International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

عدد خاص بالمؤتمر الليبي الدولي للعلوم التطبيقية و الهندسية دورته الثانية
LICASE -2
2024 / 10 / 30-29

المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

تم استلام الورقة بتاريخ: / /2024م
وتم نشرها على الموقع بتاريخ: 30/ 10/2024م

Assessment of the Effects of Random Substrate Impurity on Microstrip Line Characteristics using Monte Carlo Method

http://www.doi.org/10.62341/amis1199

[1]**Abousetta, M.**
Libyan Academy, Tripoli, Libya
m.abousetta@academy.edu.ly

[2]**Ibrahim, S.**
Libyan Academy, Tripoli, Libya
220100114@academy.edu.ly

Abstract-This paper Presents an investigation of the effect of random change of relative permittivity on the performance of microstrip transmission line, Suitable computational methods have been used; namely: MONTE CARLO and FEM. While the former Method is applied for the estimation of random variation, the Latter Method estimates resulting line parameters values. Results are encouraging due the use of truncation division within the available length rather than the techniques that are based on extra-length extension.
Keywords-Random Substrate Impurity,Microstrip Line, Monte Carlo ,Truncation, Threshold, propagation constant, Attenuation constant, phase Constant.

تقييم تأثير شوائب الركيزة العشوائية على خصائص خط الشرائح الدقيقة باستخدام طريقة مونت كارلو

[1]مرعي محمد أبو ستة
الاكاديمية الليبية، طرابلس، ليبيا
m.abousetta@academy.edu.ly

[2]سلوى محمود إبراهيم
الاكاديمية الليبية، طرابلس، ليبيا
220100114@academy.edu.ly

الملخص

يقدم هذا البحث دراسة تأثير التغير العشوائي في السماحية النسبية على أداء خط نقل الشرائح الدقيقة، وتم استخدام الطرق الحسابية المناسبة؛ وهما: طريقة مونت كارلو وطريقة العناصر المحدودة، حيث تم تطبيق الطريقة الأولى لتقدير التباين العشوائي، بينما قامت الطريقة الأخيرة بتقدير قيم معلمات الخط الناتجة.

النتائج مشجعة بسبب استخدام تقسيم الاقتطاع وذلك ضمن الطول المتاح بدلاً عن التقنيات التي كانت تعتمد على تمديد الطول الإضافي.

الكلمات الرئيسية – شوائب الركيزة العشوائية، خط الشرائح الدقيقة ، مونت كارلو، الاقتطاع، العتبة، ثابت الانتشار، ثابت التوهين، ثابت الطور.

I. INTRODUCTION

The main subject of this work is an investigation into the effect of random changes in relative permittivity on the performance of microstrip transmission lines, so it can contributes to the field of RF and microwave engineering by providing insights that lead to improved designs, ultimately enhancing the performance and reliability of microstrip line applications.This work uses Monte Carlo simulations to explore how variations, like impurity substrate material, truncation width on propagation constants that effect on the performance of microstrip lines. The aim is to show behaviour of microstrip lines and improve their design for purposes, The study focuses on investigating the effect of impurities in substrates on microstrip lines. For this reason, the Monte Carlo simulation method was used to get data on how impurities affect the performance of microstrip lines, Microstrip lines play a strong role as interconnection components, in microwave integrated circuits. Random substrate impurity is a common problem in the semiconductor, as a result, the performance of microwave devices can study the effects of the dielectric substrate, such as random variation of the relative permittivity, on the performance of microwave devices, however, the investigation of the effects of random substrate impurities in microstrip lines by using Monte Carlo simulations has main reason could be simulated the random events in the substrate [1].

II. Background

A. Microstrip Line Theory:

Microstrip lines are important components in microwave engineering, commonly used in the design of microwave circuits like filters, couplers, and antennas. These lines consist of a thin metallic strip placed on top of a dielectric substrate, with the ground plane underneath. The design of microstrip lines involves understanding the relationship between the geometry of the lines and their characteristic impedances, specifically even- and odd-mode impedances Z_{0e} and Z_{0o} respectively [2]. In coupled microstrip lines, the design process is typically hindered by expressing even- and odd-mode impedances in physical geometry. [2].

