PLASTIC OPTICAL FIBER-BASED WIRING SOLUTION FOR AUTOMOTIVE POWER ELECTRONICS SYSTEMS

G. Durana [(1)], E. Ibarra [(2)], I. Kortabarria [(2)], A. Matallana [(2)], G. Aldabaldetreku [(1)]

1: Department of Communications Engineering, Engineering School of Bilbao / University of the Basque Country (UPV/EHU), Plaza Ingeniero Torres Quevedo no. 1, 48013 Bilbao (Spain).

2: Department of Electronics Technology, Engineering School of Bilbao / University of the Basque Country (UPV/EHU), Plaza Ingeniero Torres Quevedo no. 1, 48013 Bilbao (Spain).

Email: gaizka.durana@ehu.eus

Abstract: Power electronics systems represent a fundamental technology in modern electric vehicles and also in many industrial applications. In this context, the presence of high electromagnetic interferences due to high d*v*/d*t* variations make it preferable to use polymer optical fibers (POFs) to connect the controller-to-converter digital signals, thus minimizing unwanted control actions. The authors have introduced successfuly a POF-based solution in an automotive grade back-to-back multiphase electric drive test bench. In addition, a number of points for improvement have been identified and will be presented.

Key words: POF, EMI, Electric Vehicles, Power Electronics Converters, Digital Signals.

1. Introduction

Electromagnetic interference (EMI) is a critical challenge in power electronics systems, especially in environments with high-frequency switching, large currents, and densely packed wiring. Traditional copper wiring, while effective in conducting power, is susceptible to EMI, which can degrade signal integrity and lead to system malfunctions. Additionally, thick electrical cables contribute to increased system weight and complexity, limiting design flexibility. In conventional automotive wiring solutions, shielded bulky connectors and cables are employed to reduce interference-related issues [1]. Plastic Optical Fibers (POFs) offer a promising alternative as a wiring solution in such systems [2]. Unlike copper cables, POFs are immune to electromagnetic interference, providing reliable data transmission even in noisy environments. They are also lightweight, flexible, and easy to install, making them ideal for reducing system complexity and enhancing overall performance. For this application, step-index POFs have been chosen as the most convenient alternative. They offer a solution for high bandwidth and low attenuation over short distances at an affordable cost.

2. Platform description

Fig. 1 below shows the layout of the automotive electric drive testing facility (left diagram), which is mounted in a back-to-back configuration (right picture). This means that the EVO AF-30 counter-load machine (surface mounted Permanent Magnet Synchronous Machine, item 6) sets the mechanical speed of the vehicle, whereas the traction machine under test (custom-made Dual Three-Phase Interior Permanent Magnet Synchronous Machine, item 7) applies the electromagnetic torque commanded by the driver.

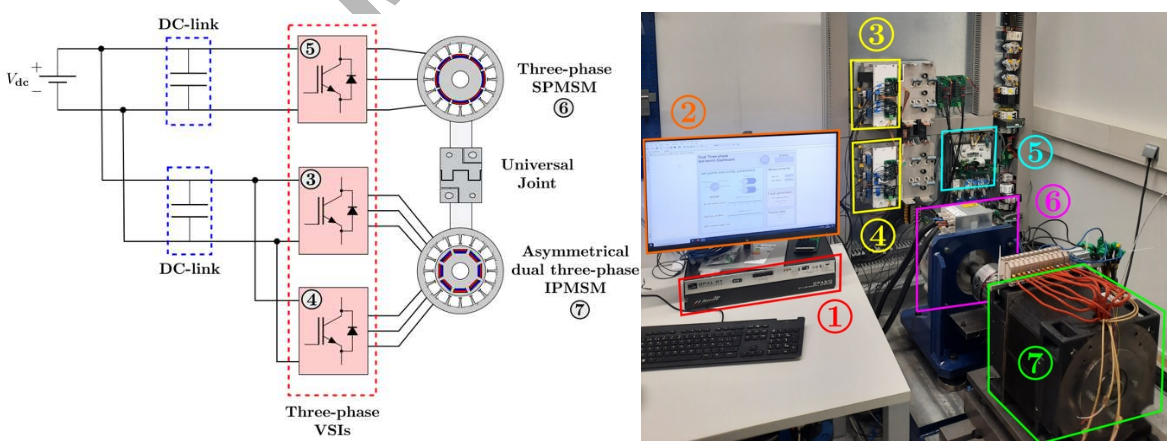

Fig. 1: (Left) Schematic representation of the back-to-back configuration of the electric vehicle drive test-bench. (Right) Electric vehicle drive test-bench.

