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CHARACTERIZATION AND SUPPRESSION OF COMMON-MODE AND DIFFERENTIAL-MODE CONDUCTED EMI

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Abstract: *Conducted electromagnetic interference (EMI) is an important aspect of electromagnetic compatibility (EMC), especially in electronics system where noise can propagate through power and signal lines, and affect of operation of other circuits. Proper identification of the dominant type of noise is therefore essential for the of effective EMI suppression. This paper presents measurement based methodology for the analysis and characterization of conducted EMI, with particular emphasis on the separation of differential mode (DM) and common mode (CM)components. The proposed approach includes the configuration of measurement equipment, acquisition and analysis of measured data, and identification of dominant frequency dependent noise component. Based on measurement results, total conducted interference is decomposed into its DM and CM component. The obtained results are used to select appropriate suppression for each noise mode. The presented methodology provides a systematic approach for distinguishing EMI mode for identification of suppression, thereby improving the effectiveness of EMC filtering.*

Keywords: *Electromagnetic compatibility, Conducted EMI, common-mode noise, differential-mode noise, characterization, EMI suppression.*

1. INTRODUCTION

The rapid development of modern electronics has led to a significant increase in the use of power electronic convertors, switching power supply, high speed digital circuits, and digitally controlled subsystem. DC/DC convertors, AC/DC power supply, motor drives, etc., have become integral parts of a wide range of electronic and electrical equipment. Although these technologies provide high efficiency, compact dimension, and improved functionality and working stability, their switching operation represents a significant source of EMI.

The EMC performance of a modern electronic devices is determined not only by its intended electrical functionality, but also by its ability to limit the generation and propagation of unwanted electromagnetic energy. EMC requirements have become an essential part of the design, and verification process of electronic equipment. A device intended for commercial, industrial, automotive, aerospace, military, or other specialized applications must satisfy the applicable EMC requirements before it can be placed on the market or introduced into service.

Practically all country, around the world, require that electrical and electronic devices must meet strict requirements regarding EMC. [1]

Various international and industry specific standard define limits and measurement procedures for electromagnetic emissions and immunity. Examples include the CISPR series of standards, IEC 61000-4series, and military standard MIL-STD-461. The specific requirements depend on intended application and environment of the equipment. In particular, conducted emission measurements are used to determine the level of unwanted RF energy present on the power inputs and output interfaces of equipment under test (EUT). In the presented paper, conducted emission measurements are performed in accordance with the requirements of the MIL-STD-461 CE102 test method, which specifies limits and measurements procedures for conducted emissions on power input leads of equipment and subsystems. [2]

A limitation of conventional conducted emission measurement is that the measured spectrum represents the combined effect of different noise type. The measured interface may contain both DM and CM components. Although these two modes may appear as a single conducted emission spectrum at the measurement port, they are completely different in term of appearance and propagation (it will be clarified in next chapter) and

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require different suppression technique.

In this paper will be presented expansion of the MIL-STD-461 CE102 method in order to obtain more precise data on the type and level of interference in order to more precisely determine the parameter of filter for suppression, and way haw to choose right filter.

2. TEORETICAL BACKGROUND

Conventional conducted measurement represents both DM and CM noise Figure 1. The yellow line represents path of the sum of the CM and DM components, while the green line represents path of difference of CM and DM component, depending which port is used for measuring from line impedance network stabilizer (LISN), URF1 or URF2.

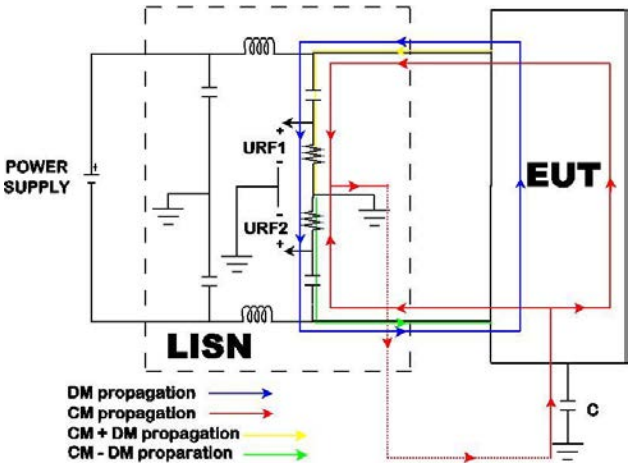


Figure 1. Conventional measurement

Identification and separation of DM and CM component represent an important step in the conducted EMI troubleshooting and process of choosing adequate filter. DM noise are associated with current flowing between power lines in opposite direction Figure 2, whereas CM noise are generally associated with currents flowing in same direction on power lines with respect to a chassis Figure 3.

