Investigations on Indium Tin Oxide Based Optically Transparent Terahertz E-shaped Patch Antenna

S. Anand*, Mayur Sudesh Darak, and D. Sriram Kumar

Abstract. An optically transparent microstrip patch antenna is designed and its radiation characteristics are analyzed in 706 - 794 GHz band. Terahertz communication systems offer advantages such as broad bandwidth, low transmit power, secured wireless communication and compactness. It has applications in various fields like hidden object detection, imaging and sensing. In the proposed antenna, transparent conducting indium tin oxide thin film is used as a radiating patch and a ground plane material. The entire antenna structure is optically transparent in the visible spectrum region. The proposed antenna is simulated using Ansoft – HFSS, a finite element method (FEM) based electromagnetic solver.

Keywords: Transparent antenna, Terahertz, Transparent conducting materials, Patch antenna, Indium tin oxide, Terahertz antenna.

1 Introduction

Nanotechnology enables the system miniaturization and component development for future wireless communication systems [1-3]. Thin film deposition and nano lithography techniques made fabrication of MEMS and NEMS devices feasible [4, 5]. Today, advanced wireless sensors, actuators, tunable RF devices, etc. are realized at the nano scale, which has not only reduced the system size but has increased the overall efficiency and accuracy of the system [6, 7]. Future wireless communication systems require higher data rate transmission capability and low

S. Anand · Mayur Sudesh Darak · D. Sriram Kumar
Department of Electronics and Communication Engineering,
National Institute of Technology, Tiruchirappalli 620015, India.
email: {anand.s.krishna,darak.mayur}@gmail.com, srk@nitt.edu

* Corresponding author.

S.M. Thampi, A. Gelbukh, and J. Mukhopadhyay (eds.), *Advances in Signal Processing and Intelligent Recognition Systems*, Advances in Intelligent Systems and Computing 264,
DOI: 10.1007/978-3-319-04960-1_17,

transmission power with reduced size [8]. The aforementioned requirements are met by usage of communication systems in terahertz spectrum, which offers secured communication with free spectrum availability [9]. Antennas for terahertz communication systems are being developed and studied for their application to various fields viz. astronomy, spectroscopy, imaging and sensing. Its military applications include screening of explosives and bio-hazards, detecting concealed objects and water contents [10, 11]. In the terahertz spectrum, the microstrip patch antenna is best suited due to its advantages such as low profile, light weight, low power requirement and conformity to planar and non-planar surfaces [12]. But transparent microstrip patch antenna has got some limitations like impedance bandwidth (< 5%), gain (< 2dB) and poor radiation efficiency [13].

The transparent conducting thin films are optically transparent and electrically conductive layers. They are widely used for the development of liquid crystal displays (LCD) [14], photovoltaic cells [15], light emitting diodes [16], optical displays [17] and transparent antennas [18]. Generally used transparent conducting materials for photo conductive devices are indium tin oxide (ITO), silver coated polyester film (AgHT), titanium-doped indium Oxide (TIO), gallium zinc oxide (GZO) and antimony tin oxide (ATO) [19, 20]. The challenge encountered in designing the transparent patch antenna is to optimize the electrical conductivity of the transparent conductive thin film while retaining its optical transmittance [21].

The work presented in this paper discusses design of an ITO based optically transparent microstrip patch antenna on a 20 μm thin substrate of polyimide in terahertz band (706 – 794 GHz). Following sections, present the optically transparent microstrip patch antenna design. Its impedance bandwidth, gain, directivity and radiation efficiency are analyzed in the desired band using the simulated results.