B. Transmission Line Parameters:

For thin conductors (t → 0), closed-form expression (error ≤ 1 %), W/h ≤ 1:

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left\{\left(1+12\frac{h}{W}\right)^{-0.5} + 0.04\left(1 - 12\frac{W}{h}\right)^2\right\} \qquad (1)$$

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\ln\left(\frac{8h}{W} + 0.25\frac{W}{h}\right) \qquad (2)$$

η is the intrinsic impedance of the medium (often related to the speed of light and the properties of the medium).

W/h ≥1:

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left\{\left(1+12\frac{h}{W}\right)^{-0.5}\right\} \tag{3}$$

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\left\{\frac{W}{h} + 1.393 + 0.677\ln\left(\frac{W}{h}+1.444\right)\right\}^{-1} \tag{4}$$

For thin conductors (t → 0), more accurate expressions, Effective dielectric constant (error ≤ 0.2 %) , u =$\frac{W}{h}$.

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{10}{u}\right)^{-ab} \tag{5}$$

$$a = 1 + \frac{1}{49}\ln\left(\frac{u^4+\left(\frac{u}{52}\right)^2}{u^4+0.432}\right) + \frac{1}{18.7}\ln\left[1+\left(\frac{u}{18.1}\right)^3\right] \tag{6}$$

$$b = 0.564\left(\frac{\varepsilon_r-0.9}{\varepsilon_r-3}\right)^{0.053} \tag{7}$$

Characteristic impedance Z_C (error ≤ 0.03 %), u =$\frac{W}{h}$.

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\ln\left[\frac{F}{u} + \sqrt{1+\left(\frac{2}{u}\right)^2}\right] \tag{8}$$

$$f = 6 + (2\pi-6)\exp\left[-\left(\frac{30.666}{u}\right)^{0.7528}\right] \tag{9}$$

$\lambda = \frac{c}{f}$, where λ is its wavelength., c = 3 × 108 m/s is the speed of light in vacuum, and f is the frequency of the electromagnetic waves .

Guided wavelength $\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{re}}}$ (10)

Propagation constant $\beta = \frac{2\pi}{\lambda_g}$ (11)

phase velocity $v_p = \frac{\omega}{\beta}$, where $\omega = 2\pi f$ (12)

$$Z_C = \frac{120\,\pi\,(1/\varepsilon_r)^{\frac{1}{2}}}{\left(W/h\right)_s + 0.882 + \left[(\varepsilon_r+1)/\pi\varepsilon_r\right]\left\{\log_s\left(W/h\right)_s + 1.88\right) + 0.758\} + [(\varepsilon_r-1)/\,\varepsilon_r^2](0164)} \tag{13}$$

Z_C is the characteristic impedance of the equivalent single microstrip line, which is equivalent to the $(W/H)_s$ shape ratio, the formula is instrumental in the synthesis step of the design procedure, to calculate the geometry of coupled microstrip lines based on the required even- and odd-mode impedances [2] Cut off frequency f_c of first higher-order modes in a microstrip:

$$f_c = \frac{c}{\sqrt{\varepsilon_{r(2W+0.8h)}}} \tag{14}$$

C. **Characteristic Impedance of Microstrip**: In Fig1 ,the transmission line's characteristic impedance assumed that the ground plane and the center conductor have potentials of one and zero volts, respectively, which determined by dividing the centre conductor into N-equal subsections, ΔC along the cross section [6], while Fig.2 displays the cross section of it with frequency, the length L is also regarded as a changeable parameter.

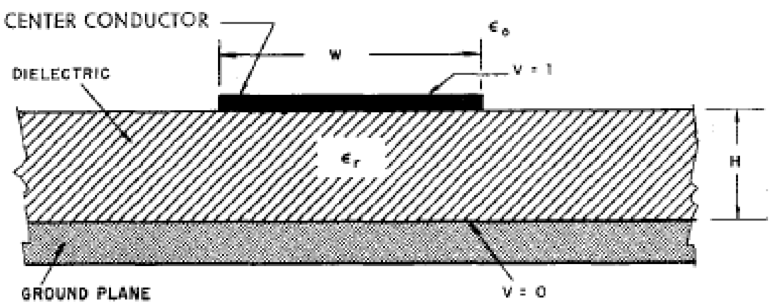

Fig. 1:Cross section of a microstrip transmission line[6]

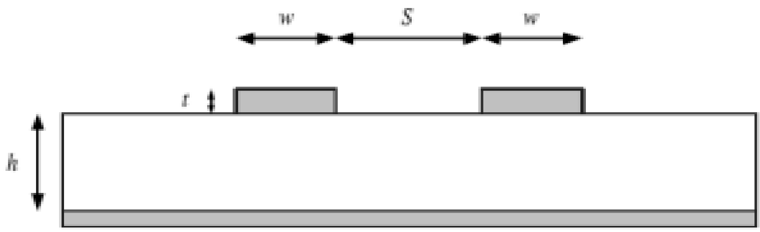

Fig.2 : Cross section of coupled microstrip lines.

