sqrt{\varepsilon_{eff}}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \tag{1}$$

Where; ε_{eff} is the effective relative permittivity which is defined mathematically in terms of physical dimensions by ($\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1+12\frac{t_1}{a}]^{-0.5}$) [21]. m and n are positive integer numbers, and a and b are radiation side dimensions of the rectangular patch as labelled in Figure 2. It should be mentioned that the resonant frequency of the propagating dominant mode (TM_{01}) can be calculated when the dimensions (a, b) are known with the relative permittivity of the substrate layer using equation 1. It has been considered in this work that when the patch dimensions (a) and (b) are changed, resonant frequency of the TM_{01} is tuned, and propagating of higher modes could occur nearby the dominant mode frequency range. More details regarding the design procedure for the (a) and (b) calculations are discussed in Section 3. The substrate layer thickness is chosen to be (t_1 = 0.2 mm), and it is made in CST from Rogers RT6006 with relative permittivity ε_r=6.15.

3. ANALYSIS AND SIMULATED RESULTS

The proposed terahertz microstrip patch antenna has been simulated using the CST simulator within the frequency range 700-850 GHz. The current line distribution on the rectangular patch at the centre frequency 770 GHz is shown in Figure 3. All the current lines have the same direction, confirming the propagation of the dominant TM_{01} mode at the centre frequency. In order to see the effect of the patch dimensions (a, b) on the tuning of the resonant frequency of the TM_{01} mode, the following investigations are performed.

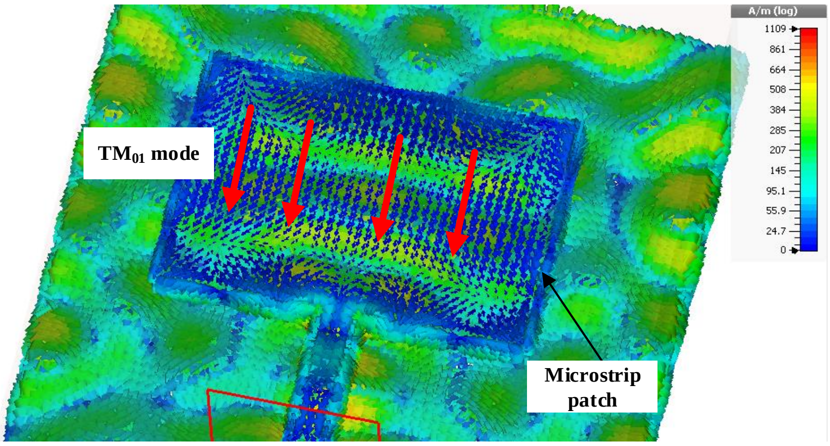


Figure 3: The 3D view of the proposed microstrip patch antenna with radiation pattern visualization using the CST simulator at centre frequency 770 GHz.

The initial patch dimension (*a*) values are changed from 0.5 mm to 0.9 mm in order to see its influence on the resonant frequency of the TM_{01} mode. One can see from the Figure 4 that the resonant frequency shifts to higher operating frequency when the (*a*) dimension is decreased. On the Other hand, the increase of (*b*) value shifts the resonant frequency to the lower operating frequency as depicted in Figure 5. It is worth mentioning that the (*a*) and (*b*) values also have influences on propagating other harmonic modes like TM_{20}, TM_{21}, and TM_{22} on the patch within the frequency band of interest. Attention is paid here on achieving the main goal which was obtaining a large reflection bandwidth (S_{11} below -10 dB from 700-850 GHz) without degrading the radiation pattern.

