Test Procedure for CAN Bus Susceptibility Evaluation Based on the Use of Radio Frequency Detectors

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Abstract

In this paper, the use of Radio Frequency (RF) detectors for measurement of the induced RF current level on terminal nodes of High speed CAN Bus due to different immunity test methods is explored. The data obtained provides a representation of the magnitude of the common mode (CM) and differential mode (DM) induced current on the CAN bus terminal nodes. As a particular result, the test procedure allows to assess the Bulk Current Injection stress level, as required by automotive manufactures, with up to a 200 V/m impinging electromagnetic field generated in a TEM Cell, in the frequency range 1 MHz – 200 MHz.

1. Introduction

The Controller Area Network (CAN) is an advanced serial bus system supporting distributed control systems. Initially introduced in 1986 by Robert Bosch GmbH, Germany, it is nowadays standardized by several automotive Standards, such as those drawn up by the International Standardization Organization (ISO) [1], and by the Society of Automotive Engineers (SAE), [2]. CAN is mainly diffused in the automotive sector. Nevertheless, it has recently found applications in the space sector, in rail environment, and for building automation.

The physical medium for the CAN-bus line is to be able to transmit the two possible bit states: “dominant” and “recessive”. To this end, Standard ISO 11898 [1] foresees that the CAN bus is a pair of wires, parallel or twisted, shielded or unshielded, depending on Electromagnetic Compatibility (EMC) requirements. In particular, Part 2 of the above Standard described the use of a twisted wire pair (TWP), loaded by termination resistors at each end of the bus line. These resistors (typically 124 Ohms) assure matching with the TWP characteristic impedance, thus reducing signal reflections.

In the space sector, EMC performances of CAN bus with respect to radiated emissions have been experimentally investigated by ESA/ESTEC in a recent test campaign, [3]. To this end, a prototype of the bus system available in small satellites has been implemented according to [4], and tested according to [5].

As regards immunity, the use of a twisted wire-pair (TWP) assures bus insensitivity to electromagnetic interference (EMI), due to the differential nature of data transmission, [6]. Additionally, the use of split terminations at the bus ends allow for further enhancement of the EMC characteristics. Basically each of the termination resistors is split into two resistors of equal value (i.e., two resistors of 62 Ω instead of one resistor of 124 Ω) in series connection, while the center tap is connected to a grounding capacitor of e.g. 10 nF to 100 nF. However, even if the CAN bus physical layer is designed in such a way to be inherently immune to EMI, development of procedures and setups for the experimental verification of bus immunity (to both conducted and radiated disturbances) is of paramount importance in order to quantitatively characterize its ability to operate in harsh environments and for the assessment of maximum performance.

This work focuses on CAN bus immunity assessment and proposes an experimental procedure based on the use of radio frequency (RF) detectors. The procedure foresees characterization of the noise levels induced in the bus terminations via measurement of both the common-mode (CM) and the differential-mode (DM) induced noise. The use of RF detector (to convert the RF disturbances to DC signals) permits to overcome typical difficulties and limitations involved in the use of current probes, and allows for consistent and accurate comparison of the severity levels of different immunity test methods. In particular, in this paper CAN bus radiated susceptibility data obtained via the transverse electromagnetic (TEM) cell method are compared versus conducted susceptibility data obtained via the bulk current injection (BCI) technique. The procedure is simple to be implemented and effective for the verification of the immunity levels of the bus, combined with the noise rejection characteristics of the terminal networks.