D. Monte Carlo Simulation Methodology

A Monte Carlo simulation is a mathematical technique that simulates the range of possible get for an uncertain event. These predictions are depending on an estimated range of values instead of a fixed set of values and evolve randomly. The historical background of Monte Carlo simulation methodology dates back to the development of the technique by Stanislaw Ulam and John Von Neumann in the 1940s during their work on the Manhattan Project. The method was named after the famous Monte Carlo Casino in Monaco due to its reliance on random sampling techniques reminiscent of gambling. Initially used for solving complex mathematical problems in physics and engineering, Monte Carlo simulation has since found applications in various fields such as finance, risk assessment, and computer graphics. The methodology involves generating a large number of random samples of input variables to estimate the behavior of a system or model under uncertainty. Setting a threshold for specific value as 0.5 that shouldn't exceed and by repeating the process multiple times, Monte Carlo simulation provides a probabilistic insight into the possible outcomes of a given scenario, making it a valuable tool for decision-making and problem-solving in diverse domains. [3]

The principles and concepts of Monte Carlo simulation revolve around the generation of random numbers to model complex systems in order to estimate their behavior and output [3]. One fundamental principle is the law of large numbers, which states that as the number of iterations or simulations increases, the average outcome converges to the expected value. This convergence is a key feature that allows Monte Carlo simulations to provide accurate estimates of system behavior [4]. the concept is the use of random variables to represent uncertain parameters in the system being modeled. By sampling from probability distributions that characterize these variables, Monte Carlo simulations can capture the variability and uncertainty inherent in real-world systems, making them invaluable tools for decision-making in complex scenarios.

E. Random Substrate Impurity Model

Provides an in-depth investigation of the impact of random substrate impurities on the performance of microstrip lines. The model takes into account variations in the dielectric properties of the substrate material due to the different values of impurities, which can introduce variations in the characteristic impedance and propagation characteristics of the microstrip line. By incorporating statistical distributions of impurity concentrations and spatial locations within the substrate, the model provides a more realistic representation of the actual operating conditions of microstrip lines in practical applications. This level of detail enables understanding of the behavior of microstrip lines under real-world conditions, which is essential for the design and optimization of high-performance RF and microwave circuits [5].

The Random Substrate Impurity Microstrip Line Model serves as a valuable tool for researchers and engineers working in the field of Radio Frequency and microwave circuit design, offering insights into the effects of substrate impurities that may not be captured by traditional, idealized models [5],The applications of the random substrate impurity microstrip line model are manifold, the model provides a valuable tool for analyzing and understanding the impact of substrate impurities on the performance of microstrip lines, which are integral components in high-frequency circuit design. By incorporating random impurity effects, the model enables researchers and engineers to simulate more realistic scenarios and make more accurate predictions about key parameters such as signal transmission loss, in fact that the truncation has been effect on propagation characteristics as a direct result of its tiny magnitude and the distance between areas. [7]**,** Now efficiently spread throughout the conductors' whole volume, resulting in notable radiation and Ohmic losses. [8] low-loss substrate that can be used to integrate passive components, but it has a lot of disadvantages, including the inability to do wafer micromachining and thinning and integration of substrate [9], The use of Monte-Carlo simulations for scattering by random rough surfaces has grown in popularity recently. Since the invention of contemporary computers, such large-scale issues can now have numerical solutions. When solving random rough surface scattering issues, the tapering wave integral equation formulation and method of moments are most frequently utilized. [10].

