Title	Effect of wave polarization in on-body propagation for the 2.4, 24 and 60 GHz ISM bands
Authors	Khan, Wasi Ur Rehman;Ammann, Max J.;Scanlon, William G.
Publication date	2024-04-26
Original Citation	Khan, W. U. R., Ammann, M. J. and Scanlon, W. G. (2024) 'Effect of wave polarization in on-body propagation for the 2.4, 24 and 60 GHz ISM bands', 2024 18th European Conference on Antennas and Propagation (EuCAP), Glasgow, United Kingdom, 17-22 March 2024, pp. 1-4. https://doi.org/10.23919/EuCAP60739.2024.10501006
Type of publication	Conference item
Link to publisher's version	https://doi.org/10.23919/EuCAP60739.2024.10501006

Effect of Wave Polarization in On-body Propagation for the 2.4, 24 and 60 GHz ISM Bands

Wasi Ur Rehman Khan[1], Max J. Ammann[1], William G. Scanlon[2]
[1] Antenna and High Frequency Research Centre (AHFR), School of Electrical and Electronic Engineering, Technological University Dublin, Dublin, Ireland
wasiurrehman.khan@tudublin.ie, max.ammann@tudublin.ie
[2] Tyndall National Institute and School of Engineering and Architecture, University College Cork, Cork, Ireland
william.scanlon@tyndall.ie

***Abstract*— A skin-based phantom is used to numerically model on-body propagation at three different frequencies, 2.4, 24 and 60 GHz. Linearly-polarized open-ended waveguides are used as antennas. The influence of polarization on path gain and antenna radiation efficiency are analyzed. The results show that path gain is highly sensitive to the antenna/body separation at 24 and 60 GHz.**

***Index Terms*—Wireless Body Area Network, Open ended Waveguide, on body propagation, path gain.**

I. INTRODUCTION

There has been growing interest in the use of wireless body area networks (WBANs), leading to increased attention and further exploration of their applications in the area of communication, real time health monitoring, sports and aerospace industries [1-2]

Most WBAN research has focused on the 2.45 GHz ISM band rather than higher frequencies due to low path loss and better penetration depth into the body that can be useful for in-body applications. In [3] various polarization schemes and body movements were taken into account to investigate on-body wireless communication channels. The effect of polarization on ear-to-ear on-body communication is studied in [4]. These [3-4] and many other studies at 2.45 GHz established that having the E-field normal to body surface provides better path gain. In [5] wearable antennas were designed at 2.45 GHz and their on-body performance in terms of path gain are analyzed. It was suggested that low-profile higher-order mode microstrip antenna provides comparable results to monopole antenna.

Increasingly, researchers have been exploring the use of the mm-wave spectrum for WBAN applications due to its advantages, such as higher data rates, improved security, compact devices and unlicensed frequency bands [6]. The 60 GHz ISM band has been proposed for WBAN use and several studies were made regarding on-body propagation. The effect of polarization was reported on a skin equivalent phantom using open-ended waveguides [7]. In [8], experimental characterization of on-body propagation was conducted across the 900 MHz and 60 GHz bands, considering both vertical and horizontal polarizations. The effect of textiles in the vicinity of human skin has also been investigated using an open-ended waveguide [9]. In contrast to the 2.45 GHz case, these studies demonstrated that horizontally polarized antennas are well-suited for on-body wireless applications at 60 GHz [7-9].

Within the mm-wave spectrum, researchers highlighted the advantages of selecting the 24 GHz ISM band over 60 GHz, due to lower path-losses, reduced shadowing and use of less directive antennas [10]. Only a few studies have focused on WBAN 24 GHz antennas. These include a Koch-shaped bowtie slot antenna backed by an electromagnetic bandgap (EBG) structure [10] and an EBG-backed multi-input multi-output (MIMO) patch antenna [11].

In this paper, the effect of polarization on path gain and antenna radiation efficiency in proximity to human skin is compared and analyzed at three frequencies: 2.4 GHz, 24 GHz, and 60 GHz. The study uses linearly-polarized open-ended waveguides as antennas.

a) Simulation setup

The simulation setup depicted in Fig.1 is implemented using CST Microwave Studio. Two standard open-ended waveguides [12], i.e., WR-430 for 2.4 GHz , WR- 42 for 24 GHz and WR-15 for 60 GHz are separated at a distance ρ = 250 mm above a homogenous skin-equivalent phantom at height h. The length and width of the phantom are 200mm and 270mm, respectively, with a thickness of 10mm for 24 and 60 GHz, and 25 mm for 2.4 GHz.