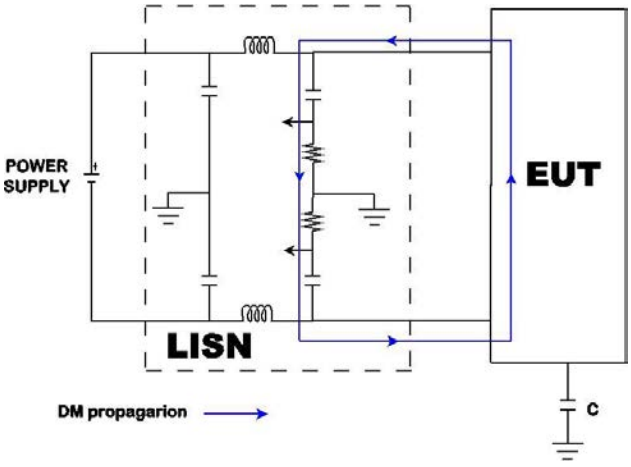


Figure 2. DM noise propagation

Mathematically speaking it is possible to distinguish U_{CM} and U_{DM} from URF1 and URF2 in following way:

$$U_{CM} = \frac{UREF1 + UREF2}{2} \quad (1)$$

$$U_{DM} = \frac{UREF1 - UREF2}{2} \quad (2)$$

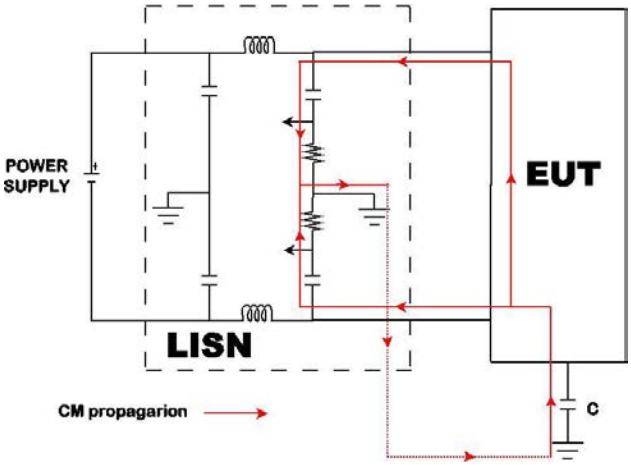


Figure 3. CM noise propagation

3. MEASUREMENT MODEL

The measurements were performed in EMC test chamber. General test setup was as proposed by MIL-STD-461 standard [2]. General test setup is shown on Figure 4. Same figure represents position of equipment distances of cable, size of ground plane, dimension of non-conductive standoff, separation of element relatively to the ground plane on the table and also to the ground of the EMC test chamber etc.

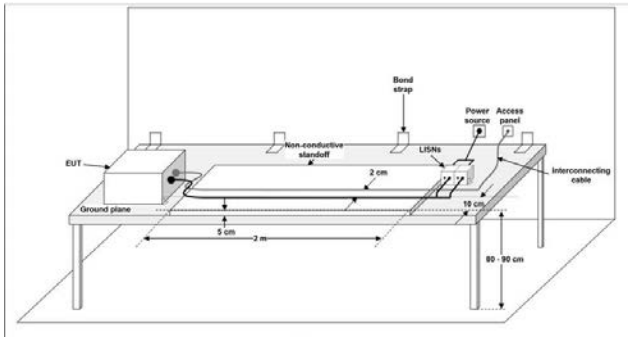


Figure 4. General test setup [2]

For MIL-STD-461, CE102 conducted emission measurement is used equipment setup as shown on Figure 5. The equipment are consists of 2 LISN unit, termination of 50ohm, which is used to terminate unused RF port from LISN unit, attenuation from 20dB, which is used to protect measuring equipment in case of appearance of very high level of conductive interference, EUT, measurement devices and data recording device. Lately last two devices are integrated in same unit. Also power supply should be galvanically isolated.

