DUBLIN CITY UNIVERSITY
SCHOOL OF ELECTRONIC ENGINEERING

A Final Project report in

Simulation and exploration of THz TRNASMISSION LINES

By Mohammed AL Shuaili

BACHELOR OF ENGINEERING

IN

ELECTRONIC AND COMPUTER ENGINEERING

MAJORING IN

THE INTERNET OF THINGS

Supervised by Dr Marissa Condon

Acknowledgements

Declaration

I declare that this material, which I now submit for assessment, is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work. I understand that plagiarism, collusion, and copying are grave and serious offences in the university and accept the penalties that would be imposed should I engage in plagiarism, collusion or copying. I have read and understood the Assignment Regulations set out in the module documentation. I have identified and included the source of all facts, ideas, opinions, and viewpoints of others in the assignment references. Direct quotations from books, journal articles, internet sources, module text, or any other source whatsoever are acknowledged and the source cited in the assignment references. This assignment, or any part of it, has not been previously submitted by me or any other person for assessment on this or any other course of study.

I have read and understood the DCU Academic Integrity and Plagiarism policy at https://www.dcu.ie/policies/academic-integrity-plagiarism-policy

Name: Mohammed Al shuaili Date: 8/2/2025

Abstract

This final report presents the simulation and exploration of terahertz (THz) transmission lines, focusing on the development and validation of numerical models for high-frequency applications. The project addresses the challenges of accurately modelling THz transmission lines, which are essential for next-generation technologies such as 6G networks, wireless data centres, and biomedical imaging. The primary goal is to create computationally efficient and precise models capable of simulating time-domain behaviour at THz frequencies. Three key methods were employed: the Finite-Difference Time-Domain (FDTD) approach for initial approximations, the Numerical Inverse Laplace Transform (NILT) for exact s-domain solutions, and RLC ladder approximations for efficient time-domain modelling. The FDTD simulations provided a baseline for understanding transient and steady-state behaviours, while the RLC ladder method, combined with NILT, demonstrated the ability to closely match exact solutions when sufficient sections were used. The results highlight the importance of optimizing the number of sections in the RLC ladder to balance accuracy and computational efficiency. The report concludes with a validated time-domain model suitable for THz transmission line simulations, supported by iterative testing and comparison with exact solutions. This work contributes to the advancement of THz communication systems by providing reliable modelling tools for future research and development.

Table of Contents

Table of Figures

Chapter 1 - Introduction

- The growth of communication technologies has led to the exploration of terahertz (THz) frequencies (0.1 to 10 THz) for applications like 6G networks, wireless data centers, and biomedical imaging, but accurate THz transmission line models remain a challenge.
- This project aims to develop and validate efficient numerical models for THz transmission lines to predict signal behavior and optimize system performance, addressing key propagation challenges such as high attenuation and dispersion.
- Three primary methods are employed: Finite-Difference Time-Domain (FDTD) for transient analysis, Numerical Inverse Laplace Transform (NILT) for exact s-domain solutions, and RLC ladder approximations for computational efficiency.
- The motivation comes from the demand for high-speed THz communication systems, which are crucial for future technologies, but currently lack reliable and efficient modeling tools.
- The report includes a literature review, implementation details of the three modeling methods, simulation results, challenges faced, and future work plans.
- This research contributes to THz transmission line modeling by providing a validated numerical framework that can aid in the advancement of THz communication technologies.

1.2.4 Summary

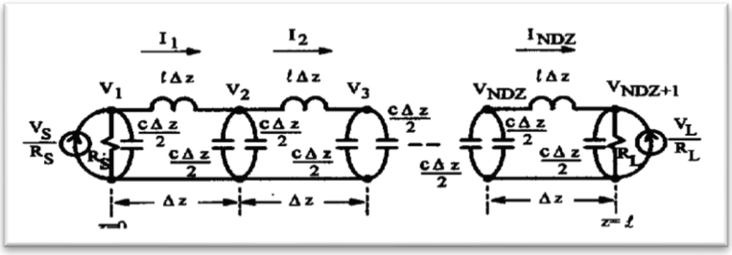
Chapter 2 - Technical Background

- Modeling THz (0.1–10 THz) transmission lines requires understanding wave propagation, transmission line theory, and numerical methods.

- Transmission lines follow Telegrapher's equations, where resistance, inductance, capacitance, and conductance vary with frequency, complicating THz modeling.

$$\frac{dV(x,t)}{dx} = -R(x) * i(x,t) - L(x)\frac{di(xi,t)}{dt}$$
$$\frac{di(x,t)}{dx} = -G(x) * V(x,t) - C(x)\frac{dV(xi,t)}{dt}$$

- The FDTD method discretizes transmission lines for time-domain simulations, capturing transient and steady-state behaviors but with high computational costs.