III. Simulation Results and Analysis:

The results Analysis provides the following:

In Table 1 and with varying the truncation width, allow to observe changes the propagation constants for different Epsilon values in the signal propagating via microstrip line. by increasing the value Epsilon Values, the Attenuation constant and phase constant will increase as in Figures [2,4,6,8,10,12] ,The histogram displays the frequency of current values in the ensemble average, and a threshold line is calculated as in Table 2 and plot to indicate the specified threshold values as in Figures [1,3,5,7,9,11] for each epsilon value, this allows for analysis of the distribution of current values that exceed or meet the threshold. In Table 3 there is the computing of Ensemble Average over 60 truncation width, the values represent as current distribution along the microstrip line at discrete locations is listed in Table 4.

Table 1.Calculate the propagation constants for different Epsilon values

Epsilon values	Attenuationconstant	Phaseconstant
3.8	7.82566	7.77566
4.0	7.92665	7.87665
4.2	8.02393	7.97393
4.4	8.1178	8.0678
4.6	8.20851	8.16851
4.8	8.29632	8.24632

Table 2. Calculate the thresholds different Epsilon values

Epsilon values	Threshold
Epsilon =3.8	0.494721
Epsilon =4.0	0.488282
Epsilon =4.2	0.495411
Epsilon =4.4	0.491700
Epsilon =4.6	0.490102
Epsilon =4.8	0.481829

A. Ensemble Average Current Distribution and Histogram for Epsilon =3.8.

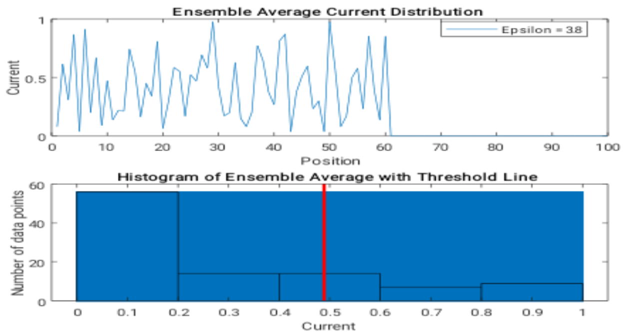

Fig. 3: Ensemble Average Current Distribution for Epsilon =3.8 with a threshold = 0.494721

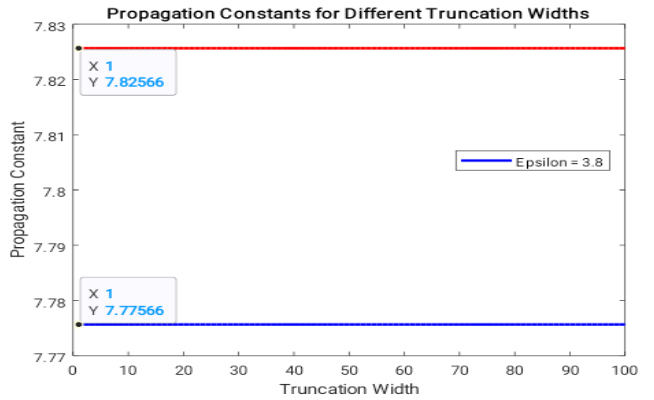

Fig.4: propagation constants for different truncation widths for Epsilon =3.8 ,With and attenuation constant value of 7.82566 and phase constant =7.77566

B. Ensemble Average Current Distribution and Histogram for Epsilon =4.0

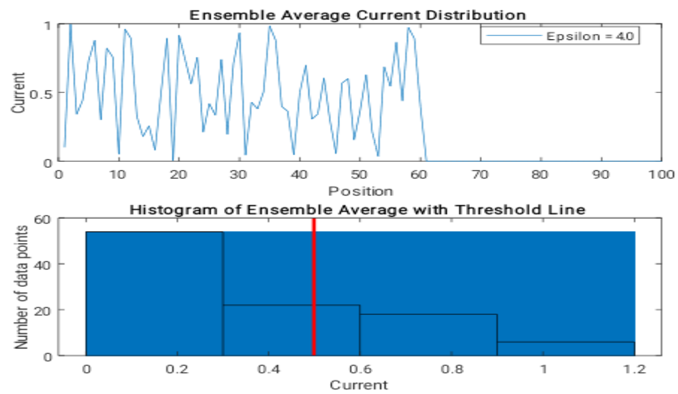

Fig. 5: Ensemble Average Current Distribution for Epsilon =4.0 with a threshold =0.488282

