Design of Dipole antenna using Finite Element Method (FEM)

Mehak Chaturvedi,
BPSMV, Sonepat
(E-mail – mehakc31@gmail.com)

Abstract **-** The dipole antenna is one of the best suitable and commonly used types of Radio Frequency (RF). This antenna is also incorporated into many other Radio Frequency antenna designs where it acts as driven element for that particular antenna. In present work, the detailed explanation of design of dipole antenna at wavelength 4mm using FEM (Finite Element Method) i.e. COMSOL Multiphysics is presented. The RF module of COMSOL Multiphysics will be used for designing the Dipole antenna. The antenna will be designed using Copper with relative permeability of 1 and electrical conductivity 5.998e7 [S/m] and using Silicon having relative permeability of 1 and electrical conductivity 1000[S/m] respectively. This antenna has cylindrical gap between the arms of antenna and the cylindrical gap act as a voltage source of the antenna. This voltage source of feed structure induces electromagnetic fields and surface currents on the adjacent conductive faces. The design of dipole antenna will be analyzed by using COMSOL Multiphysics and the obtained simulation results present that dipole antenna provides better performance.

Keywords **-** *Radio frequency Antenna, Finite Element Method, Dipole Antenna, radiation and patterns etc.*

I. INTRODUCTION

Antenna is any structure that can radiate electromagnetic energy typically for communications purposes. Some of the common antennas are Dipole Antenna with a Quaterwave Coaxial Balun, Circular polarization in a patch antenna, Vivaldi antenna far-field pattern, Mobile devices planar inverted-F antenna, antenna crosstalk in an airplane are some of the examples of antennas. The dipole was the oldest and primitive type of antenna; it was invented by German scientist Heinrich Hertz around 1886 in his advanced research of radio waves. When a radiation of energy is done with the help of a bent wire, then the end of transmission line is termed as Dipole or dipole antenna. In dipole antenna, we have two arms in its structure. These two are vertically oriented pieces of metal this antenna is being driven at a feed point. So there is a power supply that is bringing a signal via transmission line and that's going to be a applying a sinusoidal time varying voltage difference across this feed gap between the two arms. The antenna itself is going to radiate into the surrounding free space and we roughly break down the surrounding free space into two regions; The Near field region and The Far Field region. In the Near field region the field have both innocent and propagating component but in the Far field region the electromagnetic field are rarely propagating. Inside of our model we cannot differentiate the near field and far field region; this all will model as a single domain. There will be an additional layer or additional region that is called as Absorbing Region (PML). This Perfectly Matched Layer (PML) region is going to act as an absorber of any outgoing radiation so it acts quite summarily to the walls of inequality chamber absorbing any outgoing radiation coming from this antenna. We will also compute Electromagnetic fields, the far field parent and the antenna impedance. There are different types of the dipole are also used, such as the folded dipole, short dipole, cage dipole, bow-tie, and batwing antenna. Dipoles can be used as standalone antennas themselves, but they are also used as feed antennas (driven elements) in many more advanced antenna types, such as the Yagi antenna, parabolic antenna, reflective array, turnstile antenna, log periodic antenna, and phased array. Many type of antenna are analyzed and used in many different applications but the most common type of dipole used is two straight rods or wires that are connected end to end on the same axis, with the feed line connected to the two adjacent ends. This is one the easiest type of antenna from a theoretical based view. Dipoles are also known as resonating antennas, because the elements serve as resonating elements, with standing waves of radio current which flows back and forth within both of their ends.

II. COMSOL MULTIPHYSICS SOFTWARE

Here the simulation tool used is COMSOL Multiphysics. It has a several problem-solving benefits. It is easy to understand your problem, while using COMSOL Multiphysics as a simulation tool for a project. Identifying or testing various Geometrical and physical characteristics of a project is easy in COMSOL. It has a flexible nature which facilitates further analysis by making different cases easy to set up and run in the tool and also allow users to model all physical aspects of their design. By optimizing the project it is possible to take the simulation at production level. In the user interface, parameter sweeps and target functions can be executed. From start of the simulation to the end of the simulation, COMSOL is a complete problem-solving tool. The graphic user interface (GUI) of COMSOL offers an effective platform to get solutions of your problem. Script based modeling also can be done in COMSOL when it is combined with MATLAB.

