Numerical investigation on a Body-Centric Scenario at W Band

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***Abstract*- Numerical analysis has been presented for a short-range on-body channel at 94 GHz. Finite Difference Time Domain technique has been adopted to investigate the scenario. Since at higher frequency FDTD becomes computationally expensive, a parallel version of the method has been implemented in an in-house software. Path loss values have been calculated for head to shoulder link. Results are compared with measurements and commercially available software adopting a ray-based approach. A further analysis is provided for both parallel and perpendicular polarization of the source.**

Index Terms— FDTD; Ray-tracing, BAN, Path Loss, V band

I. INTRODUCTION

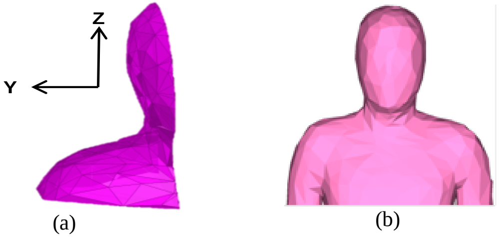
In recent years, interest on body centric wireless communication systems has expanded significantly. Various systems operating at microwave frequencies ranging from 401 MHz of MICS to 10 GHz of UWB region [1] have earned popularity in the research community. However these portions of the spectrum have become saturated due to a strong overlap with the frequencies dedicated to mobile communication systems. As a consequence, new on-body systems might struggle to acquire licenses. Moving up to higher frequencies seem to provide a plausible solution [2], specifically V and W bands, which jointly cover from 60 GHz to 110 GHz. Small wavelengths, enabling miniature antennas with higher data rate and greater bandwidth make these spectrums potentially more lucrative. Adoption of this band may accelerates the development of many innovative, personalized and integrated electronic applications, suitable from health care to defense, from lifestyle to fitness. Since at these frequencies, losses increase significantly at higher distances, they also offer the additional advantage of an easier confinement of the energy around the body, with reduced problems in terms of interference, safety and security.

It is worth mentioning that at V and W band frequencies the human body is large compared to the wavelength and acts as a highly lossy medium for the propagating signal. Therefore even for shorter link channels a correct characterization becomes crucial. A good amount of groundwork has already been performed in terms of experimentation for analyzing the channel characteristics at mm-wave frequencies [3], [4]. On the other hand, numerical approaches give the flexibility to consider the propagation scenario closely and overcome many issues arisen during of measurement campaign. Generally, ray-tracing based techniques, hybridized along with Finite Difference Time Domain (FDTD), Finite Element Method (FEM) and Method of Moments (MoM) have been proposed to study outdoor propagation and radiation problems dealing with large objects [5], [6]. Preliminary studies involving the implementations of ray-based techniques in body-centric scenarios have been presented [7], [8]. However, Finite Difference Time Domain method is one of the most versatile full wave numerical approaches for bio electromagnetic simulations. Despite the fact that at higher frequencies FDTD becomes highly expensive in terms of computational burden it can still be efficiently employed for short-range communication.

In this paper, firstly the analysis has been presented for a head-to-shoulder link at 94 GHz in terms of path loss values. Initially this link has been investigated with the aid of in-house software implementing a full wave Parallel FDTD (P-FDTD) method. Subsequently the results have been compared with commercial software RemCom XGTDv2.5, which is based on Geometrical Optics (GO) and Uniform Theory of Diffraction (UTD), and measured data. In addition, both parallel and perpendicular polarization of the source has been considered for the above mentioned link in PFDTD domain.

II. SIMULATION SETUP

In order to characterize an on body channel at W band, different experimental techniques can be adopted. However measurement campaigns include a lot of artifacts with a limitation in repeatability. Numerical approaches, on the other hand, provide considerable flexibility in investigating the propagation scenario. More specifically, full wave numerical techniques are highly useful for channel characterization. In this paper FDTD, a highly reliable full wave method has been adopted. Since at the investigated frequency human body is large compared to the wavelength, to obtain a good tradeoff between accuracy and computational effort only half of the investigated structure has been taken into consideration in the FDTD simulation environment. The numerical model used in the full wave simulation domain is presented in Fig. 1 (a). In fact, due to the high losses in human tissues at 94 GHz, the contribution of the other half of the phantom can be considered negligible. This model has been generated statistically from the MRI (Magnetic Resonance Imaging) scanned images of various human subjects representing different body shapes and proportions [9]. A high frequency based ray based method is compared along with the measurement results as in Fig.1 (b).