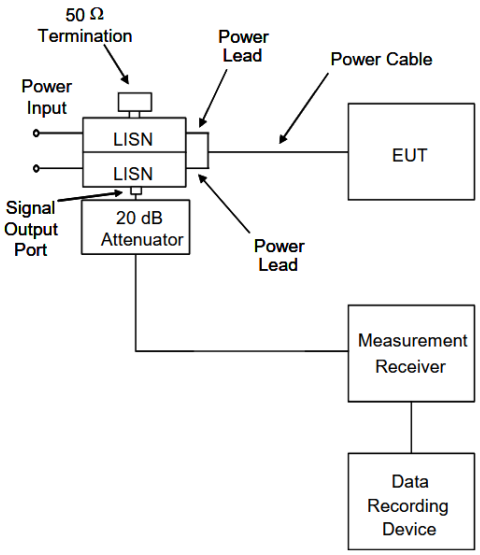


Figure 5. Measurement equipment setup [2]

Modification of measurement setup as proposed MIL-STD-461, CE102, consists of using MISN-MATE unit. This unit is feed from booth RF outputs, from each LISN unit, RF signal from LISN on positive power line is connected to the RF1 port of the LISN-MATE, and RF signal from LISN on negative power line is connected to the RF2 port of LISN-MATE unit.

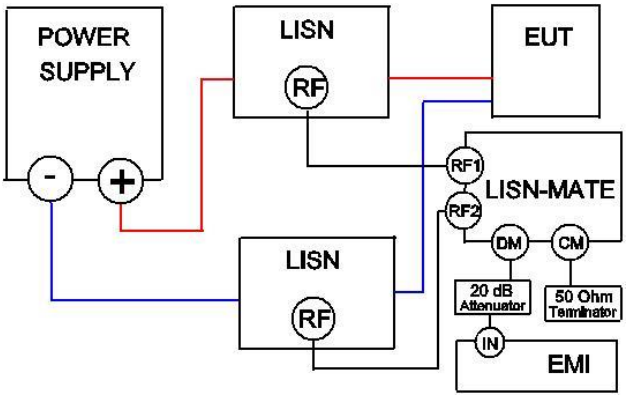


Figure 6. Expanded measurement equipment setup for DM component

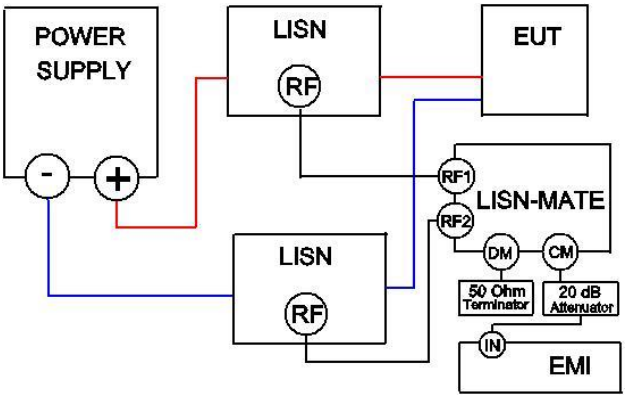


Figure 7. Expanded measurement equipment setup for CM component

LISN-MATE at its output provides DM signal output, which is calculated according to quotation (3), and CM signal output which is calculated according to quotation (4).

$$U_{CM} = URF1 + URF2 \quad (3)$$

$$U_{CM} = URF1 - URF2 \quad (4)$$

Comparing quotation (3) and (4) to quotation (1) and (2) respectively, is obvious that LISN-MATE provide twice the level on both outputs, so it is necessity to set attenuation of 3dB in measuring equipment, for compensation.

Proposed expanded measurement equipment setup is shown on Figure 6. and Figure 7., respectively.

Data presentation shall be as follows:

a. Continuously and automatically plot amplitude versus frequency profiles on X-Y axis outputs. Manually gathered data is not acceptable except for plot verification.
b. Display the applicable limit on each plot.
c. Provide a minimum frequency resolution of 1% or twice the measurement receiver bandwidth, whichever is less stringent, and a minimum amplitude resolution of 1 dB for each plot.
d. Provide plots for both the measurement system check and measurement portions of the procedure. [2]

The measurement system check is performed using the measurement system check chart for CE102, shown on Figure 8.

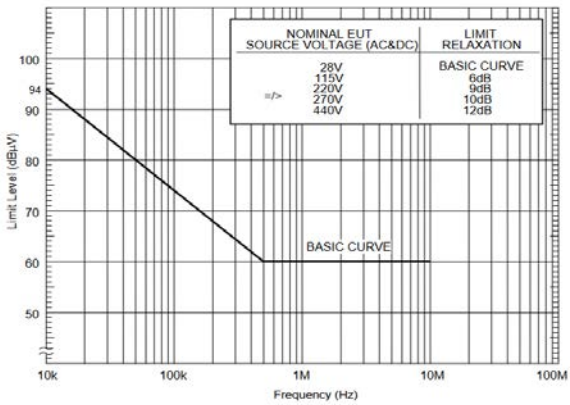


Figure 8. CE102 limit (EUT power leads, AC&DC) [2]

4. RESULTS

In this chapter, concrete measuring equipment, measurement results, a proposal for selecting a filter, and a verification measurement for confirmation will be presented.