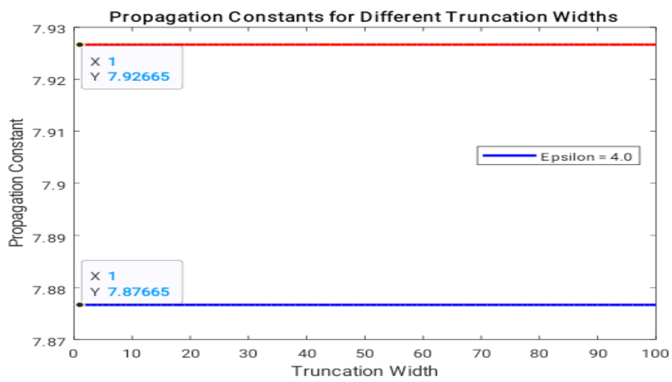

Fig. 6: propagation constants for different truncation widths for Epsilon =4.0 , With and attenuation constant value of 7.92665and phase constant =7.87665

C. Ensemble Average Current Distribution and Histogram for Epsilon =4.2

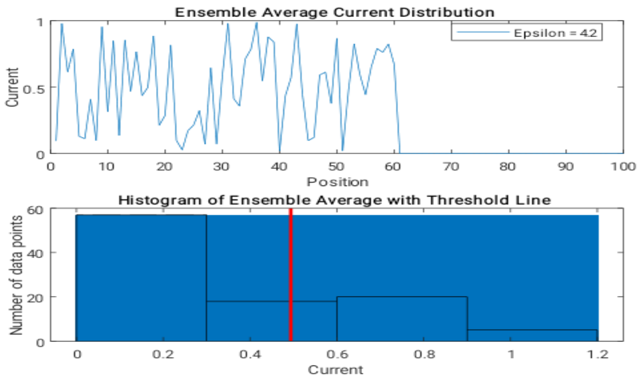

Fig. 7: Ensemble Average Current Distribution for Epsilon =4.2with a threshold =0.495411

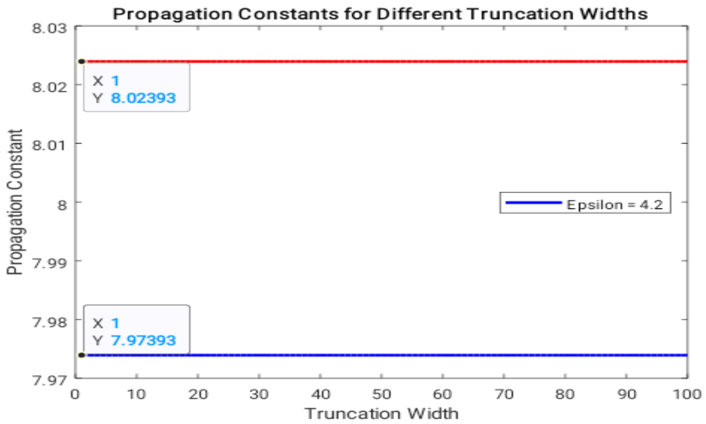

Fig. 8: propagation constants for different truncation widths for Epsilon =4.2, With and attenuation constant value of 8.02393 and phase constant =7.97393

D. Ensemble Average current Distribution and Histogram for Epsilon =4.4

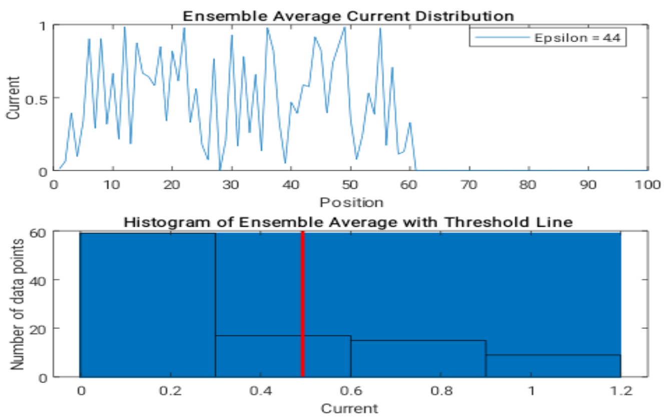

Fig.9 Ensemble Average Current Distribution for Epsilon =4.4with a threshold =0.491700

