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Fleet Management Module Electromagnetic Interference Investigation

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***Abstract*—Experimental investigation of electromagnetic interference created by transport fleet management module is presented. Novel conducted interference evaluation technique has been rectified from CISPR 25 standard which was adapted to limited abilities for electromagnetic compatibility pre-compliance estimation. Several input filter topologies have been investigated aiming to evaluate the best performer. Common mode current measurement transformer has been designed and calibrated. Ferrite bead impedances have been measured in order to evaluate the suitability for DC input filtering. Common mode and differential mode conducted interference measurement results are given. Optimal filter selected.**

***Index Terms*—Electromagnetic compatibility, power supply filter, precompliance testing.**

I. INTRODUCTION

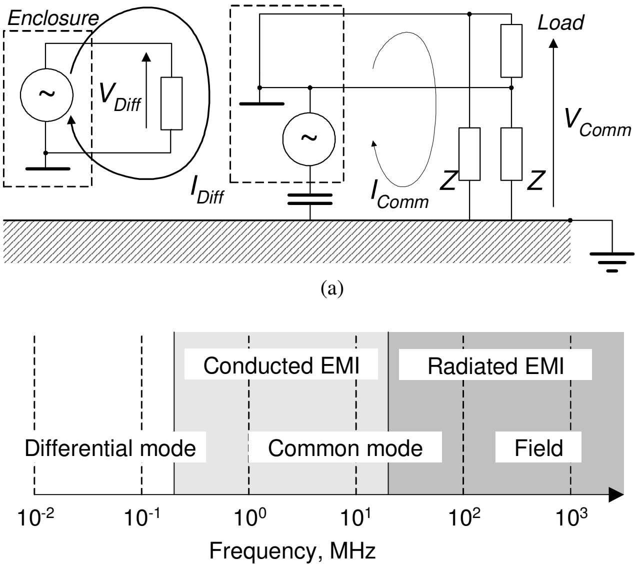
Electronics is widely used in telecommunication, medicine, consumer goods, transport and almost any field where smart functions are demanded. Such equipment operated in close neighbourhood is influencing each other's operation. In race for power consumption reduction and speed the electronics supply voltage is decreasing and this causes the decline of the equipment's noise margin. In case of uncontrolled energy emissions the operation of the last may be jeopardized. Release of the electronic equipment into market demands to adhere to specific norms of the electromagnetic compatibility (EMC). Exploitation of majority electronic equipment in EU is allowed when it carries CE mark [1]. Actually, this mark [1], [2] has much broader meaning, in essence it is manufacturer's declaration that the product complies with the essential requirements of the relevant European health, safety and environmental protection requirements, Product Directives. In order to ease the product certification, several standards are drawn which are covered by corresponding directive. For the scope of this paper we are interested in directive 2004/108/ EC [3], the Electromagnetic compatibility.

New generation of the fleet management module was developed by UAB Simbiotecha. Module included novel solution of the power supply, composed by several DC/DC converters for incoming powertrain efficient management. Due to pulsed nature of DC/DC converters evaluation of module's EMC compliance is needed. Equipment suppose to be used as the on-board component for the vehicle, the requirements of the CISPR25 standard are applicable [4].

The aim of the analysis presented was the worst case scenario investigation of the module electromagnetic interference (EMI) emissions on the fleet management module's power supply lines in differential and common mode for 150 kHz to 30 MHz frequency range.

II. DIFFERENTIAL AND COMMON MODE EMI

Interference can be divided into two main types by current return reference: common-mode and differential-mode. Differential mode interference is a symmetrical type. It occurs between two lines and in our case signals are referenced to internal ground (reference node of the power supply) of the device (Fig. 1).



(a)

(b)

Fig. 1. Differential and common mode signals.

Propagation [5] of this type of interference is high at low frequencies (up to several hundred kilohertz, Fig. 1).

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Common-mode interference is of asymmetrical type. It occurs between the line leaving the device (Fig. 1) and the reference potential (field ground). It occurs mainly at frequencies above 1 MHz. By propagation type EMI interference can be further classified into conducted and radiated [5] (Fig. 1). At low frequencies it mainly propagates along conductive structures, while at high frequencies electromagnetic radiation prevail.