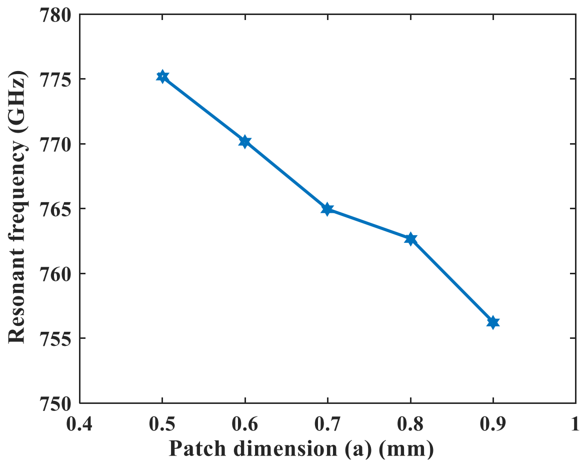


Figure 4: The influence of (*a*) dimension variation of the rectangular patch on the resonant frequency shift of the dominant mode TM_{01} when the (*b*) dimension is fixed at 0.4 mm.

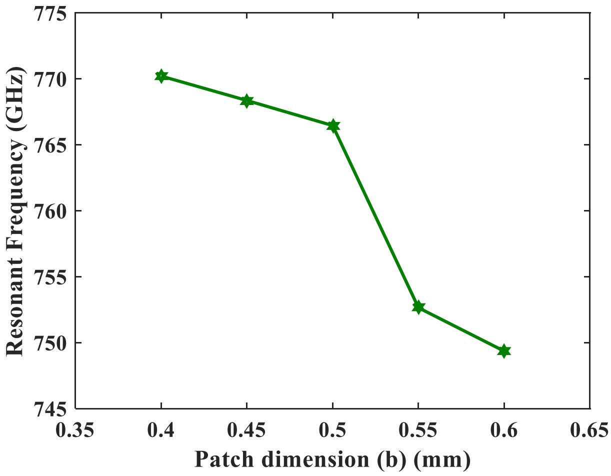


Figure 5: The influence of (*b*) dimension variation of the rectangular patch on the resonant frequency shift of the dominant mode TM_{01} when the (*a*) dimension is fixed at 0.6 mm.

The (*a*) and (*b*) values are chosen, based on the analysis mentioned above, to be 0.6 mm and 0.4 mm respectively. These values can fulfill the goal which make the antenna resonant at centre frequency 770 GHz with a reflection coefficient S_{11} below -10 dB within the operating frequency range as shown in Figure 6. It can be seen that there is a very good impedance matching over the entire operating frequencies, especially at 770 GHz. This leads the antenna to provide an extremely large impedance bandwidth.

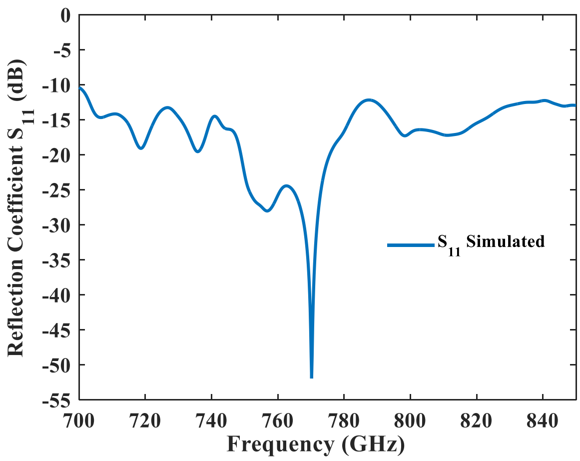


Figure 6: The S_{11} response of the microstrip patch antenna versus the operating frequencies.

The impact of the patch thickness (*t*) on the electrical performances such as the antenna gain and bandwidth is investigated in this paper. It has been found in this work that the patch (*t*) has no significant influence in tuning the resonant frequency and enlarging the bandwidth. However, the increasement of the patch thickness (t) degrades the antenna peak gain at 770 GHz as can be noticed clearly in Figure 7. In this work, a thickness of 0.04 mm is chosen as an optimum dimension for the patch due to the fact that such dimension can facilitate the modeling and the fabrication process.