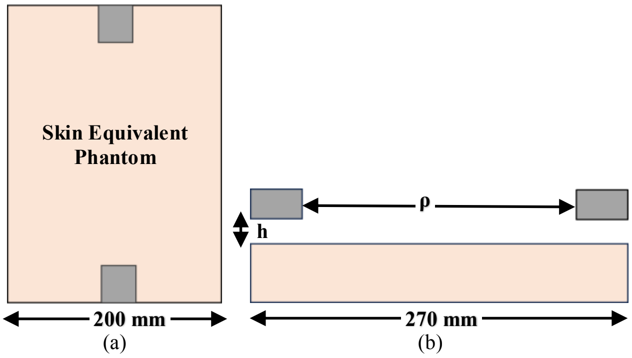


Fig. 1. Simulation setup (a) Top view (b) Side view

(b) Dielectric properties of skin

The permittivity and conductivity of skin at different frequencies are given in Table. I

TABLE.I Dielectric properties of skin [13-14]

Frequency (GHz)	**Relative Permittivity (ε_r)**	**Conductivity (S/m)**
2.4	38.03	1.44
12	29.32	10.33
18	23.64	17.17
24	18.99	22.81
60	7.98	36.38

II. RESULTS AND DISCUSSION

A. Path Gain

The open-ended waveguide used in the calculation of path gain had a realized gain of 6.2, 7.0 and 7.7 dBi at 2.4, 24 and 60 GHz, respectively.

Path gains $|S_{21}|$ for normal and tangential polarization at different heights *h* (0 to 7mm) are shown in Fig. 2. It is evident that path gain at 24 GHz is 13.6 dB higher than 60 GHz and 25.5 dB lower than at 2.4 GHz in close proximity to the body (i.e. $h = 0$mm) for normal polarization. It is 4.6 dB higher and 27.4 dB lower than that at 60 GHz and 2.4 GHz respectively, for tangential polarization at $h = 0$mm.

It is also noted that path gain rises faster for tangential polarization compared to normal polarization at 24 GHz as *h* increases. However, the path gain remains almost same for both the polarizations at 2.4 GHz for all values of *h*.

It is important to mention that simulated path gain at 60 GHz for tangential polarization is better than free space at $h = 7$mm.

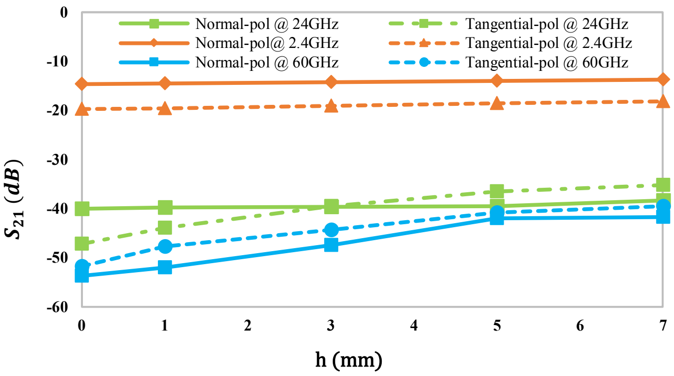


Fig.2. Path gain (S_{21}) at different height

Table. II provides comparison of path gain at 2.4, 24 & 60 GHz.

TABLE. II Comparison of path gain $|S_{21}|$

h (mm)	**2.4 GHz**		**24 GHz**		**60 GHz**	
	Normal-pol	**Tangential-pol**	**Normal-pol**	**Tangential-pol**	**Normal-pol**	**Tangential-pol**
0	-14.6	-19.8	-40.1	-47.2	-53.7	-51.8
1	-14.5	-19.6	-39.8	-43.9	-52.0	-47.8
3	-14.3	-19.1	-39.6	-39.5	-47.5	-44.3
5	-14.0	-18.6	-39.5	-36.5	-42.0	-40.8
7	-13.7	-18.2	-38.3	-35.3	-41.8	-39.5

The comparison of $|S_{21}|$ at 12, 18, and 24 GHz for normal and tangential polarization is shown in Fig.3 to provide better view of cross-over points for both polarizations at certain antenna/body separation. The open-ended waveguide realized gain at 12 and 18 GHz is 6.3 and 5.6 dBi, respectively

According to Fig. 3, path gain for normal polarization at 12 GHz is better than tangential polarization for all values of *h* in the range 0 to 7 mm.