III. TEST PROCEDURE DERIVATION FROM CISPR 25

Though CISPR 25 defines frequency range up to 108 MHz, our aim was to investigate the lower part of the range, covered by CISPR 22B since majority of EMI generated by DC/DC converters will be concentrated here. Therefore our range if investigation spans from 150 kHz to 30 MHz and 150 kHz to 5 MHz. Two types of tests were carried out. One was aimed at differential mode EMI and partially was derived from voltage method defined in section 6.2 of CISPR 25. Equipment under test (EUT) was connected to artificial network (AN) with EUT's power return line locally grounded. Typical loads were attached to simulate installation and operation in the vehicle (Fig. 2). Such setup corresponds to the case when negative power supply lead is connecter to car chassis in close proximity of the device.

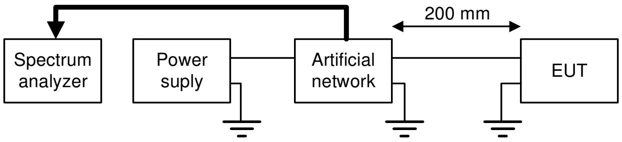

Fig. 2. Differential mode test configuration.

The essential EMI sources expected from the internal digital circuitry switching noise and power supply step-down converter pulses. In CISPR 25 [4] these sources are regarded as narrowband disturbance sources. Sources as ignition system, wiper, blower motor, which exhibit short wideband spikes are regarded as broadband in [4]. In our case these EMI sources were absent, so 9 kHz bandwidth of the measuring instrument was used. Sensitivity and bandwidth were adjusted to ensure that spectrum analyser noise floor is at least 6 dB lower than the lowest limit curve defined in [4]. Though CISPR requires the video bandwidth to be at least three times the resolution bandwidth we used same 10 kHz video bandwidth (VBW).

Agilent N9320B spectrum analyser was used for the EMI investigation. Instead of 9 kHz, as advised in [4] 10 kHz RBW was used with VBW the same. Positive Peak Detector was used. Artificial network (Fig. 3) was designed close to CISPR 25 requirements, with exception that inductance was formed by special low frequency ferrite bead LFB095051 from Laird, mounted on incoming wires.

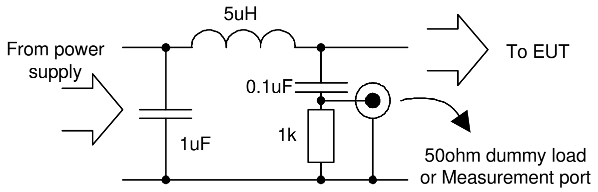

Fig. 3. Artificial network arrangement.

The levels registered by spectrum analyser were compared against CISPR 25 defined spectral masks. There are 5 limiting masks which depend on device placement. The defined levels in dBμV and the conducted emissions levels obtained with no input filter are presented in Fig. 4. It can be seen, that such device arrangement does not satisfy even the class 1 requirements. These measurements were used as the reference point for input filter optimization. Differential test mode configuration was used until the final goal was reached.

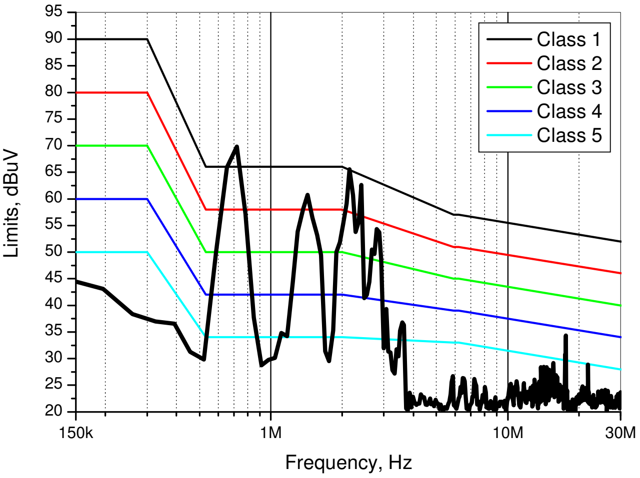

Fig. 4. Initial conducted emission levels obtained in differential mode test configuration.