III. DIPOLE ANTENNA CONSIDERATION

The geometry of proposed dipole antenna, having two arms termed as Antenna boundaries and a feed point is shown in fig. 1.1. Here the length and radius of antenna boundaries and feed point are 1m and 3cm. The gap between these two arms is 3cm:

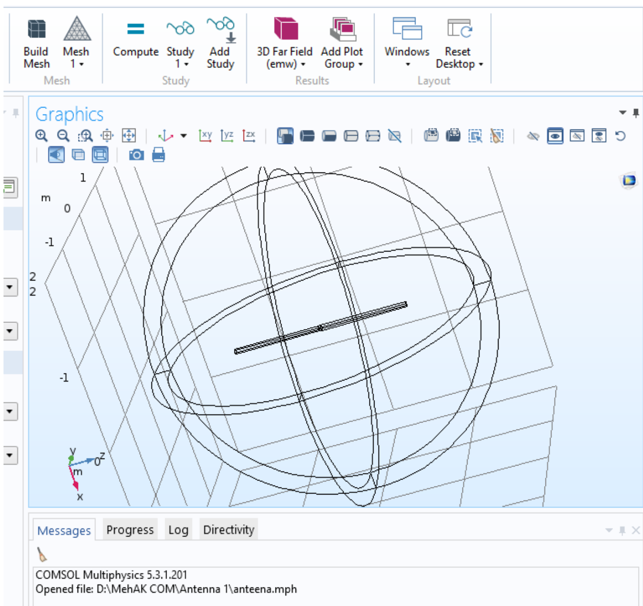

Fig. 1.1 Geometry Visualization

The proposed dipole antenna is enclosed in a spherical domain having radius 2m as shown in fig. 1.2

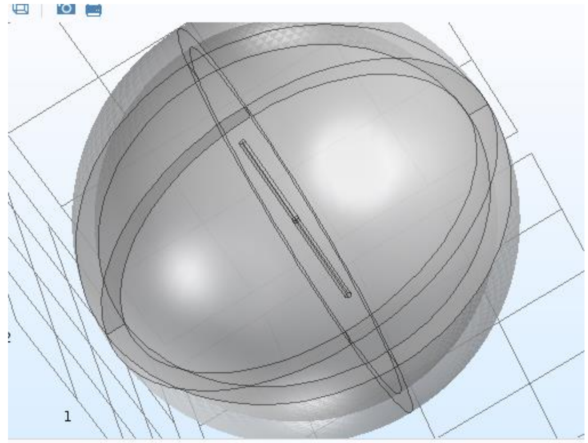

Fig. 1.2 Antenna enclosed in spherical domain

Now mesh is applied to the model, meshing type is completely depending upon the number and size of the element. In this model the physics controlled mess is applied i.e. based on domain features, material properties and the operating frequency or the operating wavelength and second order element is used in this model i.e. second order polynomial that is used for the dispersion of fields. Finer mesh is applied on the antenna boundaries, (shown in fig. 1.4) to get good resolution and swept mesh is applied on the PML (Perfectly matched layer) region shown in fig. 1.3