(a) (b)

Figure 1. Numerical model of the human body(a)Model used in Ray Tracing (b)Model used for FDTD simulation

The models are considered to be homogeneous with the dielectric properties as that of dry skin at 94GHz.This are due to the fact that at this frequency penetration depth is significantly lower and the transmitted signal diminishes within a few millimeters from the top of the skin. Therefore, according to [10], a dielectric permittivity, ε_r of 5.97 and an electric conductivity σ of 38.19 S/m have been assigned to the model.

The Parallel FDTD Simulation

In the simulation domain, a properly voxelized version of the geometry shown in Fig. 1 (a) has been imported and further separated in several subdomains. A parallel version of FDTD has been adopted by analyzing each subsection by different processors. The whole volume is constituted by 603×543×1010 cells which discretize a domain of about $20\times20\times30$ cm^3. The cell size has been chosen equal to 0.3 mm. A hard source has been imposed in order to polarize the electric field along the x axis and y axis for exciting parallel polarization and perpendicular polarization respectively. A continuous sinusoidal function at 94 GHz is applied to excite the transmitter. The source is positioned at a distance of 1cm from the head.

The Ray-based approximation using XGTD

After importing the structure shown in Fig. 1 (b), in XGTD, a set of receivers have been defined near the shoulder. The transmitting antenna has been placed at 1cm far from the head, above the ear, as mentioned above. Two open-ended standard rectangular waveguides WR-10 (Fig. 2c) have been used both as transmitter and receiver. The patterns on the E-plane and H-plane, shown in Fig. 2(a), (b), (d) and € respectively, have been obtained by simulating the waveguide in proximity of a digital phantom representing the properties of human skin at 94 GHz. in order to correctly take into account the modification of the radiation pattern due to the proximity of the head and the shoulder.. The WR-10 at the transmitter end is positioned such that the E-plane is perpendicular to head. On the receiver side the rectangular waveguide provides an E-plane parallel to the shoulder. In order to correctly take into account the modification of the radiation pattern due to the proximity of the head, then imported and interpolated in XGTD.

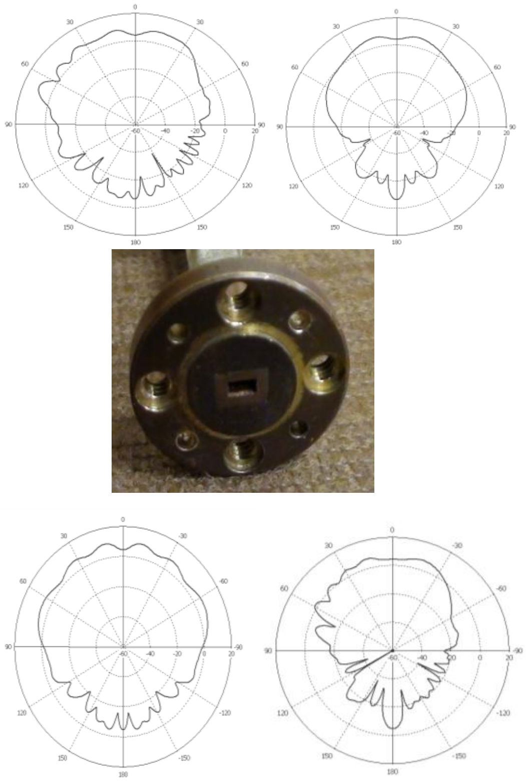


Figure 2. Radiation pattern in E-plane for perpendicular polarization(a) and on H-plane for same polarization(b)WR-10 used in measurements (c), 3D pattern (b), Radiation Pattern on E-plane for parallel polarization (d) and on H-plane (e)

III. EXPERIMENTATION SETUP

An experimental procedure has been carried out for a real human subject with regard to numerical simulation. Results have been compared in terms of path loss for two of the cases. The measurement has been performed as shown in Fig. 5. Signal has been generated by a Continuous Wave (CW) generator at 10.4 GHz. It acts as an input for the frequency multiplier. A 20 dB directional coupler has been connected at the output of multiplier in order to obtain a reference signal. Both the reference and the received signals at 94 GHz are down-converted to 20MHz by using a 9th harmonic mixer and the signal generated by a Local Oscillator (LO).