2. BUS Configuration Under Analysis

For a full description of the susceptibility of a CAN bus system, the ability of the system to reject the CM and DM noise currents induced in the termination networks by radiation or conduction should be characterized. To this aim, the canonical CAN bus configuration composed of a TWP with split terminations was considered, and one of the two terminations was suitably modified in order to be able to sense CM and DM noise currents. To this end, a circuit was designed to provide the termination load requirements (according to ISO 11898), and equipped with suitable voltage monitor ports. Fig. 1 illustrates the overall CAN bus configuration that was designed, implemented in a real setup, and experimentally characterized. As regards the right-end load, it should be noticed that the use of a center-tap RF transformer as balancing device represents a specific choice and, as such, it contributes to the immunity levels of the CAN bus configuration. Nevertheless, here the attention is primarily focused on the procedure for the experimental characterization of the immunity of a general CAN bus system, rather than on the role played by a specific configuration of the terminal networks on the immunity levels of the overall wiring system.
For the implementation of the right-end load, a Mini-Circuit ADT2-1T RF center-tap transformer was used. The transformer has a bandwidth 0.4—450 MHz and impedance ratio (secondary to primary) of 2. The series connection of 10 Ω and 50 Ω resistors on the output port of the transformer is used to obtain approximate matching with the bus characteristic impedance ($Z_C = 124\,\Omega$), whereas the 50 Ω resistors are used to sense the DM noise current (output port) and the CM noise current (connection of the split node to ground), respectively. RF detector is used to convert the RF noise currents (through the 50 Ω resistors) into dc signals (at the output port of the detector). This assures accurate measurement of the induced currents, also in the case of the TEM cell test, in which the entire structure (interconnection between CAN bus right load and measuring device included) is exposed to the impinging EM field. The RF detector used in this setup is a Linear Technology LT5537. The RF detector is characterized by a wide dynamic range and has a bandwidth extending up to 1 GHz. It operates according to the following log-linear relationship between the RF input power and the dc output voltage:

$$V_{\mathrm{dc}}^{\mathrm{out}} = S(f)\cdot[P_{\mathrm{dBm}}^{\mathrm{in}}(f) - P_0(f)] \tag{1}$$

where $V_{\mathrm{dc}}^{\mathrm{out}}$ is the output dc voltage in Volts and $P_{\mathrm{dBm}}^{\mathrm{in}}$ is the input RF power at frequency f in dBm. In (1), S and P_0 are the slope and the intercept respectively. These parameters can be obtained by frequency interpolation of data reported in the RF detector data-sheet. The RF Detector circuit was built on a 4-layer PCB. The PCB and its dc power supply was placed inside a metallic box. RF input power, at the input port of each detector, was protected from excessive RF levels by insertion of a 30 dB attenuator. In order to preserve the 90 dB dynamic range of the detector circuit, it was required to main a high quality power supply at 4.5 V dc.

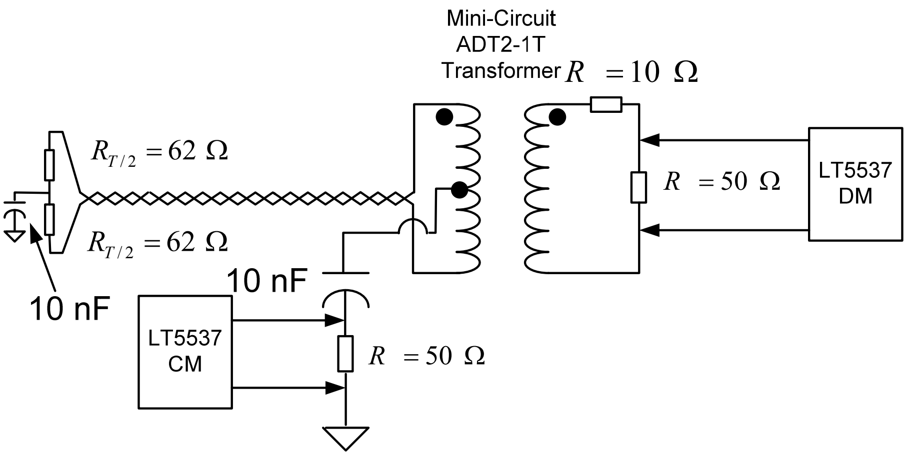

Figure 1. Overall wiring structure under test, composed of a TWP with standard split termination at one end, and center-tapped RF transformer with RF detectors at the other end.

