EMC impact of online embedded wire diagnosis

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Abstract

This paper presents EMC measurement results for an online wire-diagnosis system integrated in a vehicle. The spectrum control properties of the reflectometry-based MCTDR method make it a good candidate for EMC compliance. This was verified both for conducted and radiated EMC. Results with CAN and FM bands cancellation in the MCTDR signals are presented. This study confirmed the EMC harmlessness of MCTDR when the chosen frequency bands are cancelled in its spectrum.

1. Introduction

The need for detection and location of defects in wired networks has been recognized in many application domains such as power distribution, communications and transportation. Several methods have been investigated such as impedance spectroscopy [1] but the most promising ones are based on reflectometry: a high frequency signal is injected in a wire and propagates throughout the network. Each time an impedance discontinuity is met, a part of the energy is sent back. The analysis of the reflected signal provides information about faults characterization and location. The original Time Domain Reflectometry (TDR) has evolved and given rise to new methods such as Sequence TDR (STDR) [2], Spread Spectrum TDR (SSTDR) [3], Multi Carrier TDR (MCTDR) [4], and Orthogonal Multi-Tone TDR (OMTDR) [5] which have their specific advantages and drawbacks. These methods provide very good results for hard faults detection, i.e. open and short circuits. Location accuracy is a few percent of the total length of the wire. Recently, the need for soft faults diagnosis led to the development of Joint Time Frequency Domain Reflectometry (JTFDR), a new hybrid method merging the benefits of TDR and Frequency Domain Reflectometry (FDR) [6].

New embedded wire diagnosis (EWD) needs have appeared, mainly for transportation application. EWD has specific requirements due to the application, to the wire types and topologies, and to standards. One of the main constraints is harmlessness: the signals used for diagnosis must not interfere with the useful signals of the wire (if any, e.g. for a communication network) and the latter must not interfere with diagnosis and create false alarms. These constraints have already been studied and several compliant diagnosis methods exist (SSTDR, MCTDR, OMTDR, etc.).

But another important constraint must be considered: Electromagnetic Compatibility (EMC). Modern transportation systems must follow very stringent design norms guaranteeing they can work properly in a given operational electromagnetic (EM) environment without creating any EM perturbations which would prevent any other system from working. When high frequency signals are injected in the wires of a car, truck or aircraft, two new phenomena appear. First, the wires will radiate new RF signals which will propagate and interact with neighboring wires, creating new signals in them. Second, the diagnosis signals propagate in the wires and can perturb the loads connected to them. The existence of these perturbations and their compliance with EMC standards must be checked, and any non compliance corrected. In this paper, we show EMC measurement results of MCTDR signals used for EWD in a modern car. Both conducted and radiated EMC have been verified, using normalized measurement equipment.

2. Online embedded wire diagnosis for road transports

The road transport harness is stressed during utilization. Intermittent faults triggered by vibrations, shocks or other environmental stimulation can appear and cause system malfunction. These faults cannot be easily re-played during maintenance operations. A real time harness analysis during the whole vehicle's life can solve this problem by storing the fault's location information when it appears. This requires the analysis to be transparent to the system and vice versa. Specific diagnosis methods must be used, such as MCTDR and OMTDR, which provide a complete control of the test signal's spectrum. In this work, MCTDR method was used: the test signal is formed by a weighted sum of sinusoids (1), where the desired frequency coefficients c_n can be set to zero or any value less or equal to 1.

$$s_k = \frac{2}{\sqrt{N}} \sum_{n=0}^{N/2} c_n cos\left(\frac{2\pi n}{N} k + \theta_n\right) \quad (1)$$

To diagnose a Controller Area Network (CAN) bus, the coefficients of the CAN signals' frequency band [0 – 2 MHz] are set to 0. Other EMC rules may require conducted and radiated limits. For example FM band emission is regulated [87.5 - 108 MHz]. The corresponding coefficients can be reduced to ensure EMC compliance. To verify this, 3 MCTDR signals have been designed. In the first one, called "MCTDR full band", all coefficients are equal to 1 from 0 to 200 MHz; in the second, called "MCTDR no CAN/FM1", the coefficients of CAN and FM bands are set to 0; in the third called "MCTDR no CAN/FM2", the FM band was extended to [75 - 125 MHz] (table 1). Figure 1 compares configurations 2 and 4, measured in the frequency domain and in the time domain.