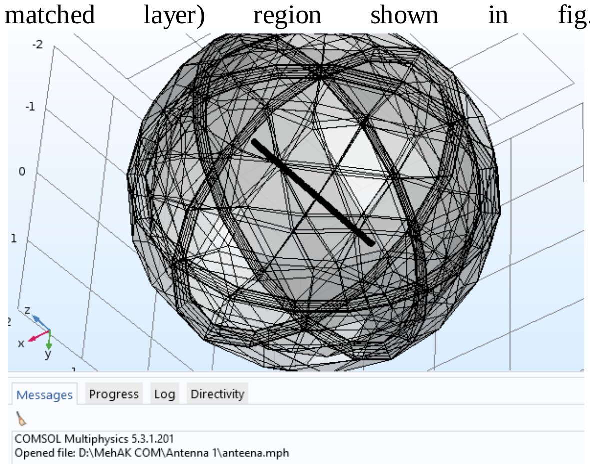

Fig. 1.3 Meshing at PML region

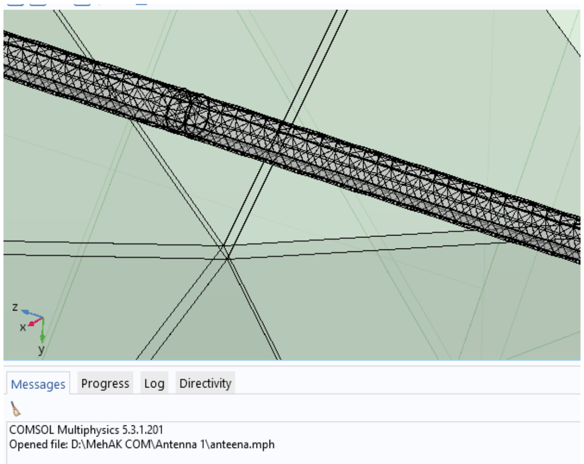

Fig. 1.4 Meshing at Antenna Boundaries

IV. SIMULATION RESULTS

Now the examination of model is to be done. Air domain has been selected for the representation of result. So, the result will be displayed within the air domain. This domain represents the direction of Electric field, Magnetic field and the direction of outgoing power. The type of study used for result is Frequency Domain with frequency f0 as modeling is done on a single frequency. The color range of electric field selected manually in the model i.e. Red and the arrow plot of the electric field is selected in the x-y plane. The plot for the magnetic field is selected in the same way and color range selected for Magnetic field is Green. Lastly, the color range for outgoing radiating energy or power flow in the model is selected as White. Now all the three arrows and direction of these arrows are easily visible in the model as shown in Fig. 1.5 (shows direction of electric field) and Fig. 1.6 (shows direction of outgoing power and magnetic fields). The 2D far field plot and 3D far field plot achieved is also shown in Fig 1.7 and Fig. 1.8.

