A Hybrid Modelling Approach for Evaluating the Emissions from a Powertrain

G. Di Mambro[#1], S. Sibilia[#$2], D. Capraro[#$3], A. G. Chiariello[*4], D. Capriglione[#5], A. Maffucci[#6]

Dept. of Electrical and Information Engineering, University of Cassino and Southern Lazio, Itay
$ E-lectra, Cassino, Italy
* Dept. of Engineering, University of Campania "L. Vanvitelli", Italy

This work presents a hybrid modeling approach for estimating the electromagnetic (EM) emissions of a powertrain (Figure 1) intended for automotive applications. EM emissions are a critical aspect during the design phase of electric and hybrid vehicles, as they directly impact compliance with electromagnetic compatibility (EMC) standards, such as UNECE Regulation No. 10 [1].

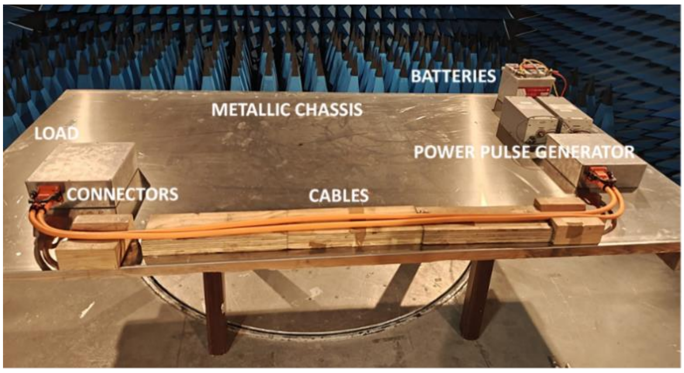

Fig. 1. The experimental mock-up of a powertrain realized for this work.

The powertrain is one of the main contributors to EM field emissions, comprising elements such as power cables, inverters, batteries, motors, and chargers. These components can generate electromagnetic interference (EMI) through both conductive coupling and radiated interactions, with disturbance levels depending on spatial, temporal, and frequency-related factors. The use of fast-switching technologies (e.g., SiC, GaN) further exacerbates EMI issues due to increased energy density and miniaturization [2].

The objective is to provide a practical yet accurate method to predict both conducted and radiated emissions from the powertrain, accounting for interactions between subsystems, which cannot be captured by analyzing components in isolation. The strategy combines:

- Full-wave electromagnetic modeling (for geometrically known components such as cables and chassis),
- Experimental characterization (for components known only via datasheets, such as batteries and inverters),
- Equivalent multiport circuit representation for system-level simulation.

The distributed subsystem (cables, connectors, chassis) is modeled using full-wave EM simulations to extract scattering parameters (S-parameters). The "black-box" components are experimentally characterized to derive equivalent circuit models (impedances and sources).

All models are integrated into a single circuit simulation to estimate high-frequency currents and voltages, enabling the prediction of conducted emissions. The full-wave EM model is reused, driven by time-domain waveforms obtained in step 3, to estimate radiated emissions.

A simplified powertrain mock-up was constructed, consisting of a power stage and a load (passive or active), housed in metallic enclosures and connected via automotive cables (both shielded and unshielded). Two configurations were analyzed:

- A passive test case powered by a sinusoidal generator and 50Ω load;
- A realistic active setup with 12V battery, SiC inverter, and control board, all housed in a shielded enclosure.

Termination impedances were measured using a network analyzer, while inverter ripple content was assessed by measuring switching currents and voltages under various load conditions. The open-circuit characterization provided the most accurate estimate of real-world emissions.

The 5 MHz simulation showed excellent agreement between simulated and measured currents (Figure 2), validating the model for conducted emission prediction.

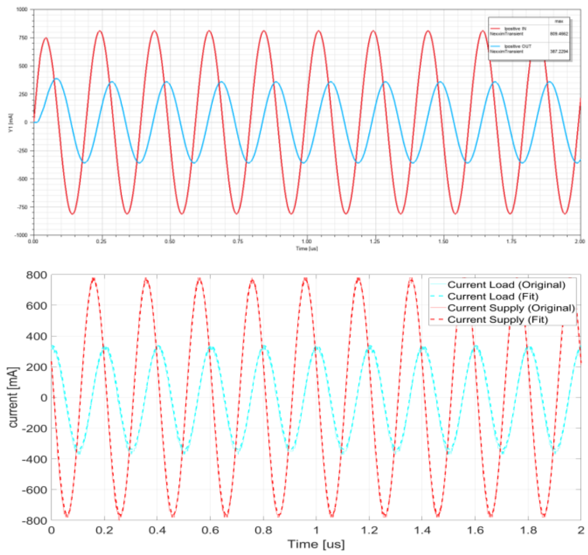

Fig.2. Currents waveforms evaluated at the cable input (red) and output (light blue): (a) simulated; (b) measured.

For radiated emissions, the simulation accurately captured key peaks above 200 MHz. Some low-frequency peaks were missed, likely due to common-mode currents not yet included in the model. Simulated electric field levels were consistent with measurements, with an accuracy of approximately ±6 dB, confirming the model's reliability. The proposed method enables accurate estimation of EM emissions from a powertrain using a combination of full-wave simulation and experimental component characterization. It delivers reliable results for conducted emissions and coherent order-of-magnitude predictions for radiated emissions, making it a valuable tool for early-stage design. Future work will focus on including common-mode effects to enhance the modeling of low-frequency radiation.

ACKNOWLEDGEMENT

This study was carried out within the MOST – Sustainable Mobility Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033 17/06/2022, CN00000023). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

REFERENCES

[1] ECE R 324 (Addendum 9, Regulation No. 10, Revision 6), https://unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/r046r1e.doc.

[2] C. Li, Q. Ma, Y. Tong, J. Wang, P. Xu, "A survey of conductive and radiated EMI reduction techniques in power electronics converters across wide-bandgap devices," IET Power Electronics, Vol.16, no.13, 2121-2137, Nov. 2023.