Table 1. Tested configurations

Configuration	CAN signals	Diagnosis system	MCTDR signals
1	ON	ON	No signal
2	ON	ON	MCTDR Full band
3	ON	ON	MCTDR no CAN/FM1
4	ON	ON	MCTDR no CAN/FM2

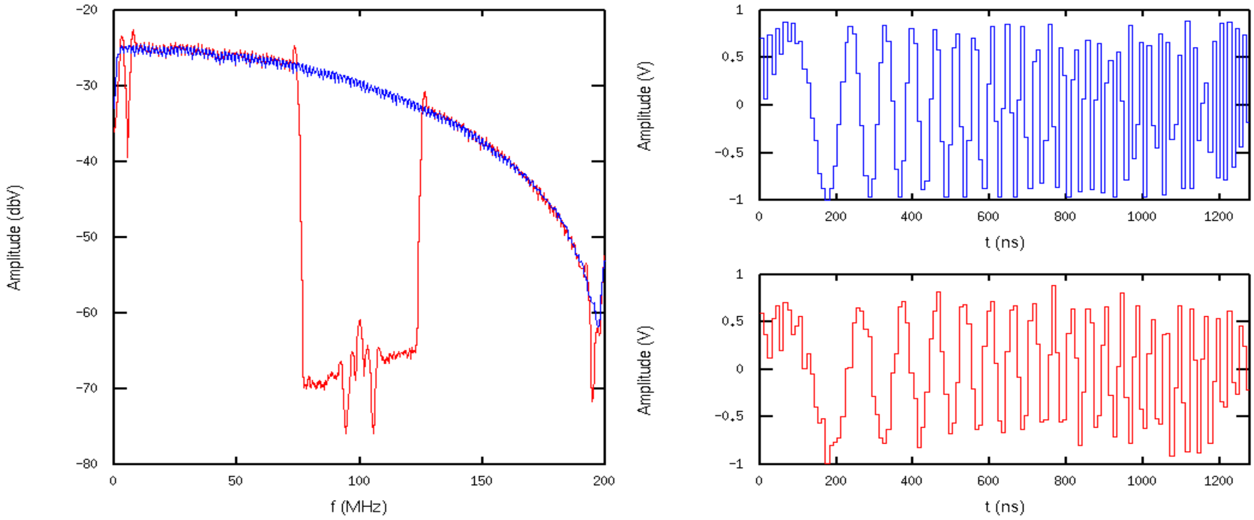

Figure 1. Comparison of the MCTDR signals in the frequency domain (left) and in the time domain (right). Blue: configuration 2, red: configuration 4

3. Conducted EMC measurements

3.1. Measurement setup

The measurement setup was based on the requirements of the CISPR25 norm, from the International Electrotechnical Commission (IEC) [7]. An Electronic Control Unit (ECU) from Delphi was equipped with an additional FPGA-based card implementing the MCTDR diagnosis, as shown on Figure 2 (left). The harness was connected to the ECU, and the diagnosis signals injected into 4 different wires (signal and supply), through the ECU's connectors. The current clamp was positioned at various places along the wires, to measure the current in the 150 kHz – 108 MHz frequency band. Various configurations were tested (table 1): diagnosis system OFF, diagnosis system ON but no signal injected, full band MCTDR injected signal and MCTDR signal with CAN and FM bands cancelled.

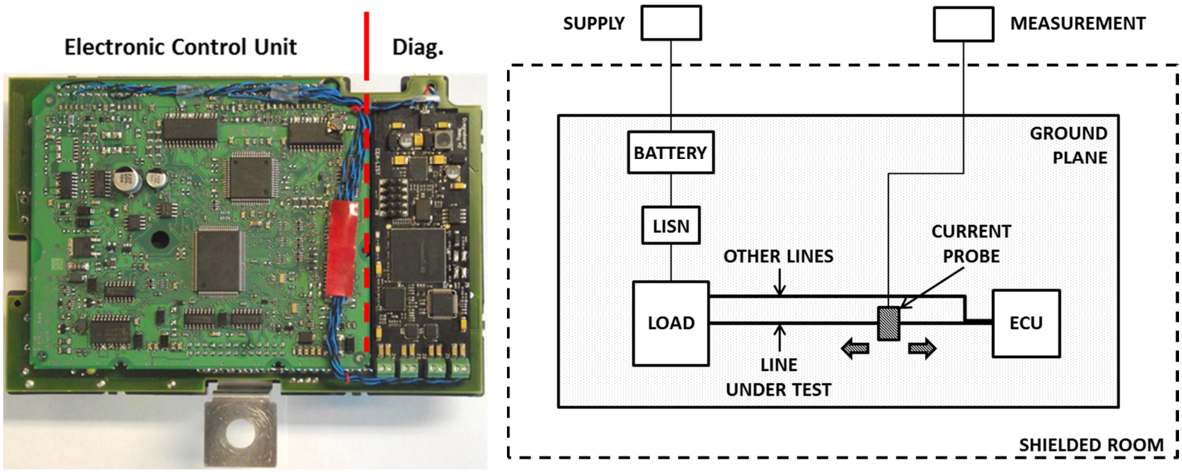

Figure 2. ECU equipped with diagnosis board (left), conducted EMC test setup (right) [LISN: Line Impedance stabilization Network].