3. Test Setups and Concluding Remarks

This section describes the two setups that were implemented in order to test and compare the conducted and radiated susceptibility of the high speed CAN described in the previous section. In particular, Fig. 2(a) illustrates the BCI setup, whereas in Fig. 2(b) the TEM cell setup is sketched. BCI tests were performed on 2 m and 90 cm TWPs, but in this paper only the case of a 90 cm long TWP is considered, since such a length allows for direct comparison of BCI test outputs versus TEM cell outcomes.

In the BCI test, injection probe locations were selected according to the indications provided by various automotive standards, which (for a harness length of 2 m) foresee that the injection device is placed at 15 cm and 75 cm from the termination under test. Additional tests (not reported here for brevity) were also performed at scaled distances. The amplitude of the RF current (injected via a FCC F130A-1 probe clamped onto the bus) was limited to 30 mA. Prior to injection on a CAN bus structure, probe was mounted on the calibration fixture i.e., the jig, and characterization was performed throughout the frequency range of 1 MHz – 400 MHz. Injection current was limited to 30 mA to prevent thermal damage to the bus termination components.

In the TEM cell test, a 50 Ω Symmetric Square TEM cell 102CC with a cutoff frequency of 200 MHz was utilized to illuminate the 90 cm TWP harness. The 90 cm TWP was placed inside the TEM cell along the length of the cell supported on a 5cm high Styrofoam. An isotropic field probe was placed at the center of the cell to monitor the amplitude of the RF field at each frequency. According to the indications provided for radiated immunity tests by various automotive standards, the amplitude of the TEM field in the cell was set to 200 V/m in the frequency range 1 MHz – 200 MHz.

Fig. 3(a) and Fig. 3(b) illustrate the CM and DM noise currents induced in the bus load and measured via the RF detector. In particular, the curves referring to BCI were obtained by scaling the experimental data according to the frequency dependent injection profile foreseen for the BCI test by the Standard DC-11224 [7]. The BCI test results to be more severe than the TEM cell test, especially for frequencies up to 100 MHz. The large levels of CM currents due to injection is explained by recalling that BCI is inherently based on the injection of CM currents. On the other side, the DM noise current is largely influenced by the EMC behavior of the termination network, that is by the ability of the terminal network to prevent conversion of noise from CM to DM.

Alternatively, Fig. 4(a) and Fig. 4(b) were obtained by scaling the outcomes of the BCI test according to the frequency dependent profile foreseen for the BCI test by the Standard ES-XW7T-1A278-AC [8]. On the whole, also in this case the test based on injection appears to stress more severely the CAN bus load than the test based on radiation does. Nevertheless, the different initial value (and slope) of the frequency profile foreseen for injection by [8] allows to obtain DM noise currents with frequency shape and levels closer to those obtained via the TEM cell, excited with a 200 V/m electric field.

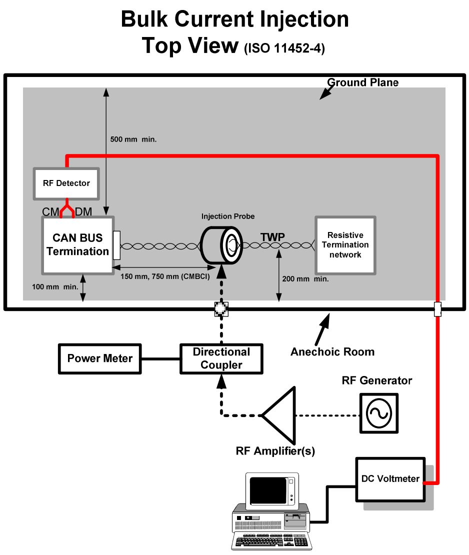

Figure 2(a). BCI setup.

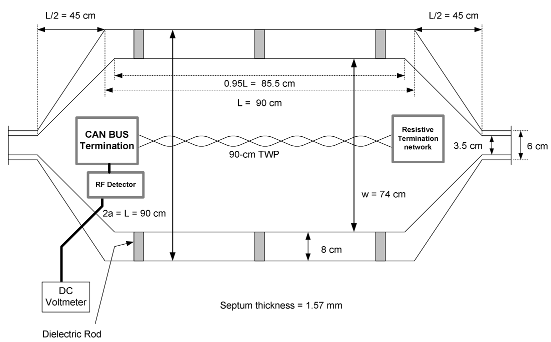

Figure 2(b). TEM cell setup.