4.1 Equipment

In conducted tests are used next equipment.

LISN is LI-3100 from COM-POWER, very powerful, up to 100Amps, can be used and for DC and for AC, and also very good quality, more detail is given at the reference [3]

LISN-MATE is TBLM2 from TEKBOX, with adequate parameters, and also very good quality, more details at the reference [4]

EMI from Agilent Technologies N9038A, nowadays is Keysight Technologies N9038A, it's a standards compliant EMI receiver and diagnostic signal analyzer built on an upgradeable platform. In the lab and on the bench, it provides the accuracy, repeatability, and reliability you need to test with confidence. [5]

Terminator 50 Ohm from HP, nowadays Keysight 909A coaxial terminator. Terminate a 50 Ω coaxial system in its characteristic impedance with this precision, low-reflection load. [6]

Attenuator 20dB from HP 8491B, nowadays Keysight Technologies, provides precision attenuation, flat frequency response, and low SWR over a broad frequency range. [7]

RF cables from HP very good quality, is good to mention, that cable for connection between LISNs and LISM-MATE unit should be from same manufacturer and same length, because difference in attenuation in this cable can affect this measurement and provides inaccurate data in difference in levels between CM and DM interference.

Power cables should be calculated according to maximum load of the EUT, and also cables length, between LISN and EUT must be 2 m long, as shown on Figure 4.

Power supply in our case was DC, and galvanically isolated.

EUT is multi rail switching power supply.

4.2 Equipment setup

For measurement is used setup as shown on Figure 6, for measurement of DM interference, and as shown on Figure 7, for CM interference.

EUT is set to 100% of load. Reason is that the switching power supply, what is EUT in this case, would generate the most interference at maximum load.

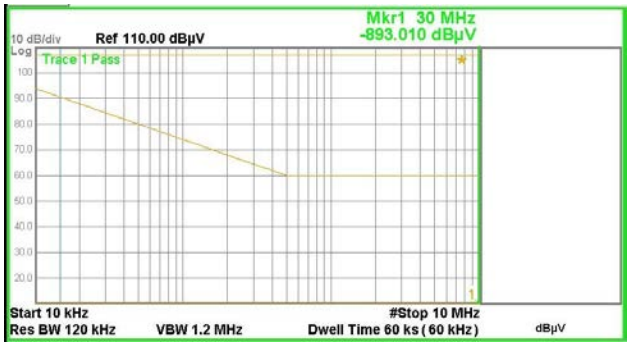


Figure 9. EMI state for CE102

Since we use EMI to collect and record data, the possibilities it offers are used, a state is created, (called state CE102) according to the requirements of data presentation and configuration of the equipment (Figure 6 and Figure 7). For the threshold curve according to the CE102 standard, Figure 8, basic curve is used, because power supply voltage was 24Vdc. Also, the attenuation of the attenuator from 20dB was entered, and an attenuation of 3dB was added due to LISN-MATE unit multiplication of output signal. This state is shown on Figure 9, before measurement.

4.3 Measurement

After calibration of equipment, all equipment were connected, as shown on figure 6, power supply is off, state CE102 is called and ambient noise is measured Figure 10.

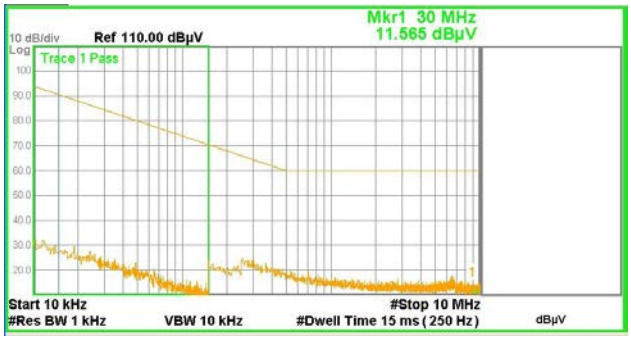


Figure 10. Ambient interference

4.3.1 DM component measurement

Difference to previous setup is that power supply was turn on, load is set to maximum load, everything else was the same, state CE102 was recalled and DM interference level was measured Figure 11.