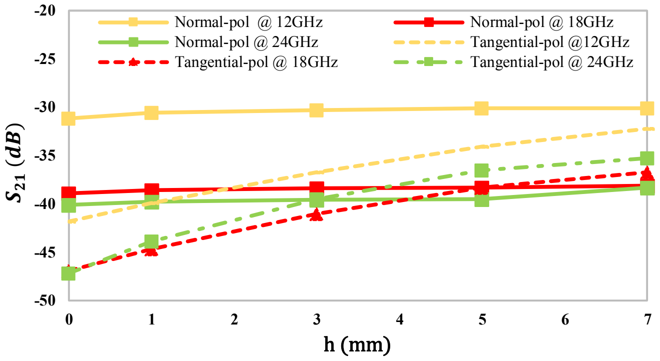
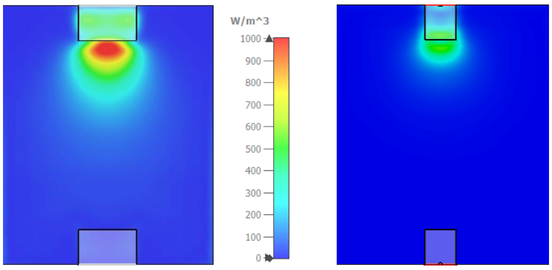


Fig.3. Path gain S_{21} at different heights for different frequencies

It can also be seen that the tangential and normal polarization path gains are equal (crossover) at $h = 5$mm for 18 GHz. At 24 GHz, the path gain for both the polarizations are equal at $h = 3$mm. It is clear that crossover point is dependent on the operating wavelength.

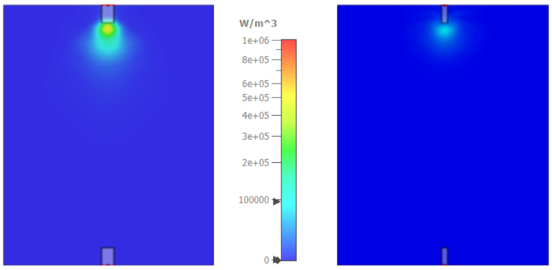
B. Power Density Distributions

Power density distributions at 2.4, 24 and 60 GHz for both the polarizations and for antenna/skin spacing, namely $h = 5$mm are illustrated in Figs 4-6. Distinct color scale is used for 2.4 GHz to differentiate power loss between both the polarizations. It is evident that there is more absorption in skin for normal polarization compared to tangential polarization for these frequencies.



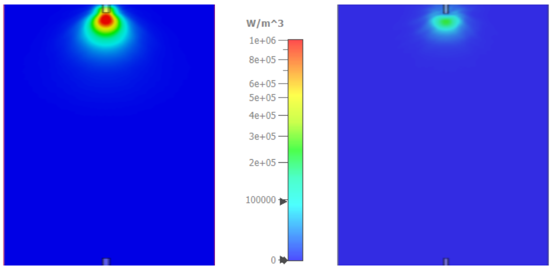
(a) (b)

Fig.4. Power loss density at 2.4 GHz (h = 5 mm) (a) Normal polarization (b) Tangential polarization



(a) (b)

Fig.5. Power loss density at 24 GHz (h = 5 mm) (a) Normal Polarization (b) Tangential polarization



(a) (b)

Fig 6. Power loss density at 60 GHz (h = 5 mm) (a) Normal polarization (b) Tangential polarization

C. *Antenna Radiation Efficiency*

Power loss on a skin equivalent phantom is further characterized through radiation efficiency. Fig 7 shows comparison of radiation efficiencies for both polarizations at varying heights (ranging from 0mm to 7mm). It shows that radiation efficiency is significantly lower for normal polarization compared to the tangential polarization at 2.4, 24 and 60 GHz for all values of h. It is also noted that radiation efficiency drops significantly for the normal polarization and remains almost constant for the tangential polarization at 24 and 60 GHz as h reduces. However, at 2.4 GHz it remains almost constant for both the polarizations.