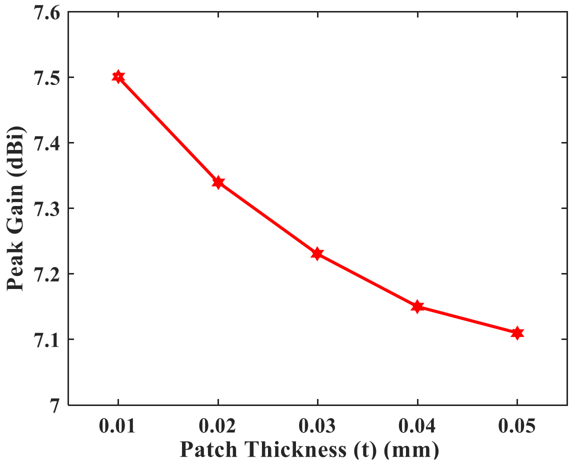


Figure 7: The peak gain variation versus patch thicknesses at centre frequency 770 GHz.

The antenna has a simulated directivity which is about 8.1 dBi at the centre frequency 770 GHz as presented in Figure 8. While, the realised gain is smaller than the directivity and is equal to 7.15 dBi. This difference goes back to the losses introduced by the material (Silver) used in the design of the patch and the ground. Also, the propagations of the other harmonic modes within the operating frequency band could contribute in the creation of the losses. As shown in Figure 9, the antenna efficiency is poor at the start frequency band and resonant frequencies (75 %), but it has become more efficient around 780-820 GHz, and the difference between the directivity and realised gain values become smaller. As mentioned before, the patch and ground plane layers of the antenna are modelled in CST out of PEC material. In case the fabrication process is considered, the PEC material is converted to a lossy silver material with conductivity (α=6.3×10^7) in order to see its impact on the antenna realised gain and directivity. Figure 8 shows that there is a negligible degradation in the realised gain and directivity values.

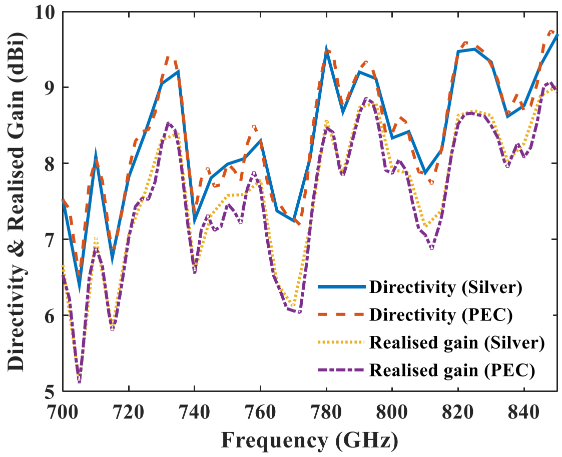


Figure 8: The directivity and realised gain variation versus frequencies for both PEC and Silver materials.