2 Transparent Patch Antenna

Microstrip antenna consists of a radiating patch, substrate and a ground plane. As shown in Fig. 1. The E-shaped patch of transparent conducting TIO is placed on a 20 μm thick substrate of transparent polyimide. Polyimide has a relative permittivity of 3.5. Transparent TIO ground plane is on the other side of the substrate. Thickness of the patch is selected such that it is 0.001 times the free space wavelength [22]. By tuning the arms of the E-shaped patch, antenna is made to resonate at 750 GHz. A microstrip line is used for impedance transition from coaxial cable to the patch of the antenna. This enables microstrip line to feed the power from coaxial cable to antenna patch with minimum mismatch loss. Antenna performance such as its bandwidth, radiation efficiency improves for substrates with lower dielectric constants and increasing thickness [23]. But this results in increased size of the antenna. Hence there is a tradeoff between performance parameters of antenna such as bandwidth, radiation efficiency and compactness of the antenna. The effect of fringing of electric field lines occurs at the edges of the patch as well as at the boundaries of microstrip line [24]. The majority of antenna radiation is from fields fringed at the edges of the patch. Most of the field lines near the boundaries of microstrip line are confined in the substrate. However, parts of lines reside in air. Thus, the effective dielectric constant to account for the combined effect of air and substrate media must be calculated [25]. The dimensions of the antenna structure are given in Table 1.

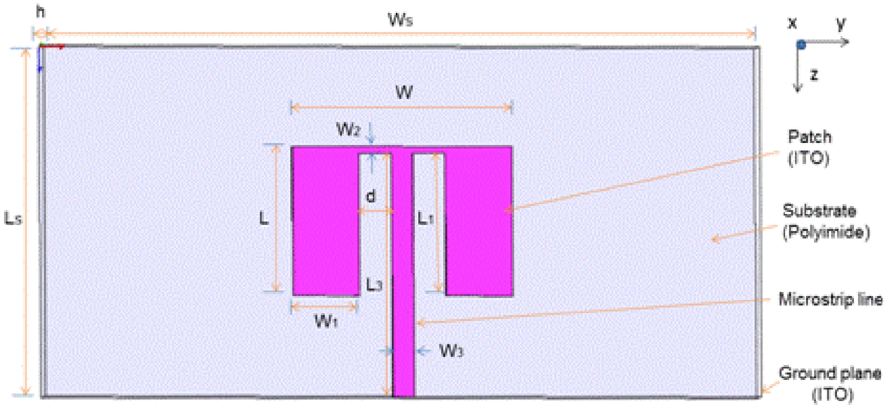

Fig. 1 ITO based optically transparent antenna

Table 1 Design parameters and dimensions of the optically transparent antenna

Parameters	Dimensions
E-shaped patch length (L x L_1)	88.98 µm x 83.9 µm
E-shaped patch width (W x W_1 x W_2)	133.2 µm x 41.75 µm x 17. 9 µm
Patch thickness (t)	0.4 µm
Spacing (d)	5.08 µm
Substrate length and width (L_s x W_s)	208.98 µm x 433.2 µm
Substrate thickness (h)	20 µm
Microstrip line length and width (L_3 x W_3)	143.9 µm x 13.9 µm

3 Results and Discussion

The proposed transparent antenna structure is simulated using electromagnetic solver, Ansoft – HFSS. The return loss (S_{11}) and radiation characteristics are

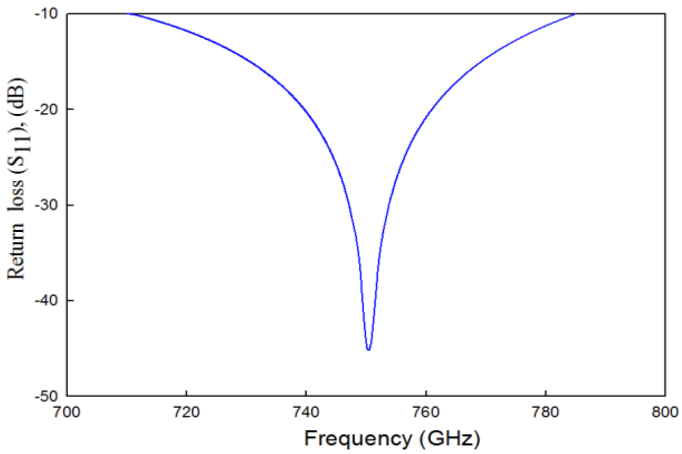

Fig. 2 Return loss (S_{11})