The platform incorporates these additional elements:

1. A commercial three-phase Semikron power inverter (item 5) to feed the counter-load machine.

2. Two three-phase APS ICEPAC power inverters (items 3 and 4) to feed the Dual Three Phase PMSM.

3. An AMREL SPS600-10-K053 DC power supply to emulate the battery pack of an electric vehicle (EV).

4. The control electronics (items 1 and 2), which includes an OPAL-RT RT-Lab OP4510 RCP/HiL system (Intel Xeon E3 CPU with four cores at 2.1 GHz and a XilinX Kintex 7 FPGA). This real-time digital device provides closed-loop control to both counter-load and traction drives. The Field Oriented control algorithms for the electric machines are implemented in the CPU, along with the corresponding state machine, communications, scaling, alarms and monitoring blocks. The tasks that require very fast execution, for example the PWM modulation and I/O management, are carried out in the XilinX FPGA.

In the framework of this layout, high dv/dt derivative –ranging from 270 V up to 800 V within hundreds of ns– occurs as a result of the commutations in the power semiconductors, giving rise to harmful conducted and radiated EMI. Many techniques exist to deal with the different types of radiated and conducted EMI, i.e. shielding techniques of wires, minimization of length of the wires and tracks, etc. In the present case we have considered convenient to implement an optical solution to reduce the interference-related issues in the controller-to-converter communications. More specifically, in the present case step-index (SI) profile POFs of 1 mm of diameter have been used in conjunction with commercial fiber optic transmitters and receivers from Broadcom/Avago.

3. POF-based digital communication solution

As a first proposal for solving the potential interference issues in the diversity of digital signals (PWM, SPI, general purpose digital IOs) of the controller-to-converter communications, a fiber-optic link consisting of the following components have been considered: On the transmission side, a transmitter in a vertical mount configuration that incorporates a 660-nm LED designed to work at a rate of 5 Mbaud, and on the reception side, a digital IC receiver with an open collector Schottky output transistor [3]. Joining both sides, a 1-mm diameter SI POF with Versatile Link non-latching simplex connectors. Internal optics are optimized for 1-mm POFs. The link components are compatible with standard TTL circuitry. A photograph of the fabricated test board to evaluate the convenience of the proposal is shown in Fig. 2 (left photograph).

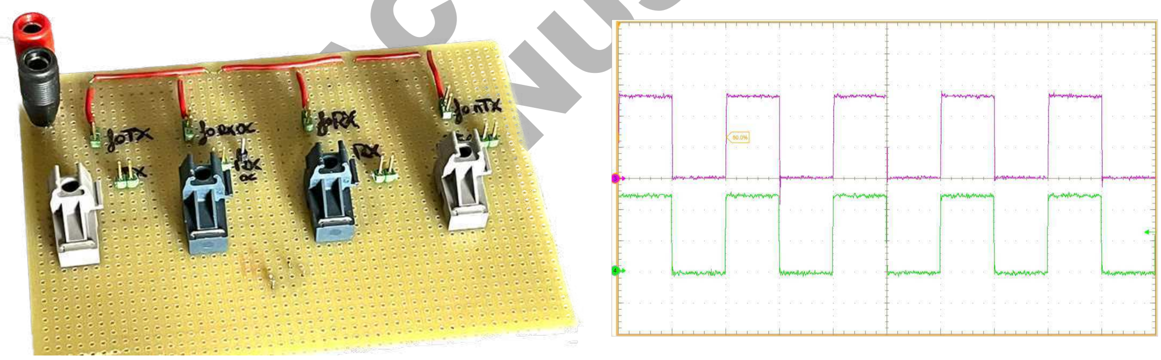

Fig.2: (Left) Fabricated test board to evaluate the POF-based digital transmissions of interest. Shown in the picture: 5 V supply voltage, and transmitter and receiver modules with their optical and electrical connections. (Right) Transmitted input signal (green curve; 50 % duty cycle 5 Vpp input signal @ 100 kHz) and the received output signal after propagating through a POF sample.

The results obtained with the test waveforms encouraged us to take further steps in the way of implementing the solution to the case of interest, i.e. the EV drive test bench described in the previous section. But in this case, with the addition that the optical communication occurs in the presence of EMI, and that the circuitry accompanying the transmitters and receivers must be integrated with the topology of the power inverters.

4. Conclusions

The solution to address some of the intrinsic problems in the digital controller-to-inverter communications that arise in EV electronic systems –as a consequence of the radiated and conducted EMI,– has been implemented in the form of a POF-based digital communication. POFs offer a number of advantages that make them ideal for the task. Thus, a simple solution consisting of a LED light source @ 660 nm and a digital IC receiver, in combination with a conventional 1-mm diameter SI POF, has proved to be very efficient in establishing a reliable digital communication against the noise created by the electromagnetic interferences of the system. The solution is satisfactory in terms of dealing with the harmful effects of this kind of noise, but simultaneously new challenges emerge. In order to make the proposal attractive from a practical point of view, we envisage new solutions in the form of novel transmitters and receptors with a smaller footprint in the PCBs, or the convenience of using multicore POFs or alike to reduce the number of cables in the system.

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