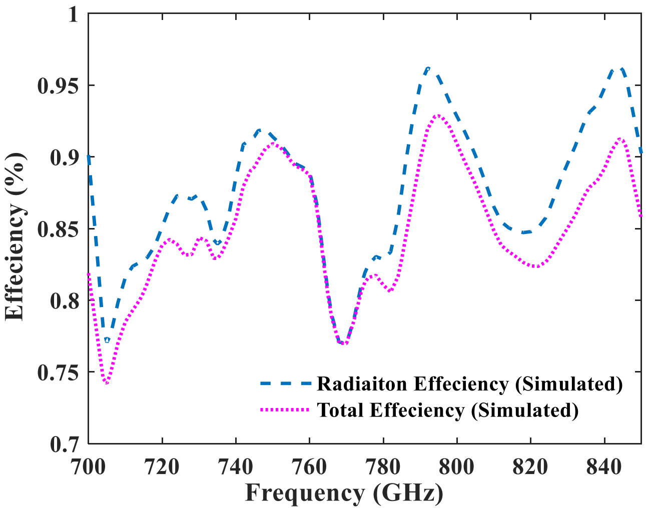
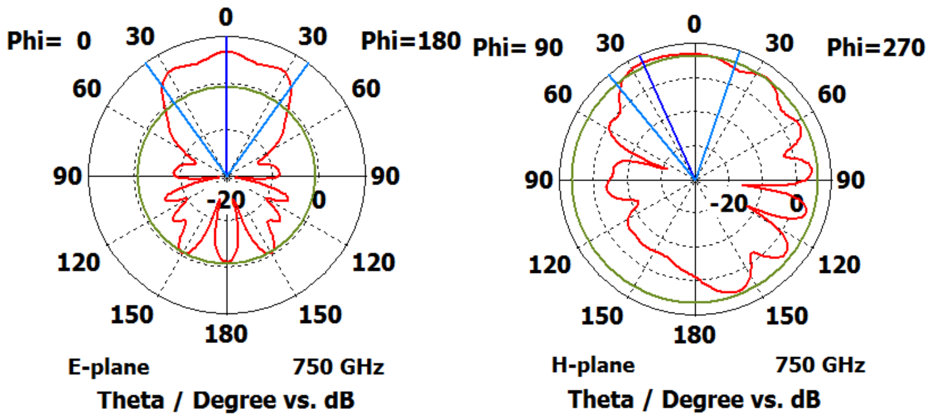
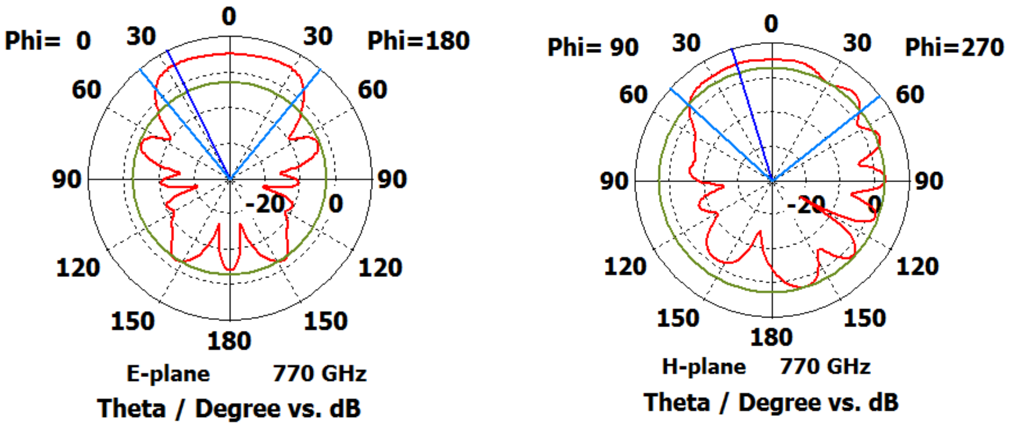


Figure 9: The radiation and total efficiencies variation versus frequencies.