Final experiment was dedicated for common mode currents investigation and was derived from part 6.3 of [4]. The modification included the reduction of test bench, absence of the shielding room and same modified artificial network as in Fig. 3. Test setup for common mode current measurement is presented in Fig. 5.

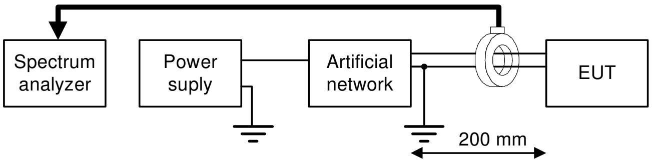

Fig. 5. Common mode test configuration.

EUT was placed 200 mm away from artificial network and EUT antenna ground was connected with artificial network ground. Such setup simulates the worst case scenario, when device antenna outer sheath is touching the vehicle case.

IV. CURRENT TRANSFORMER

Current transformer was designed using 73 material toroidal ferrite with single turn inductance (A_L) equal 5000 μH. Design was chosen to have 0.5 ohm injected impedance, therefore turns ratio was 1:11. Transformer operation was verified using PSPICE simulation and experimentally (Fig. 6).

Transformer calibration setup is presented in Fig. 7.

Universal acquisition system was used [6] for sensitivity estimation. Continuous wave (CW) was injected into current loop. Voltage on injection and secondary winding voltage were registered using deep-memory ADC and estimated using sine wave correlation procedure.

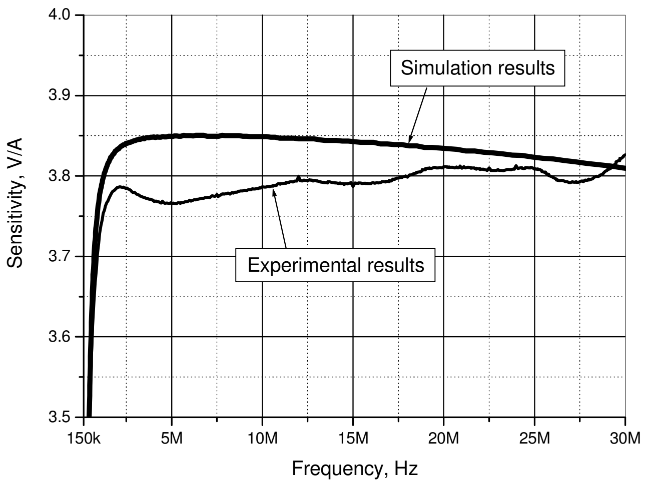

Fig. 6. Current transformer AC transfer PSPICE simulation and experimentally obtained calibration curve.

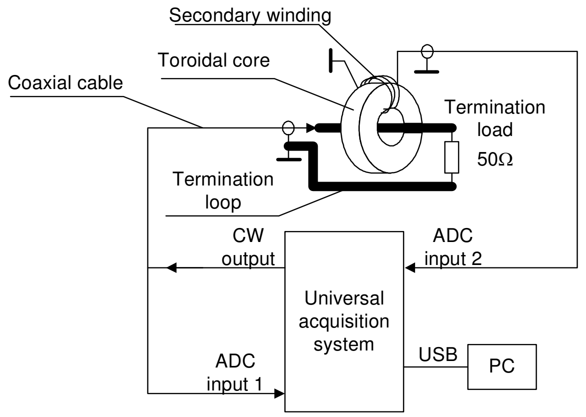

Fig. 7. Current transformer calibration setup.

V. EXPERIMENTAL RESULTS

Several filter configurations were investigated: integrated DC filter BNX022-01, offered by Murata. It is a small size (12 mmx9 mm) filter offering 20 dB insertion loss for common mode EMI at 100 kHz and 58 dB at 10 MHz. Another filter used was a 4.8 mm x 4.8 mm LPD5010-103ME coupled inductor, used as a common mode choke. The rest of filtering topologies investigated was Pi configuration filter, comprised of 10 μF capacitors and a special low frequency ferrite bead (refer Table 1 for ferrite bead details).