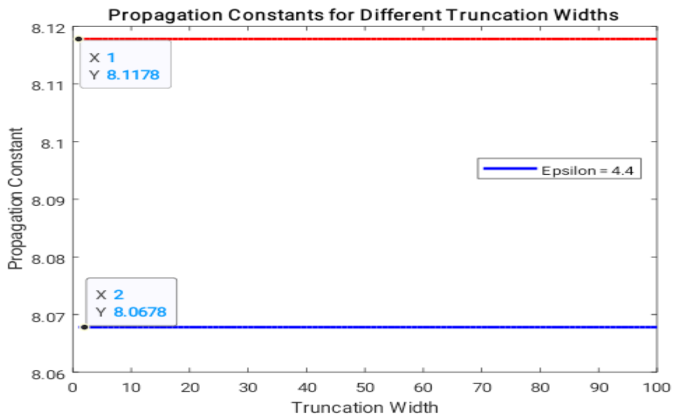

Fig. 10: propagation constants for different truncation widths for Epsilon =4.4, With and attenuation constant value of 8.1178 and phase constant =8.0678

E. Ensemble Average Current Distribution and Histogram for Epsilon =4.6

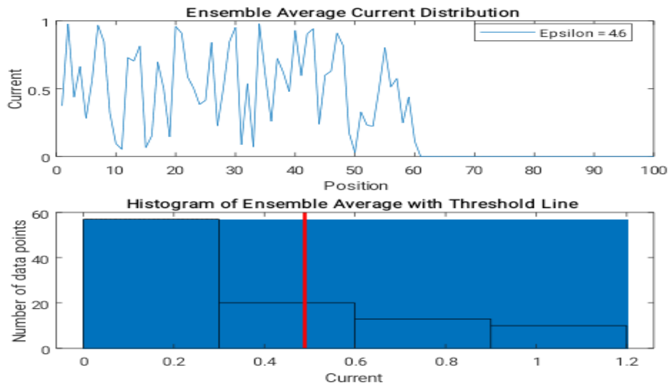

Fig.11: Ensemble Average Current Distribution for Epsilon =4.6with a threshold =0.490102

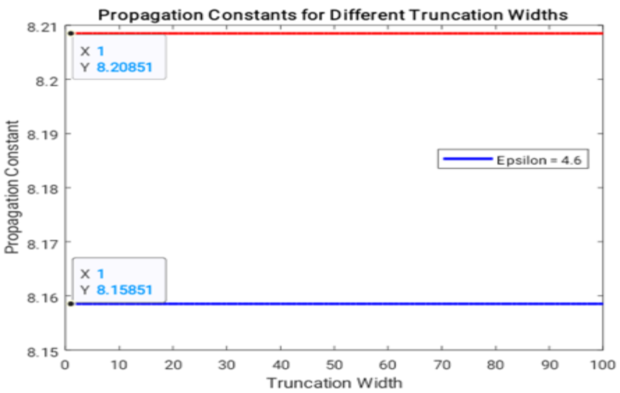

Fig.12: propagation constants for different truncation widths for Epsilon =4.6 , With and attenuation constant
value of 8.20851 and phase constant =8.15851

F. Ensemble Average Current Distribution and Histogram for Epsilon =4.8

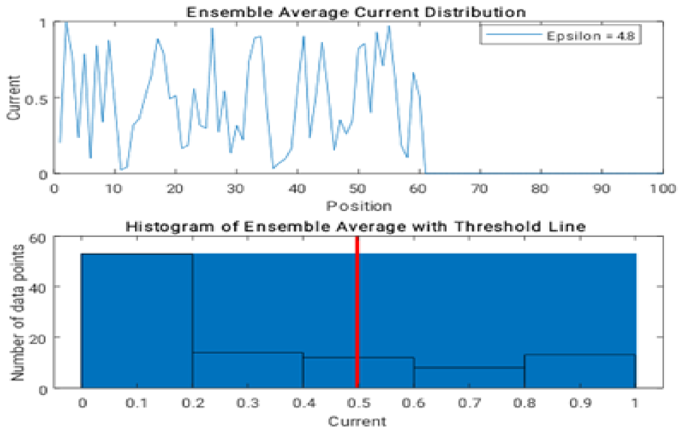

Fig.13: Ensemble Average Current Distribution for Epsilon =4.8with a threshold =0.481829