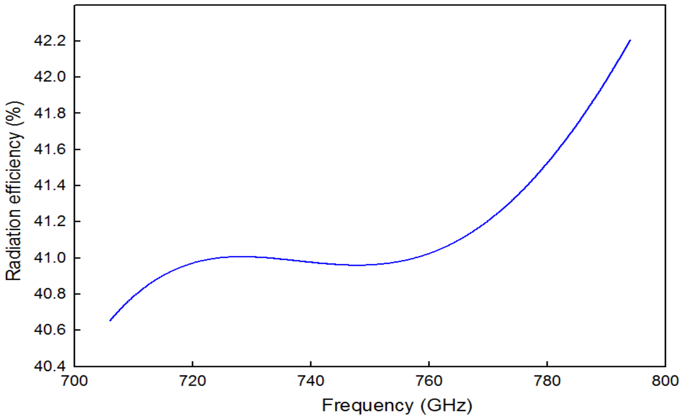

Fig. 3 Radiation efficiency (%)

investigated in 706 – 794 GHz band. As shown in Fig. 2, at resonance frequency of 750 GHz, the return loss of -40.19dB is observed. An impedance bandwidth of 11.73% is achieved with respect to centre frequency / resonance frequency in 706 – 794 GHz.

From Fig. 3, the radiation efficiency of more than 40% is achieved in desired band. At resonance frequency, it is observed that the radiation efficiency is achieved to be 40.96 %. The peak radiation efficiency of 42.2% is observed at 794 GHz. The radiation efficiency increases steeply after resonance frequency.