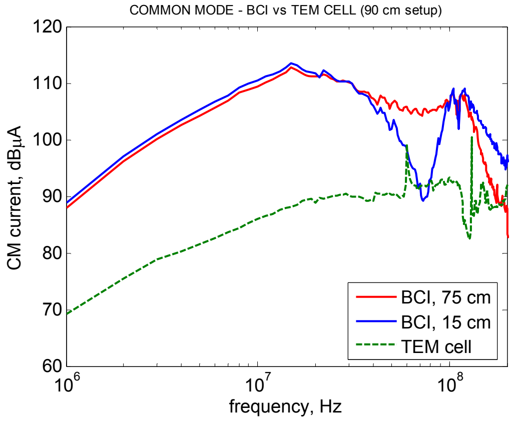

Figure 3(a). Magnitude of the CM noise current induced in the CAN bus load (BCI data scaled according to Standard DC-11224).

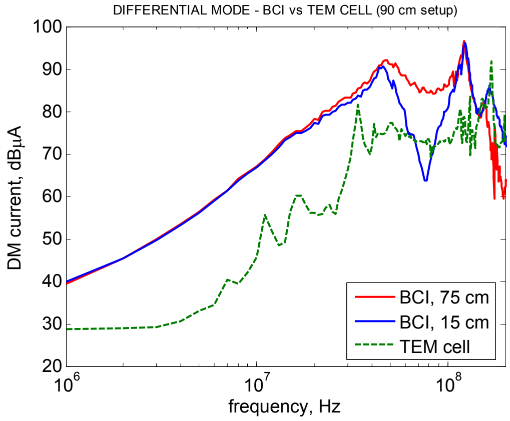

Figure 3(b). Magnitude of the DM noise current induced in the CAN bus load. (BCI data scaled according to Standard DC-11224).

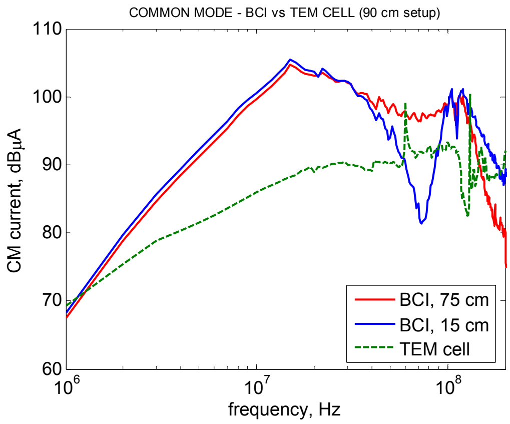

Figure 4(a). Magnitude of the CM noise current induced in the CAN bus load (BCI data scaled according to Standard ES-XW7T-1A278-AC).

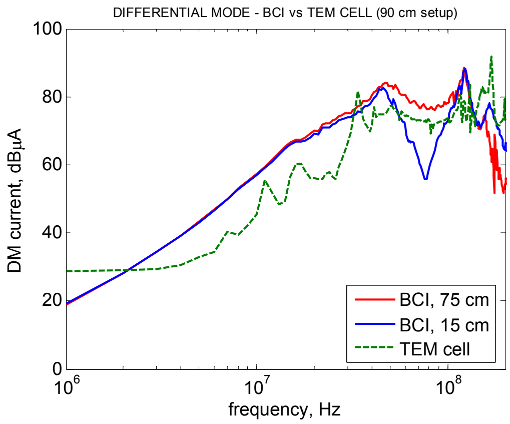

Figure 4(b). Magnitude of the DM noise current induced in the CAN bus load. (BCI data scaled according to Standard ES-XW7T-1A278-AC).

4. References

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