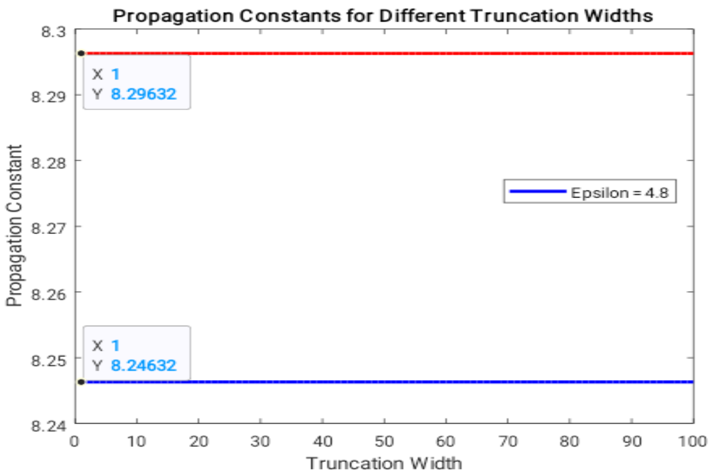

Fig.14: propagation constants for different truncation widths for Epsilon = 4.8, With and attenuation constant value of 8.29632 and phase constant =8.24632

Table 3: Ensemble Average for 60 truncation width with 0.6 of width

Trunc. width	Ensemble Average	Trunc. width	Ensemble Average	Trunc. width	Ensemble Average
0.6w	0.908557	12.6w	0.432983	24.6w	0.459017
1.2w	0.029763	13.2w	0.8982	25.2w	0.609972
1.8w	0.992817	13.8w	0.578938	25.8w	0.946861
2.4w	0.862655	14.4w	0.813565	26.4w	0.335032
3.0w	0.070217	15.0w	0.146769	27.0w	0.574947
3.6w	0.277551	15.6w	0.402591	27.6w	0.823304
4.2w	0.451067	16.2w	0.250317	28.2w	0.19018
4.8w	0.289487	16.8w	0.839802	28.8w	0.046417
5.4w	0.671915	17.4w	0.630678	29.4w	0.704312

6.0w	0.092353	18.0w	0.65912	30.0w	0.330207
6.6w	0.979966	18.6w	0.427756	30.6w	0.082319
7.2w	0.20982	19.2w	0.614743	31.2w	0.665436
7.8w	0.516494	19.8w	0.021681	31.8w	0.468846
8.4w	0.288066	20.4w	0.984792	32.4w	0.213389
9.0w	0.481395	21.0w	0.65186	33.0	0.812824
9.6w	0.552402	21.6w	0.723023	33.6w	0.156275
10.2w	0.647422	22.2w	0.377839	34.2w	0.438111
10.8w	0.172034	22.8w	0.802639	34.8w	0.15188
11.4	0.300382	23.4w	0.044395	35.4w	0.722682
12.0w	0.219664	24.0w	0.838844	36.0w	0.077879

Table 4: Current Distributions at 60 truncation width with 0.6 of width

Trunc. width	Current Distrib.	Trunc. width	Current Distrib.	Trunc width	Current Distrib.	Trunc width	Current Distrib.
0.6w	0.697298	9.6w	0.966054	18.6w	0.291446	27.6w	0.713321
1.2w	0.310258	10.2w	0.466447	19.2w	0.027561	28.2w	0.75743
1.8w	0.766878	10.8w	0.751181	19.8w	0.816948	28.8w	0.753734
2.4w	0.707993	11.4	0.522725	20.4w	0.189244	29.4w	0.317045
3.0w	0.667197	12.0w	0.684739	21.0w	0.602267	30.0w	0.393018
3.6w	0.072775	12.6w	0.563995	21.6w	0.765798	30.6w	0.672835
4.2w	0.362891	13.2w	0.027043	22.2w	0.073027	31.2w	0.452455
4.8w	0.31782	13.8w	0.946658	22.8w	0.114716	31.8w	0.389159
5.4w	0.291819	14.4w	0.863001	23.4w	0.05596	32.4w	0.719788
6.0w	0.29015	15.0w	0.04186	24.0w	0.050767	33.0	0.537852
6.6w	0.450078	15.6w	0.02261	24.6w	0.783462	33.6w	0.626812
7.2w	0.469602	16.2w	0.274427	25.2w	0.703762	34.2w	0.57833
7.8w	0.462092	16.8w	0.038169	25.8w	0.131337	34.8w	0.948658
8.4w	0.907172	17.4w	0.524285	26.4w	0.988383	35.4w	0.866551
9.0w	0.616364	18.0w	0.735638	27.0w	0.717921	36.0w	0.05208