TABLE 1. EMI BLOCKING FILTERS USED IN INVESTIGATION.

Label	Size	|Z|,Ω*	I_{max}, A
MUR	Filter, Murata BNX022-01L	-	10
LC	Filter, Coilcraft LPD5010	-	0.7
FB0	Ferrite bead 11x5mm	580	5
FB1	Ferrite bead, 3.2 × 2.5 mm	600	3
FB2	Ferrite bead, 2.0 × 1.25 mm	220	2
FB3	Ferrite bead, 2.0 × 1.25 mm	1800	1
FB4	Ferrite bead, 3.2 × 1.6 mm	50	3

*Note: */Z/ is measured at 100MHz frequency*

Initial experiments were carried out to compare the performance of the three different filter topologies. Performance was evaluated using open field inductor in DC/DC step-down converter. Results for 150 kHz to 3 MHz frequency range are presented in Fig. 8 and for 3 MHz to 30 MHz frequency range are presented in Fig. 9.

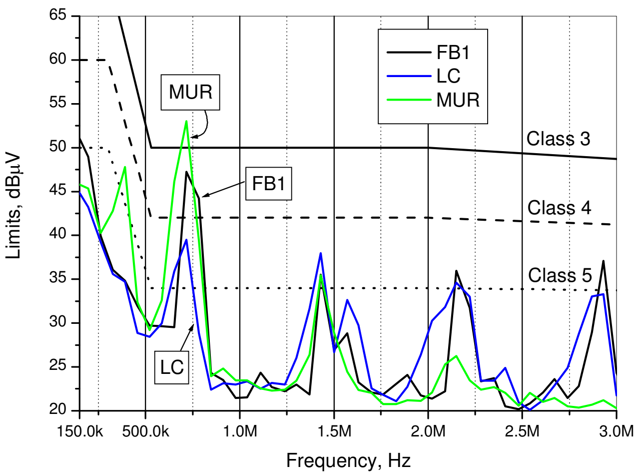

Fig. 8. Performance comparison between filter topologies for 150 kHz … 3 MHz frequency range.

Though Murata filter performance at frequencies 1 MHz to 5 MHz was better, common mode (LC) filter was able to satisfy Class 4 requirements at low frequencies. Both common mode and ferrite bead filters had better performance in attenuating on-board microcontroller frequencies in 15 MHz proximity.

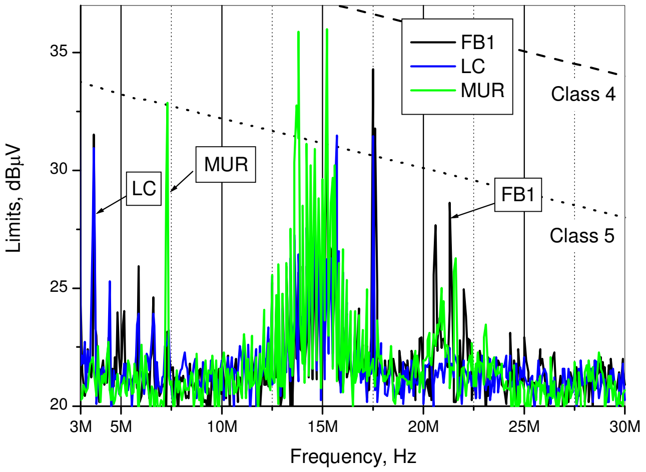

Fig. 9. Performance comparison between filter topologies for 3 MHz … 30 MHz frequency range.

Ferrite bead filters investigation started by ferrite bead impedance evaluation by acquisition system [6]. Impedance magnitude and constituting real part of the impedance are presented in Fig. 10.

Results for EMI levels are presented in Fig. 11. It can be seen that ferrite bead number 3 gives best EMI attenuation and satisfies Class 4 requirements. Common mode conducted emissions measurement results are presented in Fig. 12.

Both differential and common mode conducted EMI measurements indicate that careful selection of ferrite bead impedance greatly simplifies the input filter topology. Such filter topology has the lowest price, lowest weight and size. It can be concluded that filter impedance 600 Ω and above at 100 MHz can be an indication of suitability for low frequency EMI removal, but impedance measurements or manufacturer impedance data are needed for particular component estimation.