On the receiving end, a mechanical scan remotely controls the flanged waveguide WR-10 and enables it to move over a vertical plane with a precision of 0.1 mm. In the end, path loss values are obtained from the VNA by using the reference signal and the received one.

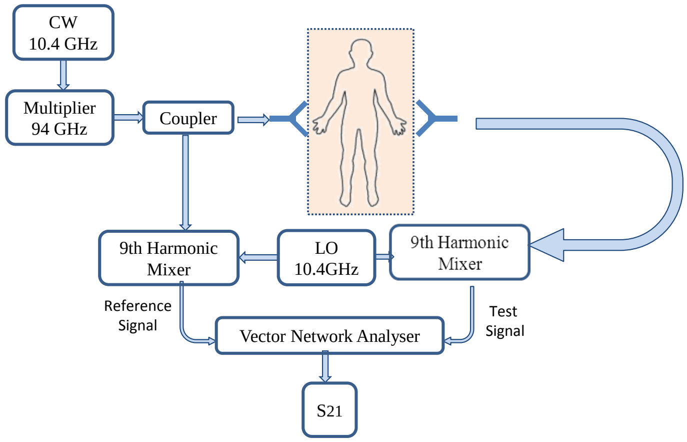
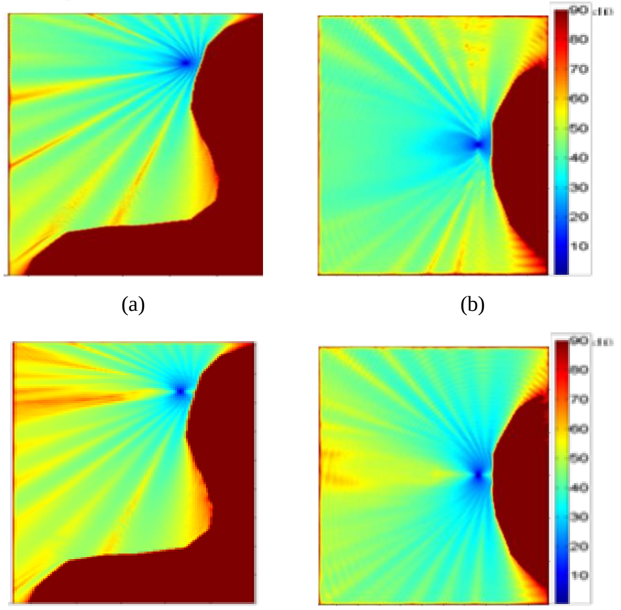


Figure 3. Setup for measurement

IV. RESULTS

The path loss distribution obtained from FDTD simulation is presented in longitudinal view (Figure-4(a) and 4(c)) and cross sectional view (Figure-4(b) and 4(d)) for perpendicular and parallel polarization.



(a) (b)

(c) (d)

Figure 4. Path loss distribution[dB] for parallel polarization in longitudinal view(a) and in crosssectional view(b)Path loss distribution[dB] for perpendicular polarization in longitudinal view(c) and in crosssectional view(d)

It is observed from figure 4 that for both the cases parallel and perpendicular polarizations signal penetration inside body is negligible.

TABLE I. COMPARISON BETWEEN PATH LOSS VALUES ACHIEVED FOR THE HEAD-SHOULDER LINK WITH FDTD MEASUREMENT AND RAY TRACING BASED TECHNIQUE, D=10MM

Distance (cm)	*FDTD Simulated Result[dB]*	*Measurement result [dB]*	*RayTracing Simulation(dB)*
24	47.03	36.5	52.5
26	49.4	39	46.8
28	52.8	40.8	41.0

It is observed from the above mentioned table that for all three cases of source to receiver distance path loss obtained from FDTD is 10dB higher than the measurement result. This occurs due to the fact that the gain of the rectangular waveguide is more than the point source adopted in FDTD domain. However the constant increase in path loss from full wave simulation agrees with the fact that FDTD is providing stable solution.

Finally, the effect of different polarizations at 94 GHz has been observed. Path gains have been monitored from FDTD along a curve (along the blue line inset of figure 5) near shoulder in the source plane. Path gain distribution with the change of distances is plotted in figure 5 in comparison with free space path loss values.

