Finite Difference Time Domain Method Based SAR Calculation and Bending Analysis of a Multiband Wearable Antenna

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***Abstract*—**In this paper, calculation of specific absorption rate (SAR) and bending analysis of a multiband wearable antenna using finite difference time domain (FDTD) method is presented. The objective of this paper is to illustrate the modelling of a wearable antenna using FDTD method and to compare the results of FDTD method with that of high frequency structure simulator (HFSS) and measured results. FDTD method has been used to demonstrate the modelling of the metal patch and ground plane, along with modelling of the substrate, coaxial feed and human tissue model. Three layer human tissue model is used for SAR calculations. The FDTD method based results are in good agreement with that of HFSS and measured results, validating the code written for FDTD method.

Keywords*—FDTD method; multiband wearable antenna; specific absorption rate; human tissue model; bending.*

I. INTRODUCTION

Now a days, most of the researchers are using simulators for the designing and analysis of the antennas. They are normally interested in the front end of the simulator and are least concerned about the backend. This approach is however easy, reliable and time saving. But they lack the in-depth understanding of how the simulator is analyzing their antennas. The actual chemistry of electromagnetic waves flow from source feed to the antenna, in the antenna and finally in free space is remained somewhat unexplained to the designer. With the help of FDTD method, the designer can write equations for the modelling of source feed, ground plane, substrate, patch, human tissue model and free space, and can have better understanding of the electromagnetic wave interaction with the antenna. In past, many researchers have used FDTD for the analysis and calculation of antenna parameters [2-7]. Also, like any available simulator, the major parameters like electric field, magnetic field, current, reflection coefficient (S11), gain, radiation pattern and SAR values can be calculated using FDTD method source code, written in C, C++ or Matrix Laboratory (MATLAB). The effect of bending on wearable antennas and the amount of energy absorbed by human tissue and there SAR values are equally important and have been calculated in the previous works [8-10, 11-14].

Recognizing the potential of the FDTD method, in this work, the calculation of SAR and bending analysis of a multiband wearable antenna using FDTD method has been presented.

II. MODELLING OF THE MULTIBAND WEARABLE ANTENNA USING FDTD METHOD

The four band wearable antenna [14] used for the calculations of specific absorption rate (SAR) and analysis under bending condition using finite difference time domain (FDTD) method is shown in Fig. 1. The major dimensions of the antenna are L_{ag} = 70 mm, W_{ag} = 70 mm, L = 23 mm, a = 30 mm [14]. The thickness and dielectric constant of the polyester substrate is 2 mm and 1.39 respectively [14]. The rest of the dimensions are not mentioned as they are available in [14]. To accurately model the wearable antenna, the cell size in *x, y* and *z* directions is kept as 0.5 mm.

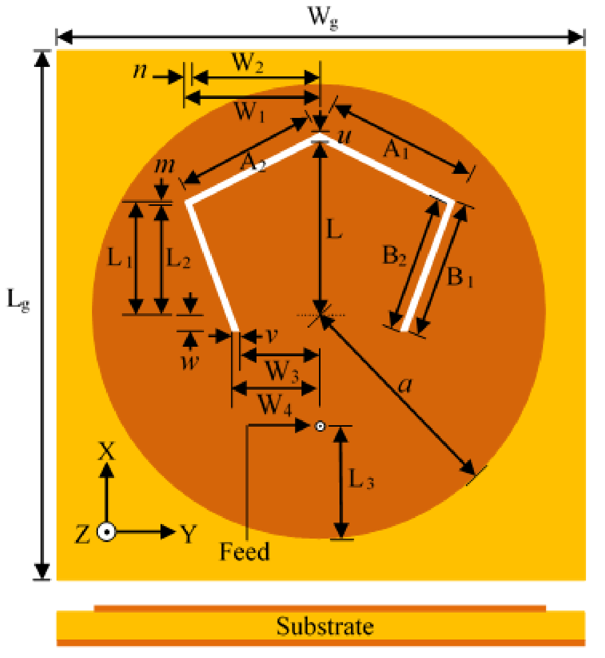

Figure 1. Wearable antenna used for SAR calculation and bending analysis using FDTD method [14], [reused courtesy of the Electromagnetics Academy]