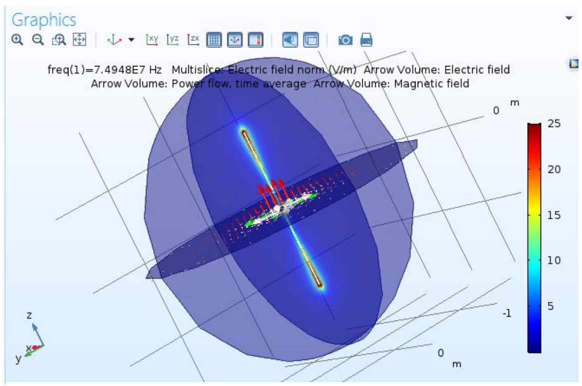

Fig. 1.5 Direction of electric field

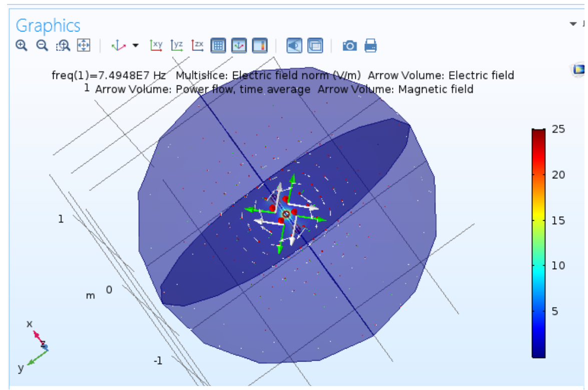

Fig. 1.6 Direction of magnetic field and outgoing power

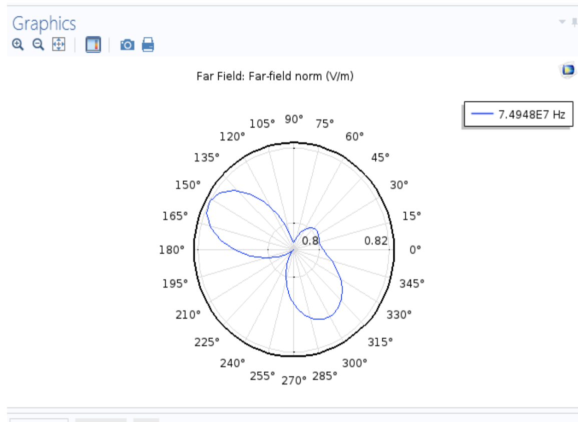

Fig. 1.7 2D far field plot

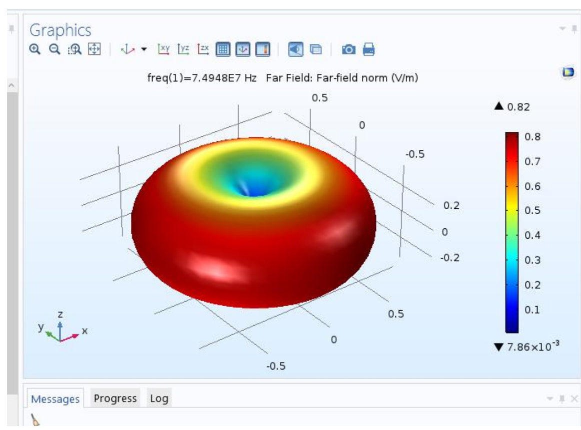

Fig. 1.8 3D far field plot

The couple of plots i.e. 2D plot and 3D plot has been achieved. 3D Far field plot shows the far field intensity pattern and achieved as typical donut type shape as shown in Figures. Both the plots are achieved at same frequency.

V. CONCLUSION

The proposed dipole antenna is designed at wavelength 4mm with radius of 3cm. The antenna is designed on the principle Electromagnetic waves to obtain the directions of electric field, magnetic field and outgoing radiation power and different polar plots at a single frequency domain. The RF module of finite element method that is COMSOL Multiphysics has been used to achieve the targets of proposed research work i.e. in designing of Dipole Antenna with different radiations and patterns. The antenna is designed using Copper with relative permeability of 1 and electrical conductivity 5.998e7 [S/m] and using electrical Silicon having relative permeability of 1 and conductivity 1000[S/m] respectively.

Meshing has been applied to the selected model based on material properties, operating frequency or operating wavelength, which results finer mesh to the antenna boundaries and swept mesh to the perfectly matched layer region. The 2D far field plot and 3D polar plot at frequency 7.4948e7 Hz has been obtained. 3D far field plot shows the far field intensity pattern and donut type shape has been obtained as presented in figures. The implementation of the proposed research work outperforms and provides better simulation results using finite element method. The proposed work is a particularly form of RF antenna which is widely used for radio transmitting and receiving applications. The Dipole is generally used at its own as an RF antenna, but it also forms the essential element in many other types of RF antenna.

ACKNOWLEDGMENT

The author would like to thank his guide Dr. Sandeep Dahiya for his constant guidance throughout the work and his family members for their support.