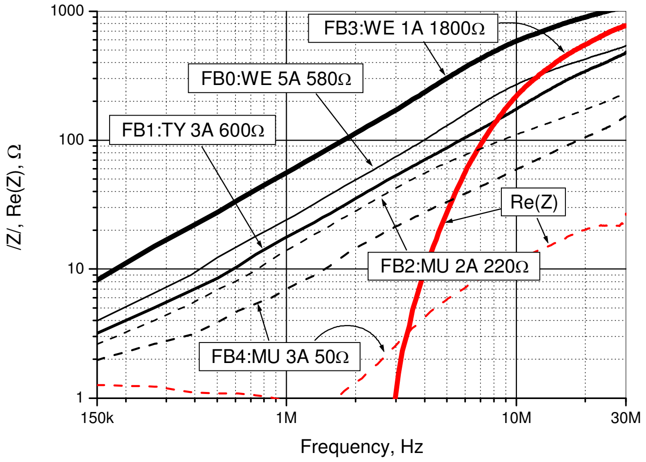

Fig. 10. Ferrite bead impedance evaluation results

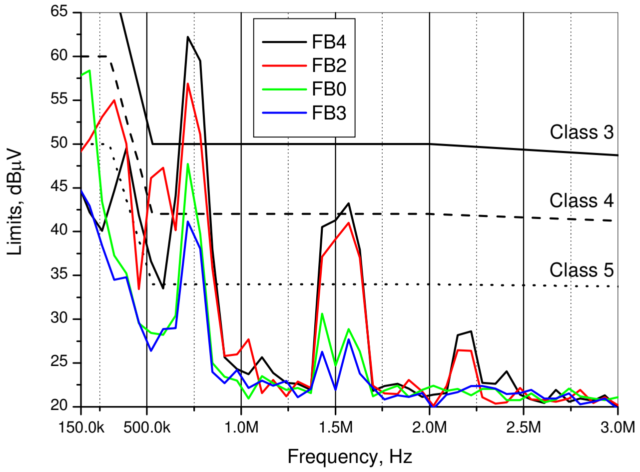

Fig. 11. Differential mode EMI for ferrite bead topologies.

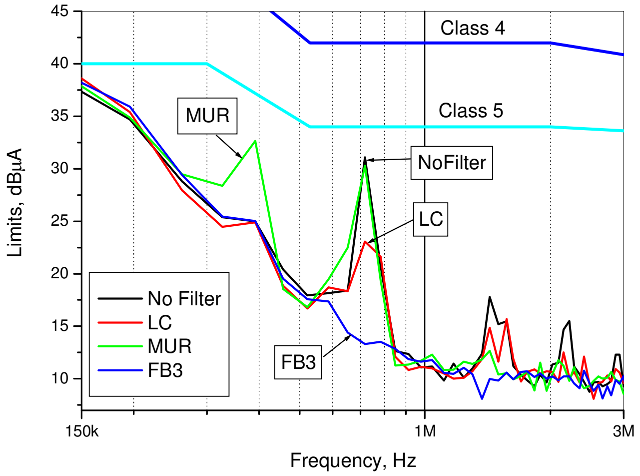

Fig. 12. Common mode EMI for all filter topologies.

Influence of succeeding DC/DC converter power inductor construction was investigated, by using open field and closed field inductor. The inductance was the same, 15 μH, the only difference was the construction. Open field inductor should exhibit better saturation performance, but closed field should allow maintaining the magnetic field in constrained geometry. Though no significant difference was obtained, it was decided to use closed field inductor since performance at some frequencies was better.

VI. CONCLUSIONS

Differential mode EMI measurement topology allows for quick and simple conducted emissions evaluation in 0.15-30 MHz frequencies range. Since this range is most vulnerable for DC/DC converters noise, such measurement fully satisfies the EMC pre-compliance evaluation and can be used for input filters topology selection. Ferrite bead topology investigation indicates that impedance at 100 MHz can be used as a simple guide: 600 W and above can be an indication of suitability for low frequency EMI removal, but impedance measurements or manufacturer impedance data are needed for particular component estimation.

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