Total 160 cells in *x*-direction, 160 cells in *y*-direction and 30 cells in *z*-direction are considered for modeling of the antenna in free space. The circular patch is modelled using 120 cells in *x*-plane and 120 cells in *y*-plane. The FDTD modelling of the slot in the circular patch using 52 × 72 cell matrix is illustrated in Fig. 2. FDTD cells with grey color are showing the modelling of the slot in the circular patch. The ground patch is modelled using 140 cells in *x*-plane and 140 cells in *y*-plane. Total 140 × 140 × 4 cells are used for the modelling of the polyester substrate in *x*, *y* and *z* planes respectively. The antenna is excited with Gaussian pulse through coaxial feed. The distribution of the E_z component in the circular patch after 300 time steps of the FDTD simulation of the multiband wearable antenna is shown in Fig. 3.

A. *SAR calculation using FDTD Method*

For SAR calculations, same three layer human tissue model used in [14] is considered. The surface size of the human tissue model is 120 × 120 mm^2 [14]. The thickness of the skin, fat and muscle layers are kept 3, 13 and 60 mm respectively, same as taken in [14].

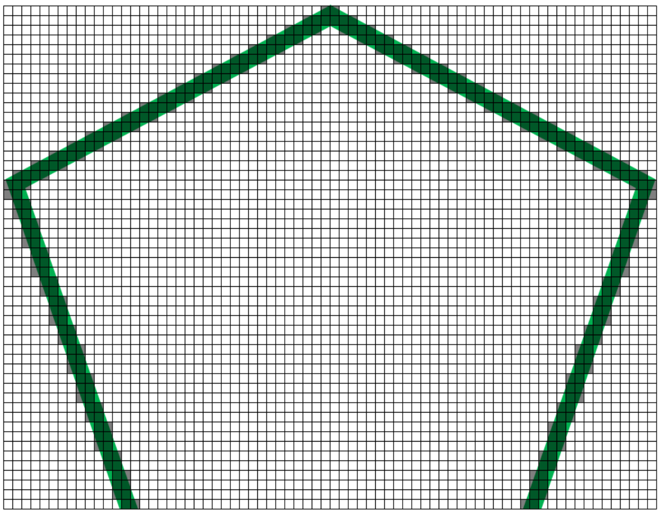

Figure 2. Modelling of the slot in the circular patch of the wearable antenna using FDTD method.

The distance between the antenna and human tissue model is 5 mm [14] and 0.5 W is used as input power to the wearable antenna for SAR calculation. The permittivity, conductivity and density of the three layers are kept same as used in [14]. SAR can be related to the electric field at a point by [10, 13],

$$SAR = \frac{\sigma |E|^2}{\rho} \quad (1)$$

where σ is conductivity of the tissue (S/m), ρ is mass density of the tissue (Kg/m^3) and E is the rms electric field strength in tissue (V/m). Total 260 cells in *x* and *y* direction each and 190 cells in *z*-direction are used for FDTD modelling of multiband wearable antenna over three layer human tissue model. The SAR values at 1.8 GHz, 2.4 GHz, 3.6 GHz and 5.5 GHz, averaged over 10 gm of tissue, are presented in Table I. Table I reveals that the SAR values calculated at 1.8 GHz, 2.4 GHz, 3.6 GHz and 5.5 GHz using FDTD method are significantly low as compared to the SAR values estimated using HFSS in [14].