REFERENCES

1. Nguyen, Tran Thanh Binh and A/P Hui Hon Tat., “Design of a dipole antenna using computer simulation”
2. S. K. Gupta, H. K. Jagnam and N. Sharma, “Theory of antenna, its advantage & application in communication system,” IJEDR, VOLUME 6, ISSUE 1, ISSN: 2321-9939.
3. T. G. Vasiliadis, E. G. Vaitsopoulos and G. D. Sergiadis., “A wideband printed dipole antenna with optimizes tapered feeding balun for ISM and FWA bands” Microwave and Optical Technology Letters, Volume 43, Issue 5.
4. D. Mounika, S. Samatha, Anusha and Suraya Mubeen., “Design of Dipole Antenna and various radiation patterns for various lengths” Volume-6, issue-4, April-2017, ISSN No. 2277- 8160
5. V.A.Kulkarni, V.S.Navale., “Polarization Diversity Printed Dipole Antenna Using PIN Diode Switching For Wireless LAN Applications” International Journal of Engineering Science and Innovative Technology (IJESIT), Volume 2, Issue 3, May 2013.
6. J. Lei , G. Fu , L. Yang and D. M. Fu., “An omnidirectional printed dipole array antenna with shaped radiation pattern in the elevation plane” Journal of Electromagnetic Waves and Applications, 20:14, 1955-1966.
7. Z. G. Fan, S. Qiao, J. T. Huangfu, and L. X. Ran., “A miniaturized printed dipole antenna with v-shaped ground for 2.45 ghz rfid readers” Progress In Electromagnetics Research, PIER 71, 149–158, 2007
8. Salvatore Tuccio, Alessandro Alabastri, Luca Razzari, Andrea Toma, Carlo Liberale, Remo Proietti Zaccaria, Francesco De Angelis, Gobind Das, Enzo di Fabrizio., “Terahertz Resonant Dipole Nanoantennas” Latin America Optics and Photonics Conference 2012.
9. T. K. Nguyen, T. A. Ho, I. Park, and H. Han., “Full-wavelength dipole antenna on a gaas membrane covered by a frequency selective surface for a terahertz photomixer” Progress In Electromagnetics Research, Vol. 131, 441-455, 2012
10. Truong Khang Nguyen and Ikmo Park., “Effects of antenna design parameters on the characteristics of a terahertz coplanar stripline dipole antenna” Progress In Electromagnetics Research M, Vol. 28, 129-143, 2013
11. Dr. P. Siddaiah, S Nagakishore Bhavanam, Vasujadevi Midasala., “Design of Dipole antenna using COMSOL MULTIPHYSICS Software” Proceedings of International Conference on Innovations in Electronics and Communication Engineering (ICIECE 2014)
12. Smith, G. S., “Teaching antenna reception and scattering from a time-domain perspective,” American Journal Physics, Vol. 70, 829–844, Aug. 2002.
13. Rao, K. V. S., P. V. Nikitin, and S. F. Lam, “Antenna design for UHF RFID tags: a review and a practical application,” IEEE Trans. Antennas Propagat., Vol. 53, No. 12, 3870–3876, Dec. 2005.
14. Karthaus, U. and M. Fischer, “Fully integrated passive UHF RFID transponder IC with 16.7-μW minimum RF input power,” IEEE J. Solid-State Circuits, Vol. 38, No. 10, 1602–1608, Oct. 2003.
15. Fan, Z. G., et al., “Signal descriptions and formulations for long range UHF RFID readers,” Progress In Electromagnetics Research, PIER 71, 109–127, 2007.
16. Mitilineos, S. A., S. C. A. Thomopoulos, and C. N. Capsalis, “Genetic design of dual-band, switched-beam dipole arrays, with elements failure correction, retaining constant excitation coefficients,” Journal of Electromagnetic Waves and Applications, Vol. 20, No. 14, 1925–1942, 2006.
17. Chuang, H.R.andL.C.Kuo, “3-DFDTDdesignanalysisofa2.4-GHz polarization-diversity printed dipole antenna with integrated balun and polarization-switching circuit for WLAN and wireless communication applications,” IEEE Transactions on Microwave Theory and Techniques, Vol. 51, No. 2, 374–381, 2003.
18. R. W. DeGrosse, et.al., "Ultra-Low-Noise measurements using a Horn Reflector Antenna and a Traveling-wave Maser". Journal Applied Physlci, pp. 2013/ Dee. 1939
19. L. J. Mlloteulc, R. Vantey "Traveling-Wave Retonator" IRE Trom. Vol. MTU, No. 2, pp. 126-143, April 1958.