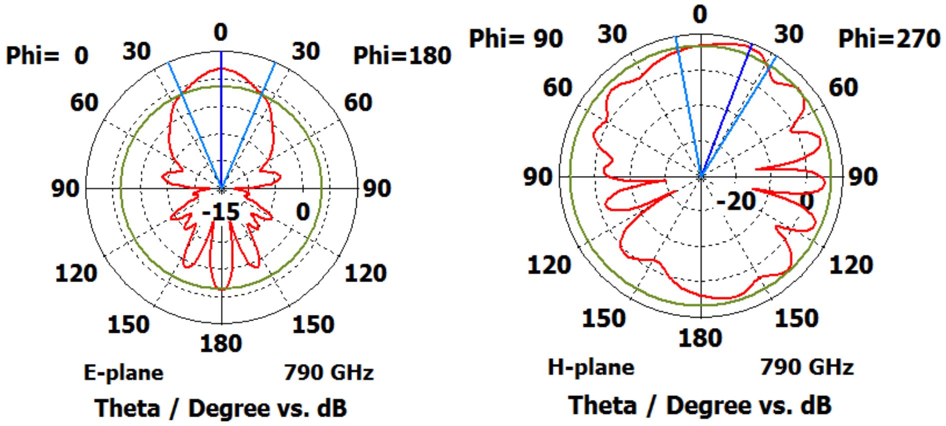
The radiation pattern for both the Electric (E) and magnetic (H) planes are investigated at the operating frequencies 750 GHz, 770 GHz, and 790 GHz, respectively. They are shown in Figure 10. The E-plane pattern has a lower side lobe level (below – 8 dB) when comparing with H-plane over the entire operating frequencies. The asymmetry of the patterns in the H-plane goes back to the asymmetry of the rectangular microstrip patch antenna in that plane.
It should be mentioned that more directive patterns can be obtained when the array theory principle is applied on the design. In this paper, extensive review has been conducted on the performance of a single microstrip patch antenna operating at terahertz frequencies. To the knowledges of the author, it has been concluded that the performance of the proposed microstrip terahertz antenna is unique and competitive especially in terms of the gain, reflection bandwidth, and geometry simplicity. For more clarifications, in the following section a comparison has been made with those works presented in the literature on the terahertz patch antennas. A comparison table has been placed as well to compare the physical dimensions (size and volume) and electrical performances (gain, bandwidth, efficiency, and so on) of the presented works in the literature.



(a)



(b)



(c)

Figure 10: The E- and H-planes radiation pattern of the proposed microstrip patch antenna at the frequencies; (a) 750 GHz, (b) 770 GHz, and (c) 790 GHz, respectively.

4. COMPARIONS AND DISCUSSION

A comparison between the electrical properties of the proposed terahertz microstrip patch antenna with some other high operating microstrip patch antennas presented in the literature is conducted in this section. Microstrip patch antennas have been focused extensively recently to operate at millimeter-wave and terahertz frequencies due to their compactness, planar structure, and low fabrication cost [22, 23]. A compact microstrip patch antenna is proposed in [24] for terahertz applications. A method to improve the gain and fabrication tolerance of a microstrip patch antenna at 95-105 GHz is proposed in [25]. A new model to design the substrate layer for microstrip patch at terahertz frequencies range based on the silicon is discussed in [26]. A new configuration for the microstrip patch is introduced in [27] for the purpose of biotin detection application. Designing the multiband terahertz antennas is a new task for researchers which has been investigating extensively. A dual band microstrip patch antenna operated at terahertz frequencies was presented in [28] for the surveillance systems. A technique to enlarge microstrip patch size is introduced in [29] for the purpose of increasing the fabrication tolerance at millimeter and terahertz frequencies. Two new techniques to feed microstrip patch and microstrip patch array are discussed in [30, 31]. Some of the electrical properties of the microstrip patch antennas mentioned above have been summarized in Table 1 with their applications. Also, they are compared with the electrical properties of the proposed terahertz microstrip patch antenna for further clarification.

Table 1: Summary of the electrical properties of some terahertz patch antennas

Refs.	**Frequency band (GHz)**	**Antenna Structure**	**Peak gain (dBi)**	**Bandwidth (%) (S_{11} below -10 dB)**	**Total Efficiency (%)**	**Applications**
[24]	600	Rectangular Microstrip	7	10.1	NA	Sensing and communication
[25]	95-105	Microstrip antenna array	13.4	5.5	93.7	NA
[26]	300-440	Dual-patch	NA	NA	NA	Sub-THz radiation detector
[27]	150-500	New shape of microstrip patch	5.17	2.2	NA	Biotin detection application
[28]	600-800	Two-layer substrate	9.8	12.8	79.7	Surveillance system
[29]	54-58	Microstrip patch	7.7	3.2	90.8	NA
[30]	288-312	Novel feed microstrip	4.39	3.3	NA	NA
[31]	288-312	Patch array feed source	10	3	NA	THz communications
Proposed Antenna	700-850	Microstrip patch antenna	7.15	19.4	75-90	Surveillance

