© Universiti Tun Hussein Onn Malaysia Publisher's Office

JEVA

http://publisher.uthm.edu.my/ojs/index.php/jeva
e-ISSN : 2716-6074

Journal of Electronic Voltage and Application

Investigation of Waveguide Propagation of Terahertz Signal with Different Polarization Angle and Twisting Rate for Terabit DSL Application

Muhamad Syahrieza Syahnon[1], See Khee Yee[2*], Fauziahanim Che Seman[2], Arslan Ahmad[1]

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, MALAYSIA

[2]Research Center for Applied Electromagnetic, Institute of Integrated Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/jeva.2022.03.02.007
Received 13 July 2022; Accepted 17 October 2022; Available online 29 December 2022

Abstract: When the demand for higher data rates grows, various telecommunications technologies are proposed; for these cases, the terabit DSL is investigated. Terabit DSLs provides solutions to the inevitable bottleneck that future wireless systems encounter. However, the propagation loss in twisted pairs becomes a massive concern in terabit DSL. Besides the attenuation, propagation characteristics at terahertz frequencies in twisted pair are not much explored by the researcher. Therefore, terahertz signal propagation characteristics in a waveguide based on surface plasmonic are investigated in this project by using simulation software CST MICROWAVE STUDIO. A circular waveguide with radius of 0.25 mm and length of 20 mm respectively has been simulated in between 360 GHz to 380 GHz. The reflection coefficient and transmission coefficient analysis of the circular waveguide are investigated in terms of the polarization angles and twisting rate. Based on the simulated results, it is discovered that the polarization angle influences the reflection coefficient and transmission coefficient of the circular waveguide. When the polarization angle difference is 90 degrees, it has the worst reflection. The circular waveguide with a polarization angle difference of 0 degrees and 180 degrees, it has the best transmission coefficient. The transmission coefficient of the circular waveguide, on the other hand, is unaffected by the twisting rate. Even though the highest twisting rate that has the highest transmission coefficient, it is still lower than 3 dB. Besides, the higher the twisting rate the lesser the number of resonances for the circular waveguide.

Keywords: Terabit DSL, twisted pair, surface plasmonic, waveguide

1. Introduction

There are approximately 1.3 billion twisted-pair phone lines in use around the world. Digital subscriber line (DSL) reuses these twisted pairs, allowing faster service implementation at a lower cost per customer than fiber deployment [1]. DSL technology transforms an ordinary telephone line into a broadband communications link, much like adding express lanes to an existing highway. DSL boosts data transmission speeds by using previously unused high frequencies to transmit signals [2]. The utility of twisted-pair telephone lines has been given a new twist thanks to DSL technology. The main advantages of using terahertz DSL are that it has a higher spectrum, high frequency, and more bandwidth to send more data. Hence, terahertz DSL is proposed. Starting 2018, when the terabit DSL is introduced,

**Corresponding author: skyee@uthm.edu.my*

many researchers are interested in exploring terabit DSL [3]. Terabit DSLs provides solutions to the inevitable bottleneck that future wireless systems encounter [4]. However, the propagation loss in twisted pair becomes a massive concern in terabit DSL [5]. The attenuation, propagation characteristics at terahertz frequencies are not yet explored by other researcher. Therefore, a terahertz signal propagation characteristic in a circular waveguide base on surface plasmonic is investigated in this work in term of two scenarios, first the polarization angle and the twisting rate by in between 360 GHz to 380 GHz based on CST MICROWAVE STUDIO software.

2. Materials and Methods

2.1 Circular Terahertz Waveguide

A circular waveguide with radius of 0.25 mm (*a*) and length of 20 mm (*b*) has been constructed in CST MICROWAVE STUDIO filled with dielectric with relative permittivity (ε_r) and relative permeability (μ_r) as shown in Fig. 1. The cut off frequency of both TE and TM modes can be calculated by (1) and (2) respectively. It is made of vacuum material with PEC background and $E_t = 0$ as the boundary condition to reduce the simulation duration. The configuration of different polarization angles and twisting rate has been explored. These configurations ensure that the simulated results such as the reflection and transmission coefficient are accurate.