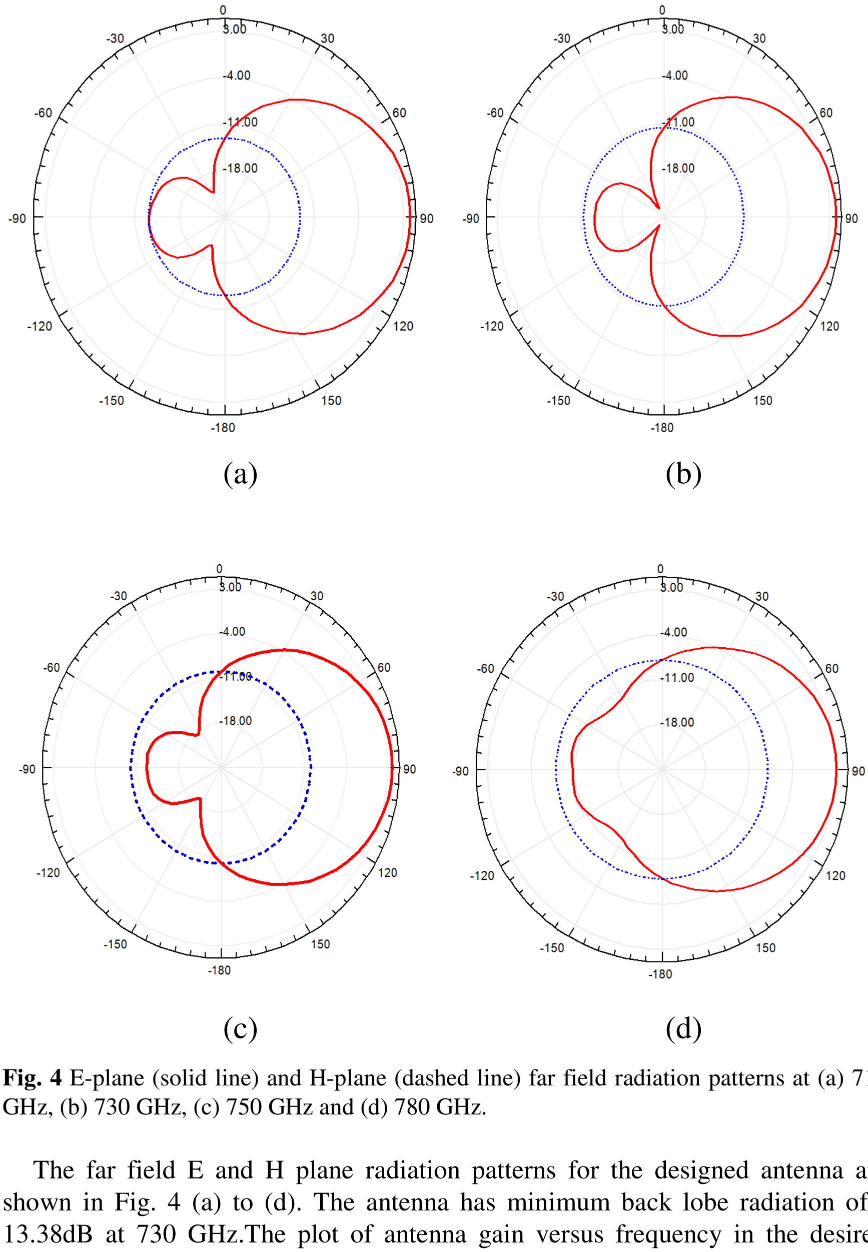

Fig. 4 E-plane (solid line) and H-plane (dashed line) far field radiation patterns at (a) 710 GHz, (b) 730 GHz, (c) 750 GHz and (d) 780 GHz.

The far field E and H plane radiation patterns for the designed antenna are shown in Fig. 4 (a) to (d). The antenna has minimum back lobe radiation of -13.38dB at 730 GHz.The plot of antenna gain versus frequency in the desired band is shown in Fig. 5. Peak gain of 4.16 dB is observed at 711 GHz. Over the entire band of interest, the gain greater than 2.8 dB is obtained.

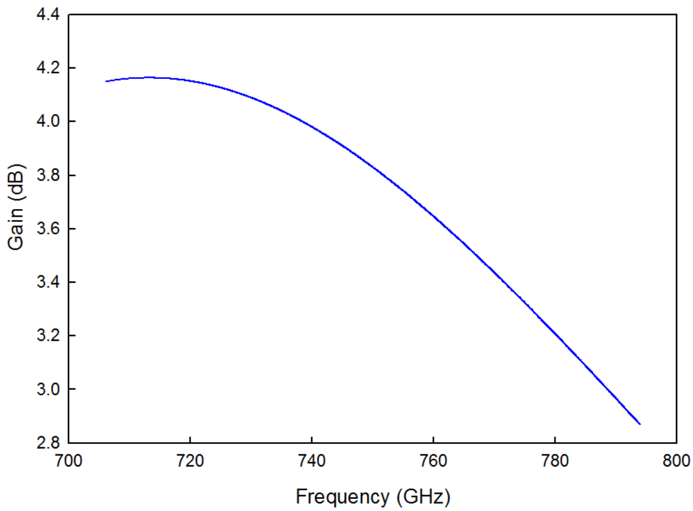

Fig. 5 Antenna Gain (dB)

4 Conclusion

Using ITO transparent conducting thin film an optically transparent terahertz patch antenna is proposed. It has achieved a gain of greater than 2.8dB and impedance bandwidth of 11.73% in 706 – 794 GHz band. A peak gain of 4.16dB is achieved at 711GHz. The gain and bandwidth obtained are relatively good for a patch antenna. The highest radiation efficiency obtained is 42.20% at 794 GHz, which is less as compared to non-transparent conventional patch antennas. Although, it has a limitation in terms of radiation efficiency, the entire structure, being optically transparent can find applications in diverse fields like military, astronomy, imaging and sensing. Its unique applications include solar cell antenna for satellite to satellite communications and screening of concealed objects in advanced recognition systems.

References

1. Dragoman, M., Muller, A.A., Dragoman, D., Coccetti, F., Plana, R.: Terahertz antenna based on graphene. Journal of Applied Physics 107, 104313–104313 (2010)
2. Llatser, I., Christian, K., Albert, C.-A., Josep, M.J., Eduard, A., Dmitry, N.C.: Graphene-based nano-patch antenna for terahertz radiation. Photonics and Nanostructures-Fundamentals and Applications 10, 353–358 (2012)
3. Jornet, J.M., Ian, F.A.: Graphene-based nano-antennas for electromagnetic nanocommunications in the terahertz band. In: 2010 Proceedings of the Fourth European Conference on Antennas and Propagation (EuCAP), pp. 1–5. IEEE (2010)