5. CONCLUSION

A new configuration of microstrip patch antenna operated at frequencies 700-850 GHz was introduced in this paper. Three layers were utilized in the design of the presented antenna. One of the unique features of the presented microstrip patch antenna was its adaptation with multilayer structure. Investigations on the effects of the geometrical parameters of the microstrip patch on the electrical performance has been conducted. The genetic algorithm optimisation technique in the CST simulator was utilised in order to enhance the realised gain and reflection bandwidth of the microstrip patch antenna. With the design analysis presented, the antenna performance was in good agreement with the theoretical expectation. The antenna provided extremely wide bandwidth for such operating frequency range. Also, the size is small and compact which could be of interest in employing at many security and surveillance applications.

6. ACKNOWLEDGMENT

The author would like to thank the University of Birmingham, UK and the Emerging Device Technology (EDT) research group for all the technical supports and allowing to use the microwave CST simulator.

REFERENCE

[1] P. H. Siegel, "THz instruments for space," *IEEE Transactions on Antennas and Propagation,* vol. 55, pp. 2957-2965, 2007.

[2] P. H. Siegel, "Terahertz technology in biology and medicine," *IEEE transactions on microwave theory and techniques,* vol. 52, pp. 2438-2447, 2004.

[3] S. Galoda and G. Singh, "Fighting terrorism with terahertz," *Ieee Potentials,* vol. 26, pp. 24-29, 2007.

[4] A. Dobroiu, C. Otani, and K. Kawase, "Terahertz-wave sources and imaging applications," *Measurement Science and Technology,* vol. 17, p. R161, 2006.

[5] K. R. Jha and G. Singh, *Terahertz planar antennas for next generation communication*: Springer, 2014.

[6] R. C. Daniels and R. W. Heath, "60 GHz wireless communications: Emerging requirements and design recommendations," *IEEE Vehicular technology magazine,* vol. 2, pp. 41-50, 2007.

[7] R. C. Daniels, J. N. Murdock, T. S. Rappaport, and R. W. Heath, "60 GHz wireless: Up close and personal," *IEEE Microwave magazine,* vol. 11, pp. 44-50, 2010.

[8] I. Frigyes, J. Bitó, B. Héder, and L. Csurgai-Horváth, "Applicability of the 50–90 GHz frequency bands in feeder networks," in *2009 3rd European Conference on Antennas and Propagation*, 2009, pp. 336-340.

[9] B. Zhang, Y. Fan, and Z. Chen, "220-GHz-band wireless link system using all-electronic technologies for 20Gbit/s data transmission," in *2010 International Symposium on Intelligent Signal Processing and Communication Systems*, 2010, pp. 1-3.

[10] H.-J. Song, K. Ajito, A. Wakatsuki, Y. Muramoto, N. Kukutsu, Y. Kado*, et al.*, "Terahertz wireless communication link at 300 GHz," in *2010 IEEE International Topical Meeting on Microwave Photonics*, 2010, pp. 42-45.

[11] M. Chia, C. Ang, B. Luo, and S. Leong, "Wideband 307 GHz transceiver system for high speed digital wireless at 12.5 Gbps," in *2011 IEEE MTT-S International Microwave Symposium*, 2011, pp. 1-4.

[12] K. Sarabandi, A. Jam, M. Vahidpour, and J. East, "A novel frequency beam-steering antenna array for submillimeter-wave applications," *IEEE Transactions on Terahertz Science and Technology,* vol. 8, pp. 654-665, 2018.

[13] L. Ranzani, D. Kuester, K. J. Vanhille, A. Boryssenko, E. Grossman, and Z. Popović, "G-Band Micro-Fabricated Frequency-Steered Arrays With 2$^\circ $/GHz Beam Steering," *IEEE Transactions on Terahertz Science and Technology,* vol. 3, pp. 566-573, 2013.