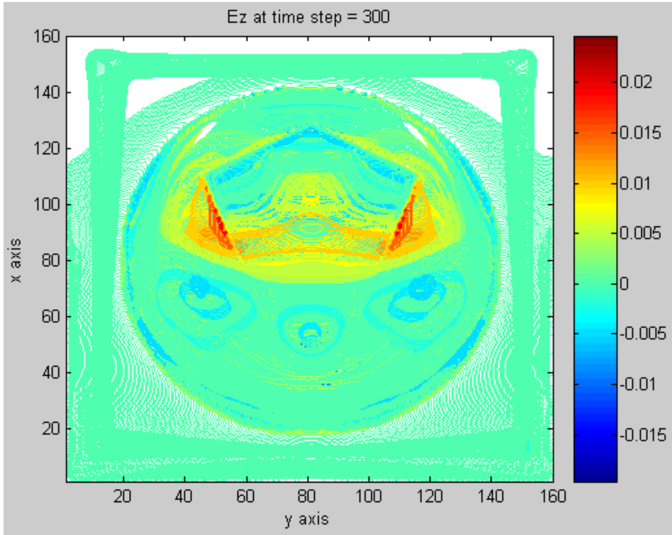

Figure 3. The distribution of the Ez component in the circular patch after 300 time steps of FDTD simulation of the multiband wearable antenna.

The reflection coefficients calculated using FDTD method and HFSS at 1.8/2.4/3.6/5.5 GHz are -10.53/-8.30/-20.26/-12.39 and -15.95/-12.98/-11.12/-18.31 respectively [14]. These low SAR values calculated using FDTD method can be attributed to the high values of reflection coefficients at 1.8 GHz, 2.4 GHz, 3.6 GHz and 5.5 GHz, estimated using FDTD method.

TABLE I. COMPARISON OF CALCULATED SAR VALUES USING FDTD METHOD WITH HFSS RESULTS [14]

Frequency (GHz)	**Averaged SAR (W/Kg)**	
	HFSS	***FDTD Method***
1.8	0.121	0.0350
2.4	0.411	0.0444
3.6	0.874	0.0382
5.5	0.954	0.0357

B. *Bending Analysis using FDTD Method*

To analyze the wearable antenna under bending condition using FDTD method, it is modelled on a PVC (poly vinyl chloride) pipe of 150 mm diameter. Considering bending of the wearable antenna along *y*-plane only, total 160, 160 and 52 cells in *x*, *y* and *z* directions are used to model the antenna on the PVC pipe respectively. The photograph of the fabricated antenna bent along y-plane on PVC pipe is shown in Fig.4. The FDTD method based staircase modelling of the wearable antenna, bent along *y*-plane on PVC pipe is presented in Fig. 5. The bended circular patch is modelled using only 102 cells along *y*-plane and 120 cells along *x*-plane. The reduced amount of cells in *y*-plane are due to the staircase modelling of circular patch along *z*-plane in 18 cells, as illustrated in Fig. 5.

The ground patch bent along *y*-plane is modelled using 116 cells in *y*-plane and 140 cells in *x*-plane. The reduced amount of cells in *y*-plane are due to the staircase modelling of the ground patch along *z*-plane in 24 cells, as shown in Fig. 5. In Fig. 6, the reflection coefficients of the flat and bended wearable antenna along *y*-plane, calculated using FDTD method, is compared with that of HFSS and measured results given in [14].

Figure 4. Photograph of the fabricated wearable antenna bent along *y*-plane on PVC pipe [14], [reproduced courtesy of the Electromagnetics Academy].