20. M. Alexander M. Salter B. Loader and D. Knight "Broadband calculable dipole reference antennas" IEEE Transactions. Electromagnetic. Compatabilty . Vol. EMC-44 ,No. 1 pp. 45-58, Feb. 2002.
21. T. Morioka and K. Hirasawa "MOM calculation of the properly dened dipole antenna factor with measured balun characteristics" IEEE Transactions. Electromagnetic. Compatabilty ",Vol. 53 ,No. 1 p. /njhhhp. 233-236 Feb. 2011.
22. K. Hirasawa M. Shintaku and H. Morishita "Received and scattered power of receiving antenna " IEEE AP-S International Symosium pp. 205-208 June 1994.
23. T. Morioka "Antenna factors of an off-resonant dipole antenna " CPEM 2012 Conf. Digest pp. 632-633 Washington D. C. July 2012.
24. L. C. Kretly and C. E. Capovilla, "Patches Driver on the Quasi-Yagi Antenna: Analyses of Bandwidth and Radiation Pattern," Proceedings of the International Microwave and Optoelectronics Conference, Vol. 1, 2009, pp. 313-316
25. J. M. Floc'h and H. Rmili, "Design of Multiband Printed Dipole Antennas Using Parasitic Elements," Microwave and Optical Technology Letters, Vol. 48, No. 8, 2006, pp. 1639-1645. doi:10.1002/mop.21714
26. Ayestaran, R. G., J. Laviada, and F. Las-Heras, "Synthesisof passive- dipole arrays with a genetic-neural hybrid method,"Journal of Electromagnetic Waves and Applications, Vol. 20,No. 15, 2123–2135, 2006.
27. R. L. Li, B. Pan, T. Wu, K. Lim, J. Laskar, and M. M. Tentzeris., "A Broadband Printed Dipole and a Printed Array for Base Station Applications" IEEE Antennas and Propagation Society International Symposium 2008.
28. K. Xu, Z. Zhu, H. Li, J. Huangfu, C. Li, L. Ran, "A printed single-layer UWB monopole antenna with extended ground plane stubs", IEEE Ant. and Wireless Propag. Lett. 12: 237-240, 2013.
29. B. G. Duffley, G. A. Morin, M. Mikavica, and Y. M. M. Antar,(2004) "A wide-band printed double-sided dipole array," IEEE Transactions on Antennas and Propagation, vol. 52, no. 2, pp. 628–631.
30. C. Votis, V. Christofilakis, and P. Kostarakis, (2010) "Geometry aspects and experimental results of a printed dipole antenna," International Journal of Communications, Network and System Sciences, vol. 3, pp. 97–100.
31. M. C. Bailey,(1984) "Broad-band half-wave dipole," IEEE Transactions on Antennas and Propagation, vol. 32, no. 4, pp. 410–412, 1984.
32. Z. Fan, L. Ran, and K. Chen,(2005) "Printed dipole antenna designed with microstrip balun on v-shaped ground plane," in Progress In Electromagnetic Research Symposium, pp. 23–26, Hangzhou, China, 2005
33. Hisiao, F.-R. and K.-L. Wong, "Omnidirectional planar folded dipole antenna," IEEE Trans. Antenna Propatat., Vol. 52, 1898–1902, July 2004.
34. Sumit Kumar Gupta, Harish Kumar Jangam, Nipun Sharma, "Theory of Antennas, Its Advantage & Applications in Communication Systems" 2018 IJEDR, Volume 6, Issue 1, ISSN: 2321-9939.
35. Mrs.S.Parameswari, N.Pon aravinth Kumar, M.Priyanka, M.Priyanga, "Half-Wave Dipole Antenna for Satellite Communication Application", International Journal of Digital Communication and Networks (IJDCN) Volume 2, Issue 3, March 2015
36. Diao, J. M., F. Yang, Z. P. Nie, J. Ouyang, and P. Yang, "Separated fractal antennas for improved emission performance of terahertz radiations," Journal of Electromagnetic Waves and Applications, Vol. 26, Nos. 8–9, 1158–1167, 2012.
37. Kominami, M., D. M. Pozar, and D. H. Schaubert, "Dipole and slot elements and arrays on semi-infinite substrate," IEEE Trans. Antennas Propagat., Vol. 33, No. 6, 600–607, 1985.
38. Williams, B. S., "Terahertz quantum-cascade lasers," Nature Photon., Vol. 1, 517–525, Sep. 2007
39. Preu, S., G. H. D¨ohler, S. Malzer, L. J. Wang, and A. C. Gossard, "Tunable, continuous-wave terahertz photomixer sources and applications," J. Appl. Phys., Vol. 109, 061301, 2011
40. Maineult, W., P. Gellie, A. Andronico, P. Filloux, G. Leo, C. Sirtori, S. Barbieri, E. Peytavit, T. Akalin, J.-F. Lampin, H. E. Beere, and D. A. Ritchie, "Metal-metal terahertz quantum cascade laser with micro-transverse-electromagnetic- horn antenna," Appl. Phys. Lett., Vol. 93, No. 18, 183508, 2008.
41. Gregory, I.S., W.R,Tribe, B.E.Cole, M.J.Evans, E.H.Linfield, A. G. Davies, and M. Missous, "Resonant dipole antennas for continuous-wave terahertz photomixers," Appl. Phys. Lett., Vol. 85, 1622–1624, 2004.
42. Bharathi Bhat AND Shiban K. Koul., "Unified approach to solve a class of strip and microstrip-like transmission lines" IEEE transactions on Microwave theory and Techniques, VOL. MTT-30, NO. 5, May 1982.
43. G.A. Evtioushkine, J.W. Kim and K.S. Han., "Very wideband printed dipole antenna array" Electronics Letters 26th November 1998 Vol. 34 No. 24.

Mehak Chaturvedi is a M.Tech student in Department of Electronics and Communication Engineering from Bhagat Phool Singh Mahila Vishwavidyalaya, Khanpur-Kalan (Sonepat). She received B.Tech degree in ECE from Bhagat Phool Singh Mahila Vishwavidyalaya, Khanpur Kalan (Sonepat). Her research interest includes Antenna design and propagation and interest tool is COMSOL Multiphysics.