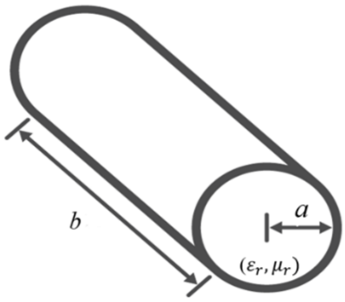

Fig. 1 - Circular terahertz waveguide

$$fc_{nm}^{TE} = \frac{c \times p'_{nm}}{2\pi a\sqrt{\mu_r \varepsilon_r}} \tag{1}$$

$$fc_{nm}^{TM} = \frac{c \times p'_{nm}}{2\pi a\sqrt{\mu_r \varepsilon_r}} \tag{2}$$

Table 1 - Value of p'_{nm} for TE wave mode and p_{nm} for TM wave mode

n	TE wave mode			TM wave mode		
	p'_{n1}	p'_{n2}	p'_{n3}	p_{n1}	p_{n2}	p_{n3}
0	3.832	7.016	10.174	2.405	5.520	8.654
1	1.841	5.331	8.536	3.832	7.016	10.174
2	3.054	6.706	9.970	5.135	8.417	11.620

where p'_{nm} and p_{nm} as tabulated in Table 1 define the the n^{th}-zero of the m^{th}-order Bessel function and Bessel function derivative, respectively, *c* is the light velocity at free space (3×10^8 m/s), while the integer *m* and *n* are related to the number of circumferential variations in the field and the number of radial variations [5].

2.2 Investigation on The Effect of Polarization Angles

In all simulation trials, the polarization angle in waveguide port 1 remains at 0 degrees. The polarization angle in waveguide port 2 varies as tabulated in Table 2; the waveguide's return loss and insertion loss at terahertz frequency for this trial are compared.

Table 2 - Polarization angles for waveguide port 1 and waveguide port 2 of circular waveguide in each trial

Trial	Polarization Angle at waveguide port 1	Polarization Angle at waveguide port 2
1	0◦	0◦
2	0◦	45◦
3	0◦	90◦
4	0◦	135◦
5	0◦	180◦

2.3 Bended Circular Waveguide Design using CST Studio Suite

The diameter radius and length of the bended waveguide is 0.25 mm and 20 mm, respectively. However, a curve is made according to the standard twisting rate for the bended waveguide. The value for the curve radius in each twisting rate from 4, 5, 6 and 7 twisting rates per inch are determined. Thus, the simulation of the bended waveguide with a different radian angles value is carried out, and the reflection coefficient and transmission coefficient results are discussed.

Table 3 - The curve radius of the bended waveguide for different twisting rate

Diameter Radius (mm)	Length (mm)	Curve Radius (mm)	Twisting Rate Per Inches
0.25	20	3.175	4
0.25	20	2.540	5
0.25	20	2.117	6
0.25	20	1.814	7

3. Results and Discussion

3.1 Polarization Angle

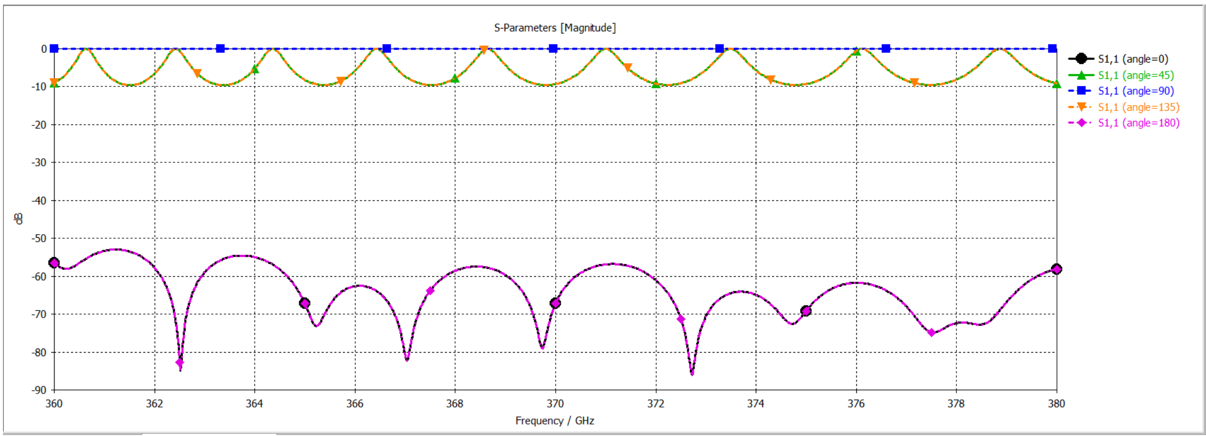

Fig. 2 - The return loss (S11, dB) at port 1 with different polarization angle, 0º, 45º, 90º, 135º, 180º at port 2 from 360 GHz to 380 GHz