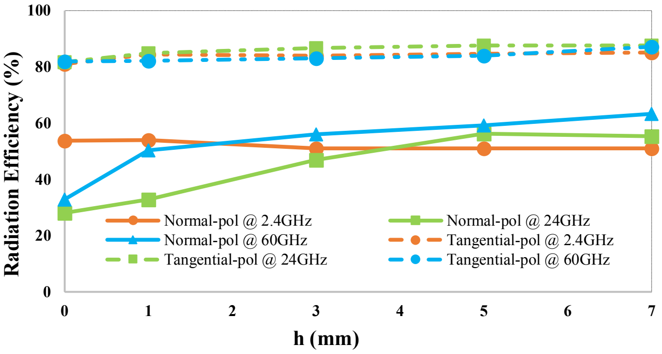


Fig.7. Radiation efficiency for different heights

Table. III provides comparison of radiation efficiency (%) at 2.4, 24 & 60 GHz.

TABLE. III Comparison of radiation efficiency (%)

h (mm)	2.4 GHz		24 GHz		60 GHz	
	Normal-pol	**Tangential-pol**	**Normal-pol**	**Tangential-pol**	**Normal-pol**	**Tangential-pol**
0	53.6	81.0	28.0	81.7	32.9	81.8
1	54.0	84.4	32.8	84.7	50.4	82.2
3	51.0	83.9	46.8	86.6	55.9	83.0
5	51.1	84.6	56.2	87.6	59.1	84.0
7	51.1	85.0	55.2	87.6	63.2	87.1

D. *Power reflection/absorption on skin*

Reflection /absorption on skin at 2.4, 24 and 60 GHz is better explained from E-field distributions as shown in Figs 8-10. It is evident that reflection on skin for tangential polarization is greater than normal polarization for these frequencies. In contrast, absorption in skin for normal polarization is greater than tangential polarization which accounts for the lower radiation efficiencies at 24 and 60 GHz.

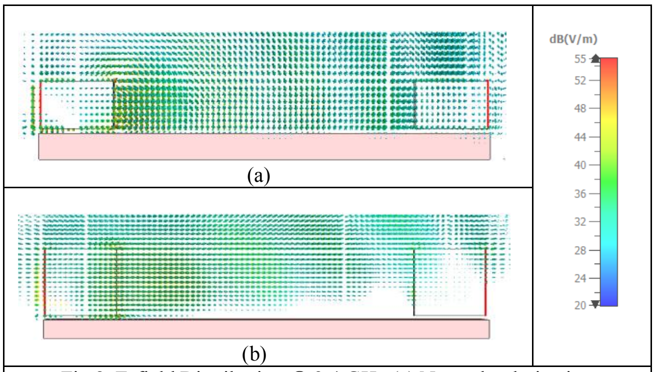


Fig.8. E-field Distribution @ 2.4 GHz (a) Normal polarization (b) Tangential polarization

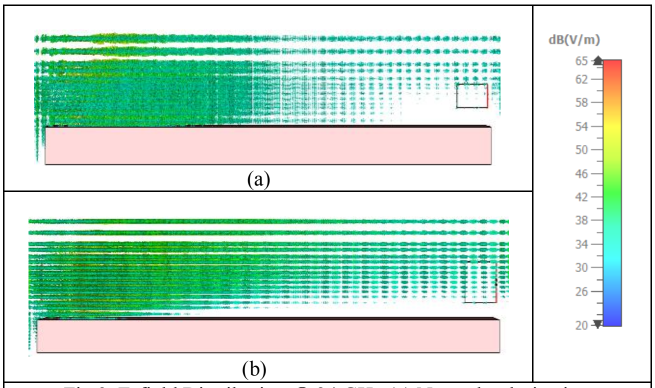
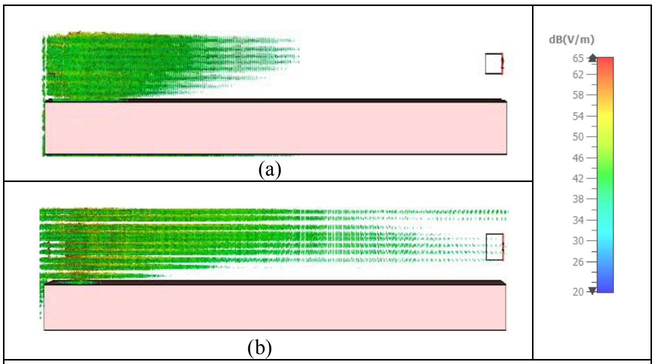


Fig.9. E-field Distribution @ 24 GHz (a) Normal polarization (b) Tangential polarization



(a)

(b)

Fig.10. E-field Distribution @ 60 GHz (a) Normal polarization (b) Tangential polarization

It is interesting to note that the path gain for tangential polarization is better than free space at 60 GHz from *h* = 7mm. This shows that the reflected waves from the phantom contribute to receive power.

