Physics-Informed Neural Networks for Time-Domain Reflectometry in Wiring Networks

M. MESSAOUDI[1], M. K. SMAIL[1,3], A. BOUBEZOUL[2] , A. GOUDJIL[1,3] and L. PICHON[1]

[1] *Group of Electrical Engineering Paris (GeePs), UMR 8507, CentraleSupelec, Université Paris-Saclay, Sorbonne University, CNRS, {melissa.messaoudi, Lionel.Pichon}@centralesupelec.fr.*
[2] *Université Gustave Eiffel, SATIE 4, rue René Thom,Gif-sur-Yvette,91190,France, abderrahmane.boubezoul@univ-eiffel.fr.*
[3] *Institut Polytechnique des Sciences Avancées (IPSA) 63, Boulevard de Brandebourg, Ivry-sur-Seine, 94200, France, {abdelhak.goudjil, mostafa-kamel.smail}@ipsa.fr.*

Keywords : Physics-Informed Neural Networks, Time-Domain Reflectometry, Wiring Network.

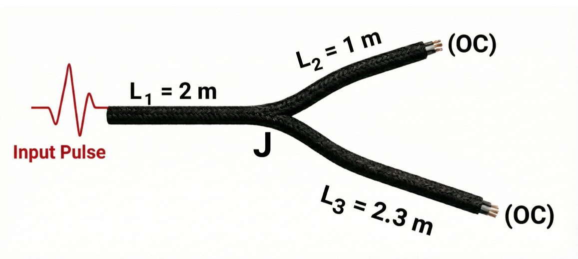
1. Introduction

Wiring networks play a critical role in the operation of many industrial and aeronautical systems, where the occurrence of faults can significantly degrade overall functionality. Among the various diagnostic methods, those based on reflectometry responses have proven to be among the most efficient and widely used [1]. In particular, Time-Domain Reflectometry (TDR) is extensively employed due to its simplicity and accuracy. TDR responses are commonly modeled using numerical approaches such as the Finite-Difference Time-Domain (FDTD) method [2]. However, these techniques suffer from several drawbacks, including mesh dependency and high computational cost. To overcome these limitations, this paper proposes a new modeling approach for TDR responses based on Physics-Informed Neural Networks (PINNs).

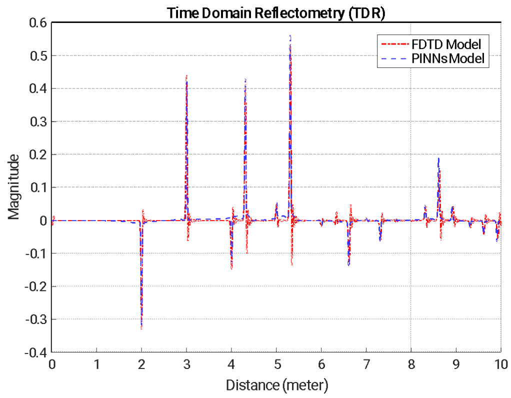
2. Methodology and Numerical Results

In this study, a PINN-based approach is developed to simulate the TDR responses in wiring networks. The governing electromagnetic equations, expressed as Partial Differential Equations, along with the associated initial and boundary conditions, are directly embedded into the network loss function, which is minimized during training [3]. This enables mesh-free modeling while enforcing the physical consistency of the solution.

To validate the proposed approach, TDR responses of a Y-shaped network are computed using both PINNs and FDTD and compared, as illustrated in Fig. 1. The results show very good agreement between the two methods, while the FDTD solution exhibits numerical oscillations due to discretization. In contrast, the PINN response remains smooth and stable, confirming the robustness and suitability of the approach for fault detection and localization in wiring networks.



(a)



(b)

Fig. 1 – (a) Y-shaped network and (b) TDR responses

References

[1] C. Furse, Y. Chung, C. Lo, and P. Pendayala, "A critical comparison of reflectometry methods for location of wiring faults," *Smart Structures and Systems*, vol. 2, no. 1, pp. 25–46, 2006.

[2] M. K. Smail, L. Pichon, M. Olivas, F. Auzanneau, and M. Lamber, "Detection of defects in wiring networks using time domain reflectometry," *IEEE Transactions on Magnetics*, vol. 46, no. 8, pp. 2998–3001, 2010.

[3] M. Raissi, P. Perdikaris, and G. E. Karniadakis, "Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations," *Journal of Computational Physics*, vol. 378, pp. 686–707, 2019.