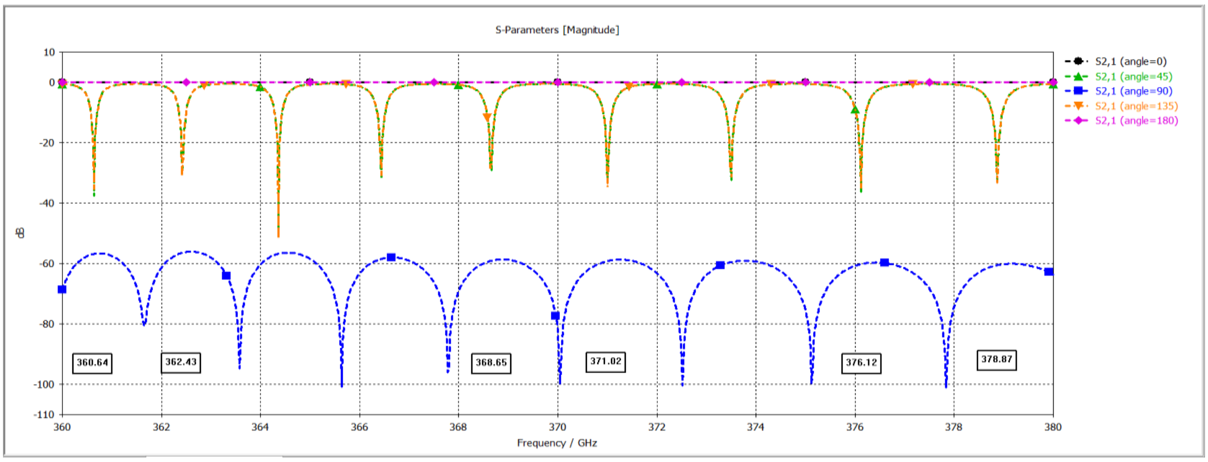

Fig. 3 - The insertion loss (S21, dB) with different polarization angle, 0°, 45 °, 90 °, 135 °, 180 ° at port 2 from 360 GHz to 380 GHz

Based on the return loss in Fig. 2, it is found that the return loss is below -50 dB for polarization angles of 0 degrees and 180 degrees. The return loss for the other polarization angles is above -10 dB. The power is reflected and is not able to radiate; it is interesting to note that both 45 degrees and 135 degrees polarization angles have identical return loss. Moreover, the waveguide port 2 with 90 degrees of polarization angle has the worst return loss. The return loss for 90 degrees of polarization angles is almost 0 dB which means that all the power is reflected, and none is radiated. On the other hand, based on Fig. 3, the insertion loss of 0 degrees and 180 degrees of polarization angles has the highest values approximate to 0 dB compared to the polarization angles of 90 degrees, which has the worst case of insertion loss below -50 dB. As for the polarization angles of 45 degrees and 135 degrees, the insertion loss is the same. It is found that their insertion loss are decreased at the interval of every 2.3 GHz; each ripple has a frequency gap on an average of 2.3 GHz. Theoretically, the ripple occurs due to the impact on the insertion loss (S21, dB) since the return loss for the simulated waveguide is more than -10 dB.