IV. CONCLUSION

More effective truncation technique within the total transmission line has been realized. A stream of relative permittivities values (range from 3.8 - 4.8 in step of 0.2) have been tried to realize the random variation effects .Another randomly chosen range can be used), both used computational Methods shown to be suitable with truncation scheme and permittivity chosen to the used procedure. Table 1 displays how varying the truncation width affects the propagation constants for various epsilon values. As seen in Figures 4, 6, 8, 10, 12, and 14, increasing εr values results in a rise in the attenuation constant as well as the phase constant. The frequency of the current values in the ensemble average is shown by the histogram analysis, for each relative permittivities value, threshold values are computed (as shown in Table 2) and represented by threshold lines in Figures 3, 5, 7, 9, 11, and 13. The distribution of current values that exceed or match the given threshold is revealed by this study. Compute the ensemble average over 60 truncation widths and compare it to the current distribution. The ensemble average represents the current distribution along the microstrip line at discrete locations listed in Tables 3 and 4, it also indicates that wider value of the attenuation and phase constants are increased result by increasing the value of relative permittivities. This gives an advantage for this work, That one can always use suitable computation code determining suitable truncation length for the desired application.

V- ABBREVIATIONS AND ACRONYMS

FEM Finite Element Method
Z_{0e} Even -mode impedances
Z_{0o} Odd -mode impedances
w Width of Strip width
h height of Strip width
ε_r Substrate Relative Permittivity
S Gaps
ω Angular frequency
fc Cut off frequency
Z_c Characteristic impedance
ε_{re} Effective dielectric constant
λ_g Guided wavelength
β Propagation constant
v_p phase velocity

VI. REFERENCES

[1]Sheng, X. Q., et al. "Monte Carlo simulations of microstrip lines with random substrate impurity." International Journal of RF and Microwave Computer-Aided Engineering: Co-sponsored by the Center for Advanced Manufacturing and Packaging of Microwave, Optical, and Digital Electronics (CAMPmode) at the University of Colorado at Boulder 11.4 (2001): 177-187.
[2]Akhtarzad, S. ,et al. "The design of coupled microstrip lines." ,*IEEE Transactions on microwave theory and techniques,* 23.6 (1975): 486-492.
[3]Rubinstein, Y.,et al . "Simulation and the Monte Carlo method.", John Wiley & Sons, (2016).
[4]Bone, S., et al. "Decentralised Multi-Robot Exploration Using Monte Carlo Tree Search." *,2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2023.
[5]Pérez-Escribano, M. ,et al. "Parameters characterization of dielectric materials samples in microwave and millimeter-wave bands.", *IEEE Transactions on Microwave Theory and Techniques* 69.3 (2021): 1723-1732.

[6]Farrar, A., et al. "Characteristic impedance of microstrip by the method of moments (correspondence).", IEEE Transactions on Microwave Theory and Techniques 18.1 (1970): 65-66.
[7]Smith, Charles E.,et al. "Microstrip transmission line with finite-width dielectric." IEEE Transactions on Microwave Theory and Techniques 28.2 (1980): 90-94.
[8]Norooziarab, M. ,et al. "Complex dielectric permittivity extraction based on multilayer thin film microstrip lines." ,IET Microwaves, Antennas & Propagation 11.7 (2017): 955-960..
[9]Goodnick, M. ,et al. "Parallel implementation of a Monte Carlo particle simulation coupled to Maxwell's equations." ,International Journal of Numerical Modelling: Electronic Networks, Devices and Fields 8.3-4 (1995): 205-219.
[10] Lou, H. ,et al. "Application of the finite element method to Monte Carlo simulations of scattering of waves by random rough surfaces: penetrable case." ,*Waves in Random Media* 1.4 , (1991): 287.
[11] Samuel, Elizabeth Rita, Luc Knockaert, and Tom Dhaene. "Parametric macromodeling using interpolation of Sylvester based state-space realizations." 10th International Conference on Informatics in Control, Automation and Robotics (ICINCO-2013). 2013.