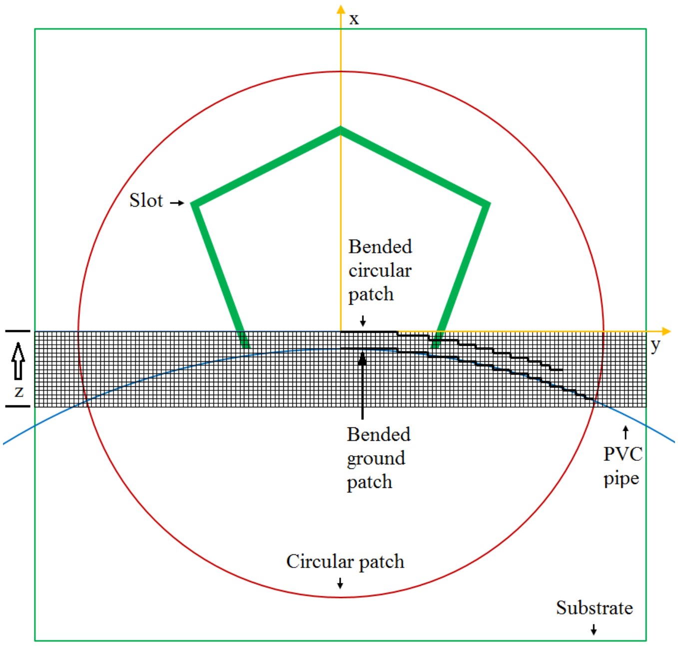

Figure 5. FDTD modelling of the wearable antenna bent along y-plane on PVC pipe.

The reflection coefficient of the flat multiband wearable antenna in free space, estimated using FDTD method, reveals that the antenna resonates at 1.94/2.78/3.62/5.54 GHz with reflection coefficient values of -13.43/-10.61/-20.51/-12.49 and impedance bandwidths of 320/280/660/420 MHz respectively. However, for HFSS case, the resonant frequencies of the multiband wearable antenna are 1.88/2.44/3.64/5.54GHz with impedance bandwidths of 310/110/110/240 MHz respectively [14]. The measured resonant frequencies of the antenna are 1.88/2.4/3.6/5.48 GHz with impedance bandwidths of 320/60/80/180 MHz respectively [14]. For FDTD case, the reflection coefficient of the multiband wearable antenna bent along *y*-plane on PVC pipe describes that the bended antenna resonates at 1.8/2.7/3.64/5.54 GHz with reflection coefficients of -15.05/-12.22/-14.84/-30.63 and impedance bandwidths of 280/300/440/600 MHz respectively. The percentage of the frequency detuning for FDTD and measured cases of the wearable antenna, bent along *y*-plane, is 7.21/2.87/0.55/0.0% and 2.13/1.67/1.12/1.45% respectively. The reflection coefficient of the bent antenna estimated using FDTD method shows that the first two bands of 1.94 GHz and 2.78 GHz shifts to the left side of the spectrum and followed the shifting trends of the measured bands of the antenna bent along *y*-plane [14]. Similarly, the third band of 3.62 GHz shifts to the right side and followed the shifting trend of the measured third band [14]. The fourth band of the antenna for FDTD case does not shift but attains wide bandwidth.

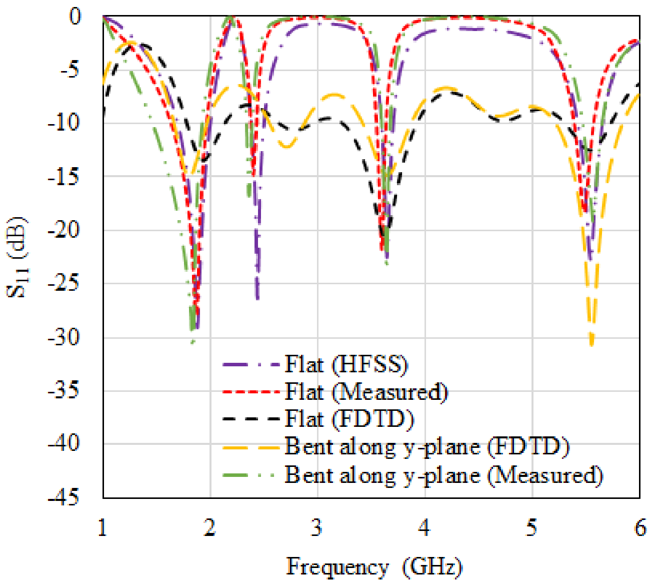

Figure 6. Comparison of reflection coefficients (S_{11}) of the flat and bent wearable antenna along y-plane, calculated using FDTD method, with HFSS and measured results [14], [reproduced courtesy of the Electromagnetics Academy]

III. CONCLUSION

FDTD method based modelling of the multiband wearable antenna for SAR calculation and bending analysis is successfully implemented and results are presented. Due to high reflection coefficient values of the wearable antenna, Calculated SAR values using FDTD method are comparatively lower than the SAR values estimated using HFSS. The results of the bending analysis of the wearable antenna using FDTD method nearly followed the trends of the measured results.