- The NILT method can be used to simulate frequency-domain solutions into time-domain responses, enabling precise validation of THz transmission line behavior. (NILT0??, NILTcv)
- RLC ladder approximations model transmission lines using lumped circuit elements, balancing accuracy and computational efficiency compare it to the FDTD.
- Challenges include high attenuation, dispersion, frequency-dependent parameters, and computational complexity, requiring optimised modeling techniques.

2.2 Summary

Chapter 2 - **Design of …**

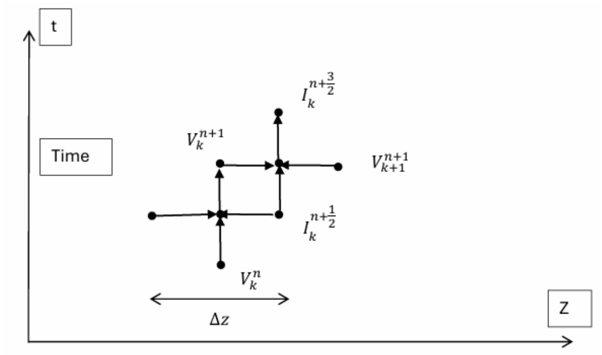
- The FDTD method is a widely used numerical technique for solving electromagnetic

$$\frac{dv(z,t)}{dz} = -R(z)\,i(z,t) - L(z)\frac{di(z,t)}{dt}$$

$$\frac{di(z,t)}{dz} = -G(z)\,v(z,t) - C(z)\frac{dv(z,t)}{dt}$$

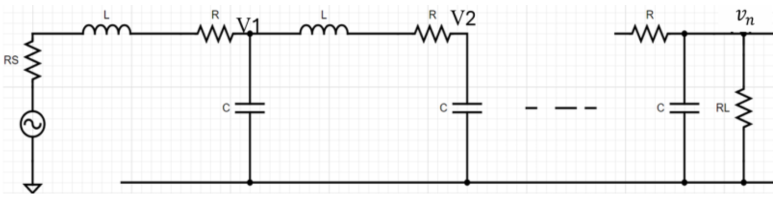
$$v_k^{n+1} = v_k^n - \frac{\Delta t}{\Delta z C}\left(i_k^{n+\frac{1}{2}} - i_{k-1}^{n+\frac{1}{2}}\right)$$

$$i_{k-1}^{n+3/2} = i_k^{n+1/2} - \frac{\Delta t}{\Delta z l}\left(v_{k+1}^{n+1} - v_k^{n+1}\right)$$



a multiconductor line?

- RLC ladder
- Explain it as, how can we plot it, why is it better than FDTD.



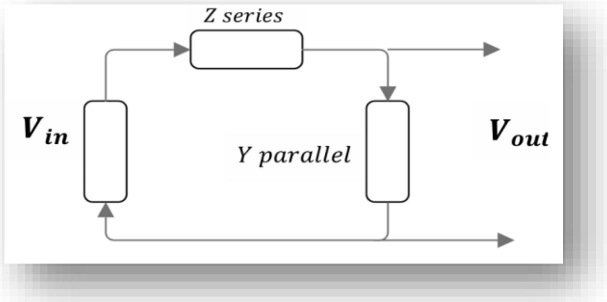
$$\frac{d}{dx}\begin{bmatrix} V(x,t) \\ i(x,t) \end{bmatrix} = \begin{bmatrix} 0 & -R(x) \\ -G(x) & 0 \end{bmatrix}\begin{bmatrix} V(x,t) \\ i(x,t) \end{bmatrix} - \begin{bmatrix} 0 & -L(x) \\ -C(x) & 0 \end{bmatrix}\frac{d}{dt}\begin{bmatrix} V(x,t) \\ i(x,t) \end{bmatrix}$$

$$\frac{d}{dx}\begin{bmatrix} V(x,s) \\ i(x,s) \end{bmatrix} = \begin{bmatrix} 0 & -Z(x,s) \\ -Y(x,s) & 0 \end{bmatrix}\begin{bmatrix} V(x,s) \\ i(x,s) \end{bmatrix} + \begin{bmatrix} 0 & L(x) \\ C(x) & 0 \end{bmatrix}\begin{bmatrix} V(x,0) \\ i(x,0) \end{bmatrix}$$

$$W(l,s) = \begin{bmatrix} V(l,s) \\ I(l,s) \end{bmatrix} = \begin{bmatrix} \Phi_{11} & \Phi_{12} \\ \Phi_{21} & \Phi_{22} \end{bmatrix} \cdot \begin{bmatrix} V(0,s) \\ I(0,s) \end{bmatrix}$$

$$V(l,s) = \frac{Vs(s)}{\cosh\left(l * \sqrt{Y * Z}\right)}$$

- Exact solution:



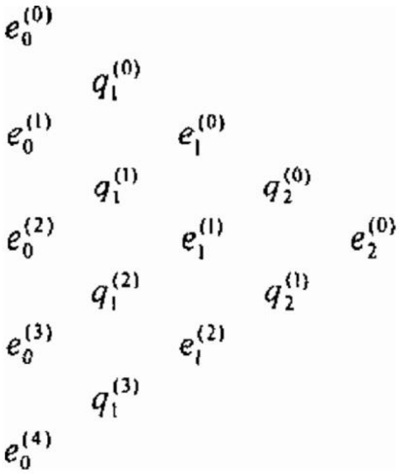
$$T(s)=\frac{V_o}{V_{in}}=\frac{1}{cosh\left(l\sqrt{(R+sC)(G+sC)}\right)}$$

- NILT0 and how it works? Why we need it?

$$\xi N,M(z)=\frac{\Sigma_{\mathrm{i=0}}^{\mathrm{N}}a_{i,M,N}z^{i}}{\Sigma_{\mathrm{i=0}}^{\mathrm{M}}(-1)^{-i}a_{i,M,N}z^{i}}$$

Challenges?
NILTcv:

$$f(t)=\frac{1}{2\pi j}\int_{c-\infty}^{c+\infty}F(s)e^{st}ds$$



- AWE..what is it and why?
AWE involves 4 main steps:
1. Form a state – space representation
2. Form the moments
3. Find the poles of the system
4. Find the residues
And then form the impulse response as:

$$h(t)=k_0\delta(t)+k_1e^{p_1t}+\ldots+k_ne^{p_nt}$$

$$\begin{bmatrix} m_0 & .... & m_{q-1} \\ m_1 & & m_q \\ . & & . \\ m_{q-1} & & m_{2q-1} \end{bmatrix} \begin{bmatrix} b_q \\ b_{q-1} \\ . \\ b_1 \end{bmatrix} = - \begin{bmatrix} m_q \\ m_{q+1} \\ . \\ m_{2q-1} \end{bmatrix}$$

- Recursive convolution based on the pole-residue representation

$$Y(s) = \frac{k_i}{s + p_i} X(s) \dots\dots . \frac{d}{dt} y(t) + p_i y(t) = k_i x(t)$$

$$y(t_n) = k_{\text{in}} x(t_n) + \sum_{i=1}^{q} y_i'(t_n)$$

- Generalise converting the RLC ladder to state space with N number of section?

$$A = \begin{bmatrix} \frac{-R_s + R_{dz}}{L_{dz}} & -\frac{1}{L_{dz}} & 0 & 0 \\ \frac{1}{C} & 0 & -\frac{1}{C} & 0 \\ 0 & \frac{1}{L_{dz}} & -\frac{R_{dz}}{L_{dz}} & -\frac{1}{L_{dz}} \\ 0 & 0 & \frac{1}{C} & 0 \end{bmatrix}$$

- Y parameters:

$$\begin{bmatrix} I_s \\ -I_R \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V_s \\ V_R \end{bmatrix}$$

$$Y_{ij} = \frac{(a_{nij} s^{n-1} + .. + a_{0ij})}{s^n + .. + b_{0ij}}$$

$$= \frac{f_{n-1} s^{n-1} + \dots + f_0}{s^n + g_{n-1} s^{n-1} + .. + g_0}$$

$$A = \begin{bmatrix} 0 & 1 & .... & ... & 0 \\ 0 & 0 & 1 & .. & 0 \\ .. & .. & .. & .. & 1 \\ -g_0 & -g_1 & -g_2 & ..... & -g_{n-1} \end{bmatrix}$$

$$H(s) = Q(s) + \frac{R(s)}{D(s)}$$

$$Y_R + jY_i = \frac{a_1 s + a_0}{s^2 + b_1 s + b_0}$$

$$A = \begin{bmatrix} -1 & Y_R^1 & 0 & -Y_i^1 w \\ 0 & Y_i^1 & -jw^1 & jwY_R^1 \\ \dots & .. & .. & .. \\ -1 & Y_R^N & 0 & -Y_i^N w \\ 0 & Y_i^N & -jw^N & -w^2 Y_i^N \end{bmatrix} \; and \; C = \begin{bmatrix} Y_R^1 w^2 \\ jY_i^1 w^2 \\ \dots \\ Y_R^N w^2 \\ jY_i^N w^2 \end{bmatrix} \; where \; A\,B = C \; and \; B = A\backslash B.$$

- Compare acquired model with the exact model at different frequencies and validate it.(next few weeks)

Chapter 4- Implementation and Testing of …

Provide a detailed explanation of all completed code implementations, including their testing processes, challenges encountered, and associated limitations. Additionally, include example tests for each point or method mentioned above.

- PSPICE Simulation?

Chapter 5 - Results and Discussion

Analyse all figures and results corresponding to specific values, explaining their significance and whether they align with expectations. Discuss any discrepancies, potential sources of error, and the reasoning behind why the results may or may not be valid.

- Complex frequency hopping?

Chapter 6 – Ethics??

Chapter 7 - Conclusions and Further Research

References

How many? I have 12 so far

Appendix 1