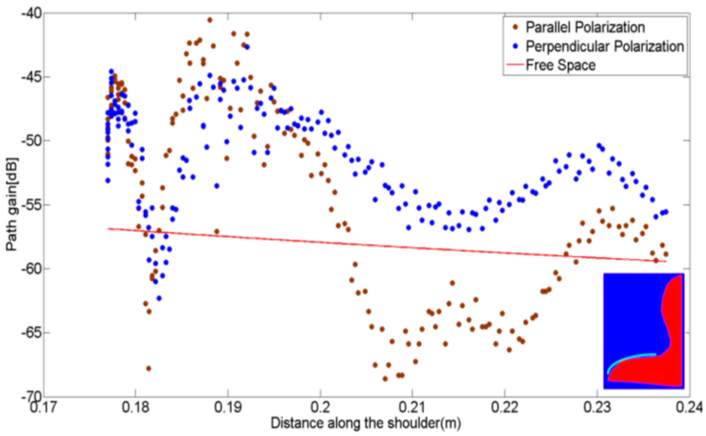


Figure 5. Receiving locations for calculating path gain(a) Path gain distribution for paralleland perpendicular polarization(b)

Figure 5 depicts that along the receiving locations near the shoulder, perpendicular polarization offers better link with higher path gain compared to the parallel polarization. As the receiving probe moves toward the edge of the shoulder, path gain values for both polarizations approximate the free space path gain.

V. CONCLUSIONS

A numerical study has been performed for an on body channel at 94GHz.Parallel FDTD technique has been applied to analyze the head–shoulder link in terms of path loss.

Results are compared with measured values and commercially available software XGTD suitable for high frequency operation. It has been observed that although the antenna gains are different in measurement and FDTD domain, path loss values follow a similar trend with a constant 10dB difference between the two, whereas the ray based algorithm fails to maintain the trend. This is due to the fact that ray based approach does not consider guided wave propagation and a more detailed model might be useful. A further analysis has been performed in FDTD with two different polarizations of transmitters: parallel and perpendicular polarization. It is observed that for head to shoulder link perpendicular polarization allows stronger link than parallel polarization. However to the edge of the shoulder, path loss tends to approximate free space losses.

REFERENCES

[1] P. S. Hall, Y. Hao, Antennas and Propagation for Body-Centric Wireless Communications, Boston, MA: Artech House, 2006.

[2] Report and Order of the Federal Communications Commission, FCC 03-248, November 2003.

[3] I P. Usai, A. Pellegrini, A. Brizzi, L. Zhang, A. Monorchio, Y. Hao, "Analysis of On-Body Propagation at W band by using Ray Tracing Model And Measurements", 2012 Antennas and Propagation Society Symposium, Chicago, USA.

[4] Y. Nechayev, C. Constantinou, S. Swaisaenyakorn, O. Rakibet, J. Batchelor, P. Hall, C. Parini, J. Hunt, “Use of motion capture for path gain modelling of millimetre-wave on-body communication links,” 2012 International Symposium on Antennas and Propagation, Nagoya, JP

[5] P.Bernardi, M. Cavagnaro, R. Cicchetti, S. Pisa, E. Piuzzi and O. Testa, “A UTD/FDTD investigation on procedures to assess compliance of cellular base-station antennas with human-exposure limits in a realistic urban environment,” IEEE Trans. on microvawe theory and techniques, vol. 51, no. 12, pp. 2409-2417, December 2003.

[6] R. Fernández-Recio, L. García-Castillo, I. Gómez-Revuelto and M.Salazar-Palma, “Fully coupled hybrid FEM-UTD method using NURBS for the analysis of radiation problems,” IEEE Trans. on Antennas and Propagation, vol. 56, no. 3, pp. 774-783, March 2008.

[7] S. Alipour, F. Parvaresh, H. Gajari, D. F. Kimball, "Propagation characteristics for a 60 GHz Wireless Body Area Network (WBAN)," 2010 Military Communications Conference, San Jose, CA.

[8] A. Pellegrini, A. Brizzi, L. Zhang, Y. Hao, “Body-centric Wireless Communications at 94GHz”, 2012 Symposium on Antennas and Propagation, Nagoya, JP.

[9] S. L. Lee, K. Ali, A. Brizzi, J. Keegan, Y. Hao, and G. Z. Yang, “A Whole Body Statistical Shape Model for Radio Frequency Simulation,” 33rd Annual International Conference of the IEEE EMBS, Boston, Massachusetts,USA, August 30 - September 3, 2011.

[10] D. Andreuccetti, Fossi R., C. Petrucci, “Calculation of the dielectric properties of body tissues”, http://niremf.ifac.cnr.it/tissprop