[14] C. Wang, Y. Yao, J. Yu, and X. Chen, "3d Beam Reconfigurable THz Antenna with Graphene-Based High-Impedance Surface," *Electronics,* vol. 8, p. 1291, 2019.

[15] R. Mahmud, T. He, M. Lancaster, Y. Wang, and X. Shang, "Micromachined travelling wave slotted waveguide antenna array for beam-scanning applications," in *10th Loughborough Antennas and Propagation Conference, LAPC*, 2014.

[16] X. Shang, M. Ke, Y. Wang, and M. J. Lancaster, "WR-3 band waveguides and filters fabricated using SU8 photoresist micromachining technology," *IEEE Transactions on Terahertz Science and Technology,* vol. 2, pp. 629-637, 2012.

[17] Y. Wang, B. Yang, Y. Tian, R. S. Donnan, and M. J. Lancaster, "Micromachined thick mesh filters for millimeter-wave and terahertz applications," *IEEE Transactions on Terahertz Science and Technology,* vol. 4, pp. 247-253, 2014.

[18] Y. Wang, M. Ke, M. J. Lancaster, and J. Chen, "Micromachined 300-GHz SU-8-based slotted waveguide antenna," *IEEE Antennas and Wireless Propagation Letters,* vol. 10, pp. 573-576, 2011.

[19] Y. Gao, X. Shang, C. Guo, J. Powell, Y. Wang, and M. J. Lancaster, "Integrated waveguide filter amplifier using the coupling matrix technique," *IEEE Microwave and Wireless Components Letters,* vol. 29, pp. 267-269, 2019.

[20] R. H. Mahmud, "Synthesis of waveguide antenna arrays using the coupling matrix approach," University of Birmingham, 2016.

[21] Y. Lo, D. Solomon, and W. Richards, "Theory and experiment on microstrip antennas," *IEEE transactions on Antennas and Propagation,* vol. 27, pp. 137-145, 1979.
[22] C. A. Balanis, *Modern antenna handbook*: John Wiley & Sons, 2011.
[23] D. M. Pozar, *Microwave engineering*: John Wiley & Sons, 2009.
[24] S. S. Kashyap and V. Dwivedi, "Compact microstrip patch antennas for terahertz applications," in *2015 9th Asia Modelling Symposium (AMS)*, pp. 157-163,2015.
[25] M. Rabbani and H. Ghafouri-Shiraz, "Improvement of microstrip antenna's bandwidth and fabrication tolerance at terahertz frequency bands," 2015.
[26] P. Kopyt, B. Salski, P. Zagrajek, D. Obrębski, and J. Marczewski, "Modeling of silicon-based substrates of patch antennas operating in the sub-THz range," *IEEE Transactions on Terahertz Science and Technology*, vol. 7, pp. 424-432, 2017.
[27] R. Bhatoa and E. Sidhu, "Novel terahertz microstrip patch antenna design for detection of biotin applications," in *2017 International Conference on Big Data Analytics and Computational Intelligence (ICBDAC)*, pp. 289-292, 2017
[28] K. R. Jha and G. Singh, "Dual-band rectangular microstrip patch antenna at terahertz frequency for surveillance system," *Journal of computational electronics,* vol. 9, pp. 31-41, 2010.
[29] M. Rabbani and H. Ghafouri-Shiraz, "Size improvement of rectangular microstrip patch antenna at MM-wave and terahertz frequencies," *Microwave and Optical Technology Letters,* vol. 57, pp. 2585-2589, 2015.
[30] K. R. Jha and S. K. Sharma, "Waveguide integrated Microstrip patch antenna at THz frequency," in *2014 IEEE Antennas and Propagation Society International Symposium (APSURSI)*, pp. 1851-1852, 2014.
[31] K. R. Jha and S. K. Sharma, "Waveguide integrated microstrip patch array feed source for a reflector antenna at THz frequency," in *2014 IEEE Antennas and Propagation Society International Symposium (APSURSI)*, pp. 1465-1466, 2014.