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REFERENCES

[1] A. Taflove and M. Brodwin, “Numerical solution of steady state electromagnetic scattering problems using the time-dependent

Maxwell's equations," IEEE Transactions on Microwave Theory and Techniques, Vol.23, pp. 623-730, 1975.

[2] A. Reineix and B. Jecko, "Analysis of Microstrip Patch Antennas Using Finite Difference Time Domain Method," IEEE Transactions on Antenna and Propagation, Vol.37, no.11, pp. 1361-1369, 1989.

[3] D. M. Sheen, S. M. Ali, M. D. Abouzahra and J. A. Kong," Application of the Three-Dimensional Finite-Difference Time-Domain Method to the Analysis of Planar Microstrip Circuits," IEEE Transactions on Microwave Theory and Techniques, vol.38, no.7, pp. 849-857, 1990.

[4] D. M. Sullivan, Electromagnetic Simulation using The FDTD Method, IEEE Press, 2000.

[5] R. J. Luebbers and H. S. Langdon, "A Simple Feed Model that Reduces Time Steps Needed for FDTD Antenna and Microstrip Calculations," IEEE Transactions on Antenna and Propagation, Vol. 44, no. 7, pp. 1000-1005, 1996.

[6] D. Mandal, and S. S. Pattnaik, " Effect of Milli Bends on Reflection Coefficient of a Wearable Antenna Using FDTD Method," Proceedings of International Conference on Soft Computing Applications in Wireless Communication - SCAWC, pp. 261-264, 2017.

[7] D. Mandal, and S. S. Pattnaik, "FDTD Based Analysis of Input Impedance of a Wearable Patch Antenna with Milli Bends," Proceedings of 5th International Conference on Advancements in Engineering and Technology (ICAET), pp. 197-200, 2017.

[8] J. Gemio, J. Parron, and J. Soler, "Human Body Effects on Implantable Antennas for ISM Bands Applications: Models Comparison and Propagation Losses Study," Progress In Electromagnetic Research, Vol. 110, 437-452, 2010.

[9] M. Klemm, and G. Troester, "EM Energy Absorption in the Human Body Tissues due to UWB Antennas," Progress In Electromagnetic Research, Vol. 62, 261–280, 2006.

[10] O. Kivekas, T. Lehtiniemi, and P. Vainikainen, "On the General Energy Absorption Mechanism in the Human Tissue," Microwave and Optical Technology Letters, Vol. 43, No. 3, 195-201, Nov. 2004.

[11] J. G. Joshi, S. S. Pattnaik, and S. Devi, "Metamaterial Embedded Wearable Rectangular Microstrip Patch Antenna," International Journal of Antennas and Propagation, Vol. 2012, Article ID 974315, 9 pages, 2012.

[12] B. Hu, G. P. Gao, L. L. He, X. D. Cong, and J. N. Zhao, "Bending and On-Arm Effects on a Wearable Antenna for 2.45 GHz Body Area Network," IEEE Antennas and Wireless Propagation Letters, Vol. 15, 378–381, 2016.

[13] S. Khalatbari, D. Sardari, A. A. Mirzaee, and H. A. Sadafi, "Calculating SAR in Two Models of the Human Head Exposed to Mobile Phones Radiations at 900 and 1800MHz," Progress In Electromagnetics Research Symposium, pp. 104-109, 2006.

[14] D. Mandal, and S. S. Pattnaik, "Quad-Band Wearable Slot Antenna with Low SAR Values for 1.8 GHz DCS, 2.4 GHz WLAN and 3.6/5.5GHz WiMAX Applications," Progress In Electromagnetics Research B, Vol. 81, 163–182, 2018.

[15] FCC: Body tissue dielectric parameters, http://www.fcc.gov/oet/rfsafety/dielectric.html

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