III. CONCLUSION

Propagation along a skin equivalent phantom at 2.4, 24 and 60 GHz is compared and investigated for WBAN applications. The results indicate that path gain as well as radiation efficiency at 60 GHz is better for tangential polarization as compared to normal polarization for all values of *h* whereas at 2.4 GHz path gain for normal polarization is better.

The results highlight the significance of selecting appropriate polarization, frequency and minimum antenna/body separation for WBAN applications. At 2.4 GHz, path gain is better for both polarizations compared to 24 and 60 GHz for all values of *h*. However, it comes with the drawback of larger antenna size and a more crowded spectrum. On the other hand, 60 GHz offers a compact antenna size and more secured data transfer, but it experiences higher path loss and has a smaller coverage area. 24 GHz serves as an transitional frequency within the ISM Bands, providing better coverage than 60 GHz and more secure data transfer than 2.4 GHz.

ACKNOWLEDGMENT

This publication has emanated from research supported in part by Advance CRT and Science Foundation Ireland under Grant number 18/CRT/6222

REFERENCES

[1] G. Gao, R. Zhang, C. Yang, H. Meng, W. Geng, and B. Hu, “Microstrip monopole antenna with a novel UC-EBG for 2.4 GHz WBAN applications,” IET Microwaves, Antennas & Propagation, vol. 13(13), pp. 2319-2323, August 2019.

[2] D. Chaturvedi, and S.Raghavan , “A compact metamaterial-inspired antenna for WBAN application,” Wireless Personal Communications, vol. 105, pp. 1449-1460, February 2019.

[3] T. Uusitupa, and T. Aoyagi, “Analysis of dynamic on-body communication channels for various movements and polarization schemes at 2.45 GHz,” IEEE Transactions on Antennas and Propagation, vol. 61(12), pp. 6168-6179, September 2013.

[4] S.H. Kvist, J. Thaysen, and K.B. Jakobsen, “Polarization of unbalanced antennas for ear-to-ear on-body communications at 2.45 GHz.,” Loughborough Antennas & Propagation Conference, pp. 1-4, Novemeber 2011.

[5] G.A. Conway, and W.G. Scanlon, “Antennas for over-body-surface communication at 2.45 GHz,” IEEE Transactions on Antennas and Propagation, vol. 57(4), pp.844-855, April 2009.

[6] H. Attia, M.L. Abdelghani, and T.A. Denidni, “ Wideband and high-gain millimeter-wave antenna based on FSS Fabry–Perot cavity,”. IEEE Trans antennas propagation, vol. 65(10), pp. 5589–5594, August 2017.

[7] N. Chahat, G. Valerio, M. Zhadobov, and R. Sauleau, “ On-body propagation at 60 GHz,” IEEE Transactions on Antennas and Propagation, vol. 61(4), pp. 1876-1888, January 2013.

[8] R. Aminzadeh, A. Thielens, M. Zhadobov, L. Martens, and W. Joseph, “WBAN channel modeling for 900 MHz and 60 GHz communications,” IEEE transactions on antennas and propagation, vol. 69(7), pp. 4083-4092, July 2021.

[9] A.R. Guraliuc, M. Zhadobov, G. Valerio, N. Chahat, and R Sauleau, “Effect of textile on the propagation along the body at 60 GHz,” IEEE Transactions on Antennas and Propagation, vol. 62(3), pp.1489-1494, March 2014.

[10] M. Ali, I. Ullah, J.C. Batchelor, and N.J. Gomes, “Ultra-thin electromagnetic bandgap backed fractal geometry-based antenna for 24 GHz ISM band WBAN,” IET Microwaves, Antennas & Propagation, vol. 17(3), pp. 216-222, January 2023.

[11] A. Iqbal, A. Basir, A. Smida, N.K. Mallat, I. Elfergani, J. Rodriguez, and S. Kim, “Electromagnetic bandgap backed millimeter-wave MIMO antenna for wearable applications,” IEEE Access, vol. 7, pp.111135-111144, August 2019.

[12] D.M. Pozar, Microwave engineering. John Wiley & sons, 2011.

[13] T. Hamed, and M. Maqsood, “SAR calculation & temperature response of human body exposure to electromagnetic radiations at 28, 40 and 60 GHz mm-Wave frequencies,” Progress In Electromagnetics Research M, vol. 73, pp. 47-59, September 2018.

[14] http://niremf.ifac.cnr.it/tissprop/htmlclie/htmlclie.php.