3.2. Measurement results

Figure 3 plots the measurement results for configurations 2 and 3, using configuration 1 as zero reference. The presence of each MCTDR carrier frequency can be seen on the measurement results. As expected, setting the FM carrier's coefficients to 0 brings the current values close to the "no signal" level (10 to 30 dB signal decrease).

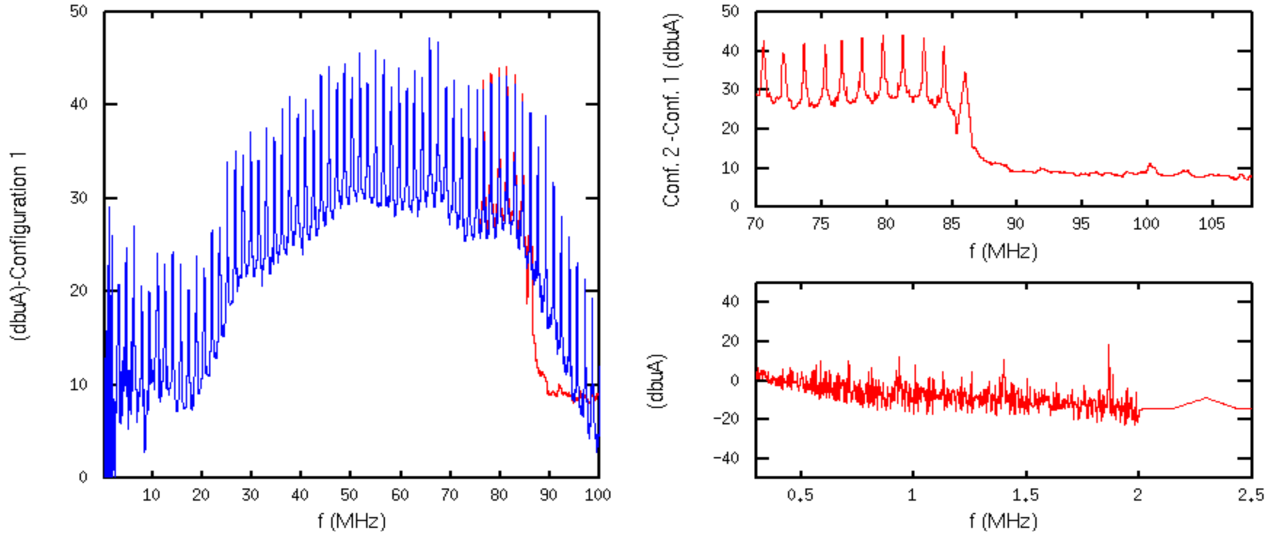

Figure 3. Conducted EMC measurement results. Left: configurations 2 (blue) and 3 (red), using configuration 1 as zero reference. Right, configuration 3: (up) zoom on FM band | (down) zoom on CAN band, showing peaks caused by the switched-mode power supply.

4. Radiated EMC measurements

4.1. Measurement setup

The modified ECU was implemented inside a passenger car in place of the serial ECU. This modified ECU was equipped with the same software/datasets as the serial ECU. The radiated emission test was performed in the VOLVO GTT EMC Laboratory inside a large anechoic chamber with two distinct test setups:

a) Vehicle-to-antenna spacing of 3.0 ± 0.2 m, in accordance with CISPR12 norm [8]. The antenna was placed at two positions (left and right vehicle side), see figure 4 (left), in order to measure the radiated emission in the frequency range from 30 to 1000 MHz;

b) Emission measurements at on-vehicle antennas were performed according to CISPR25 [7] for the frequency range from 26 to 2000 MHz, see figure 4 (right).

Various configurations were tested (see table 1).