3.2 Waveguide Bend

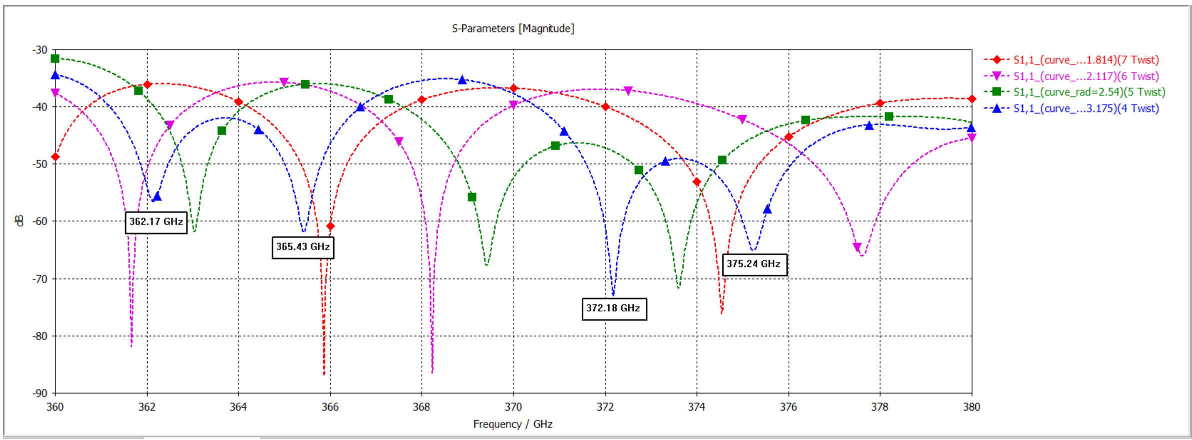

Fig. 4 - The return loss, (S11, dB) of the waveguide at different twisting rate

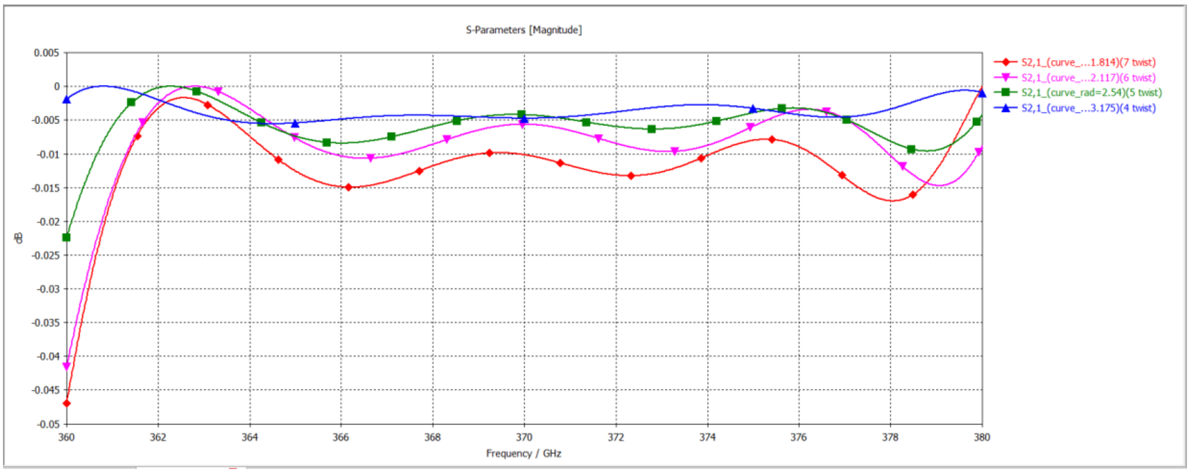

Fig. 5 - The insertion loss, (S21, dB) of circular waveguide with different twisting rates

Fig. 4 shows the return loss for the terahertz waveguide with different twisting rates. From the simulation result in general, the return loss for all the twisting rates is below -10 dB. This shows that the terahertz signal can propagate through the waveguide regardless of the twisting rate. On the other hand, Based on Fig. 5, it is found that all the insertion loss is higher than -3 dB. This is indicated a good transmission in bended circular waveguide. The twisting rate 4 with 3.175 mm of curve radius of waveguide bend has the highest transmission compared to the twisting rate 7 with 1.814 mm at 360 GHz, and at the other frequency for example at 366 GHz to 368 GHz. Besides that, from the simulation result it is observed too the twisting rate affect the stability of insertion loss. A circular waveguide with a higher twisting rate fluctuates more than a lower twisting rate.

4. Conclusion

This paper presented the investigation of the propagation characteristics of circular waveguides with different polarization angles and the propagation characteristics of a bended waveguide with different twisting rates. Based on the simulated results, it is found that the polarization angle affects the insertion loss of the circular waveguide. Great reflection occurs when the polarization angle difference is 90 degrees. The circular waveguide with 0 degrees and 180 degrees of polarization angle difference has the best insertion loss. On the other hand, the twisting rate does not affect the insertion loss of the circular waveguide. Even though the highest twisting rate (7) has the lowest insertion loss, it is lower than 3 dB.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] J. M. Cioffi, K. J. Kerpez, C. S. Hwang and I. Kanellakopoulos, "Terabit DSLs," in IEEE Communications Magazine, vol. 56, no. 11, pp. 152-159, November 2018, doi: 10.1109/MCOM.2018.1800597.

[2] R. Shrestha, K. Kerpez, C. S. Hwang, M. Mohseni, J. Cioffi and D. M. Mittleman, "Two-Wire Waveguide for Terabit DSL," 2020 Conference on Lasers and Electro-Optics (CLEO), San Jose, CA, USA, 2020, pp. 1-2.

[3] R. Shrestha, K. Kerpez, C. S. Hwang, M. Mohseni, J. Cioffi and D. M. Mittleman, "A metal wire waveguide for terabit DSL," 2019 44th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), Paris, France, 2019, pp. 1-2, doi: 10.1109/IRMMW-THz.2019.8873828.

[4] D. D. Souza et al., "Evaluation of Copper Cables as Waveguides in Next-generation Wireline Technologies," 2019 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC), Aveiro, Portugal, 2019, pp. 1-3, doi: 10.1109/IMOC43827.2019.9317425.

[5] Munir, A., & Setiawan, A. (2013). "Transmission Loss Reduction of Circular Terahertz Waveguide Using Dielectric-Lined Method", International Journal on Electrical Engineering & Informatics, vol 5, no.3, 2013.