4. Tamagnone, M., Juan, S.G.-D., Juan, R.M., Julien, P.-C.: Reconfigurable terahertz plasmonic antenna concept using a graphene stack. Applied Physics Letters 101, 214102 (2012)
5. Huang, Y., Lin-Sheng, W., Min, T., Junfa, M.: Design of a beam reconfigurable THz antenna with graphene-based switchable high-impedance surface. IEEE Transactions on Nanotechnology 11, 836–842 (2012)
6. Kingsley, N., Dimitrios, E.A., Manos, T., John, P.: RF MEMS sequentially reconfigurable sierpinski antenna on a flexible organic substrate with novel DC-biasing technique. Journal of Microelectromechanical Systems 16, 1185–1192 (2007)
7. Yashchyshyn, Y.: Reconfigurable antennas by RF switches technology. In: 2009 5th International Conference on MEMSTECH 2009, pp. 155–157. IEEE (2009)
8. Tonouchi, M.: Cutting-edge terahertz technology. Nature Photonics 1, 97–105 (2007)
9. Sharma, A., Singh, G.: Rectangular microstirp patch antenna design at THz frequency for short distance wireless communication systems. Journal of Infrared, Millimeter, and Terahertz Waves 30, 1–7 (2009)
10. Kemp, M.C., Taday, P.F., Bryan, E.C., Cluff, J.A., Anthony, J.F., William, R.T.: Security applications of terahertz technology. In: International Society for Optics and Photonics, AeroSense 2003, pp. 44–52 (2003)
11. Galoda, S., Singh, G.: Fighting terrorism with terahertz. IEEE Potentials 26, 24–29 (2007)
12. Luk, K.M., Mak, C.L., Chow, Y.L., Lee, K.F.: Broadband microstrip patch antenna. Electronics Letters 34, 1442–1443 (1998)
13. Song, H.J., Tsung, Y.H., Daniel, F.S., Hui, P.H., James, S., Eray, Y.: A method for improving the efficiency of transparent film antennas. IEEE Antennas and Wireless Propagation Letters 7, 753–756 (2008)
14. Oh, B.-Y., Jeong, M.-C., Moon, T.-H., Lee, W., Myoung, J.-M., Hwang, J.-Y., Seo, D.-S.: Transparent conductive Al-doped ZnO films for liquid crystal displays. Journal of Applied Physics 99, 124505–124505 (2006)
15. Pasquier, A.D., Husnu, E.U., Alokik, K., Steve, M., Manish, C.: Conducting and transparent single-wall carbon nanotube electrodes for polymer-fullerene solar cells. Applied Physics Letters 87, 203511–203511 (2005)
16. Gu, G., Bulovic, V., Burrows, P.E., Forrest, S.R., Thompson, M.E.: Transparent organic light emitting devices. Applied Physics Letters 68, 2606–2608 (1996)
17. De, S., Thomas, M.H., Philip, E.L., Evelyn, M.D., Peter, N.N., Werner, J.B., John, J.B., Jonathan, N.C.: Silver nanowire networks as flexible, transparent, conducting films: extremely high DC to optical conductivity ratios. ACS Nano 3, 1767–1774 (2009)
18. Katsounaros, A., Yang, H., Collings, N., Crossland, W.A.: Optically transparent ultra-wideband antenna. Electronics Letters 45, 722–723 (2009)
19. Minami, T.: Transparent conducting oxide semiconductors for transparent electrodes. Semiconductor Science and Technology 20, S35 (2005)
20. Granqvist, C.G., Hultåker, A.: Transparent and conducting ITO films: new developments and applications. Thin Solid Films 411, 1–5 (2002)

21. Saberin, J.R., Cynthia, F.: Challenges with Optically Transparent Patch Antennas. IEEE Antennas and Propagation Magazine 54, 10–16 (2012)
22. Balanis, C.A.: Antenna theory: analysis and design. John Wiley & Sons (2012)
23. Jha, K.R., Singh, G.: Effect of low dielectric permittivity on microstrip antenna at terahertz frequency. Optik-International Journal for Light and Electron Optics 124, 5777–5780 (2013)
24. Pozar, D.M.: Microstrip antennas. Proceedings of the IEEE 80, 79–91 (1992)
25. Carver, K., Mink, J.: Microstrip antenna technology. IEEE Transactions on Antennas and Propagation 29, 2–24 (1981)