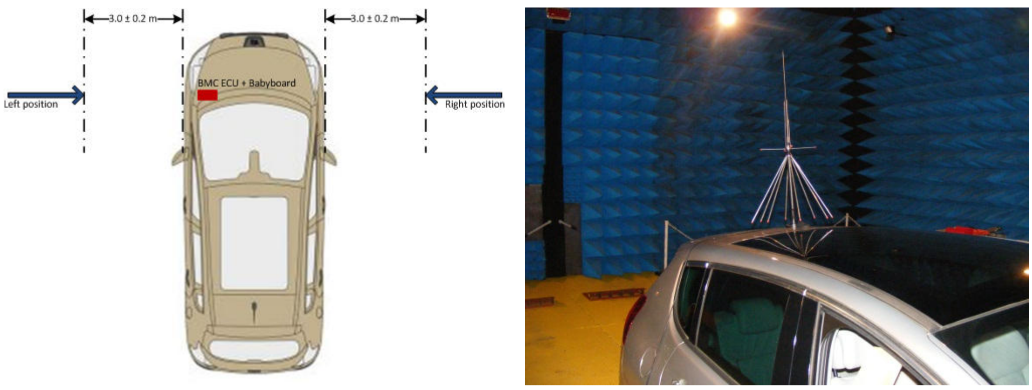

Figure 4. Radiated EMC test setup.

4.2. Measurement results

Previous radiated EMC measurements [9-10] have shown that the STDR method is not suited to fulfil EWD constraints. Furthermore, a modification of SSTDR, called "Modified SSTDR", improves SSTDR's compliance. Figure 5 shows measurement results for setup a) described above, using configurations 2 and 4. The CAN band is too low to appear in this measurement setup, but the cancellation of the FM band is clearly visible. A reduction of 20 to 30 dB on the emitted fields has been achieved.

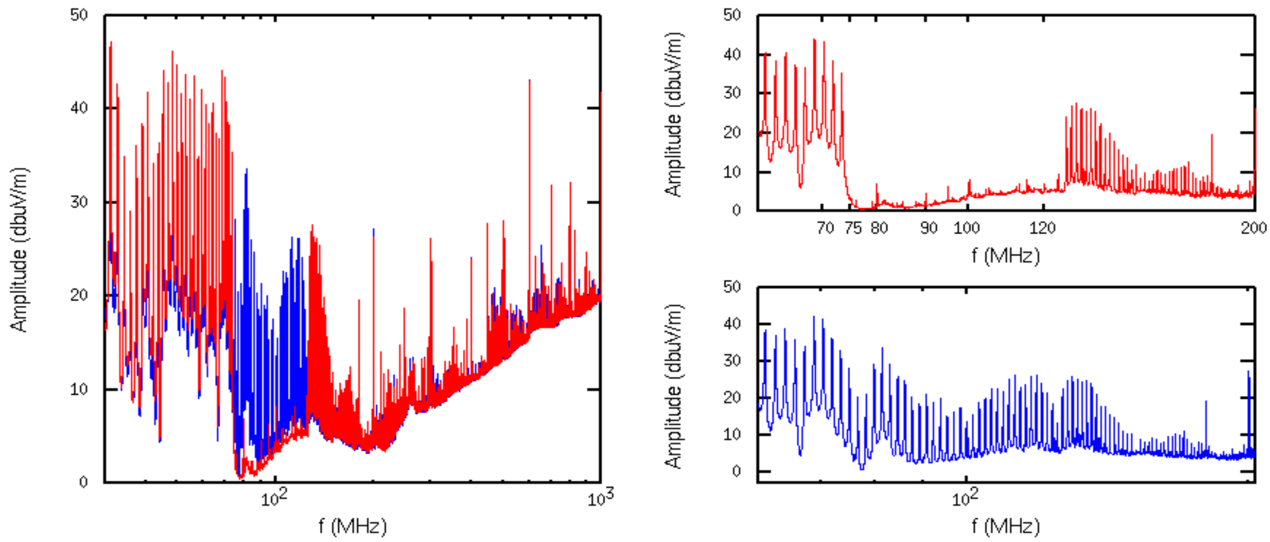

Figure 5 - Radiated EMC measurement results (vertical polarization average detector)
Left: two measurements compared | Right (up) configuration 4, (down) configuration 2 (arbitrary units)

5. Conclusion

An Electronic Control Unit was modified to add MCTDR-based wire diagnosis function. Conducted and radiated EMC measurements were performed. They have shown that cancelling frequency bands allows fulfilling automotive standard's harmlessness constraints. In both cases, the EMC signal in the band gap is 10 to 30dB lower than the same full band signal. This work confirms that from the EMC point of view, MCTDR can be used for embedded wire diagnosis.

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