

## AI-Driven Electromagnetic Modeling of Cable Harnesses: From RLGC Matrix Prediction to Crosstalk Estimation

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### Abstract

In modern aeronautics, the increasing complexity of Electrical Wiring Interconnection Systems poses significant challenges for Electromagnetic Compatibility analysis. The standard approach relies on Multiconductor Transmission Line (MTL) theory, which requires the computation of Per-Unit-Length parameters, Resistance (R), Inductance (L), Conductance (G), and Capacitance (C), to solve the Baum-Liu-Tesche (BLT) equation for crosstalk estimation. Conventionally, these parameters are extracted using numerical methods like the Method of Moments (MoM). However, these methods are computationally expensive for complex bundles or iterative optimization.

We propose a deep learning framework designed to accelerate the modeling of cable harnesses in first order and then estimate cross-talk current. Initial works [1] focused on predicting L and C matrices separately, using convolutional neural networks and Transfer Learning, achieving a speedup factor of nearly 100 compared to MoM with a mean relative error below 5%. Building upon these foundations, we propose to create a unified, physics-aware neural architecture for both. As described in [2], L and C matrices must be symmetric and semi positive definite. Furthermore, their structures differ physically: for L, diagonal elements represent self-inductances and off-diagonal elements are mutual inductances; for C, the diagonal terms are the sum of each conductor's self-capacitance and the mutual capacitance with all other conductors in the bundle. To ensure physical validity, our proposed model uses separate sub-modules steered by these specific physical definitions before aggregating the results. We evaluate a reconstruction strategy based on predicting key matrix coefficients. This approach is compared to direct prediction of the full matrix in terms of result quality.

Regarding the architecture, we adopt a **message-passing** framework for **graph-structured** data. Since a cable bundle naturally represents a graph topology, where wires are nodes and electromagnetic couplings are edges (through distance features), this architecture captures both local proximity effects and global interactions through attention mechanisms. Due to limitations of the numerical solver, matrix data corresponding to simulations with a large number of cables cannot be extensively generated because of the computational cost, resulting in an out-of-distribution setting. Nevertheless, a few high-dimensional configurations can be simulated to validate the generalization capability of the proposed graph neural network when predicting matrix coefficients beyond the complexity observed during training.

### References

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