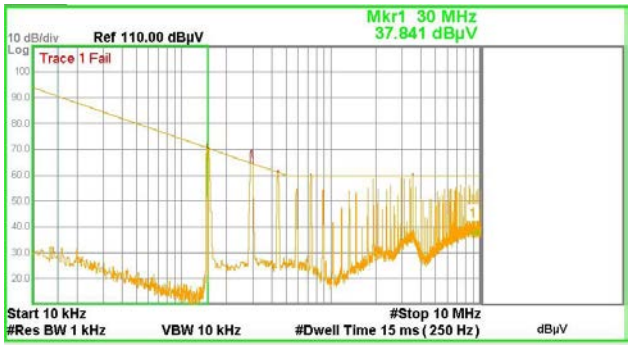


Figure 11. DM interference

4.3.2 CM component measurement

Equipment setup was changed according to Figure 7, power supply was on, load on EUT was om maximum, state CE102 was recalled and CM interference level was measured Figure 12.

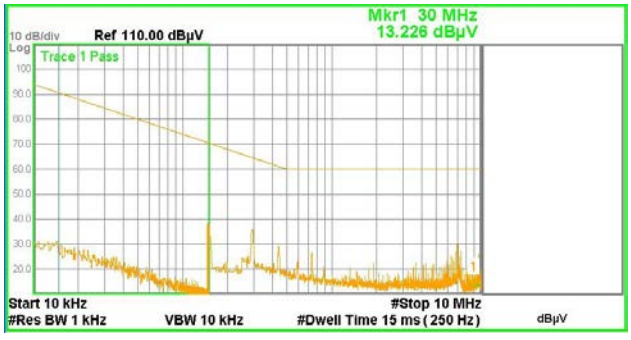


Figure 12. CM interference

4.3.3 Measurement data analysis and filter proposal

According to measurement results, on Figure 10, is shown that ambient interference is far below threshold curve for CE102 standard, so obtained measurement results are valid.

From Figure 11, is concluded that dominant interference, that EUT generate is DM, and EUT didn't passed test, its obvious that threshold curve for CE102 standard is exceeded, and in upper left corner of measurement data, Figure 11, is shown "Trace 1 Fail", so filter is needed to correct this type of interference.
On Figure 12, is shown that CM interference is significantly lower, for above 30 dB compared to DM interference, and this type is significantly below threshold curve for CE102, so this component type passed test, and for this component type, filter is not needed.

4.4 Filter proposal

For suppression of DM type of interference EMI filter is used, while for suppression of CM type of interference Choke filter is used.

As explained in privies chapter, for DM type of interference filter is needed.

The idea is to find EMI filter, with attenuation of DM type of interference, at least of 25dB or greater, according to Figure 11, and Figure 12. Also chosen EMI filter should be capable sustain maximum current capacity of EUT.

For purpose of explanation, filter FN409-6.5-02 is chosen. According to datasheet of this filter, filter have satisfying current capacity. Next, from datasheet, is analyzed attenuation chart Figure 13.

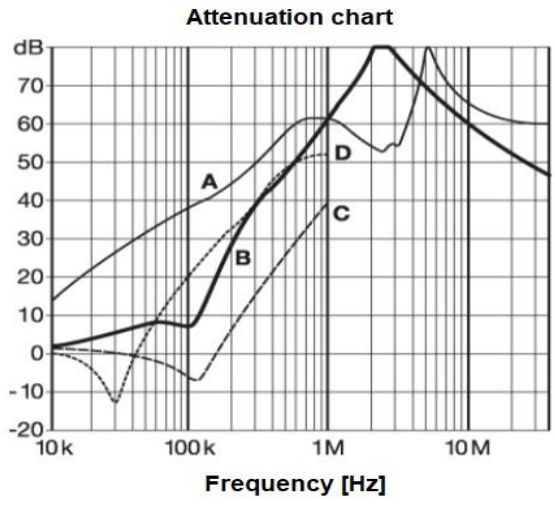


Figure 13. Typical Filter Attenuation [8]

Per CISPR 17 standard [9], each curve represents:
A = 50 Ω/50 Ω sym,
B = 50 Ω/50 Ω asym,
C = 0.1 Ω/100 Ω sym,
D = 100 Ω/0.1 Ω sym.
For calculating attenuation of DM type of interference, curve B is used.
and for calculating of CM type of interference, curve D is used. According to attenuation chart, Figure 13, measured value of DM and CM, Figure 11 and Figure 12, respectively, level of DM noise should be below 50dBµV, and level of CM noise should be at background noise level, after implementation of selected filter. Selected filter is installed on power line, between power supply and EUT, on the side of EUT. If the filter has ground connection, it connects to the chassis.

4.5 Verification

After filter implementation, as described in previous chapter, the tests, as shown on Figure 6 and Figure 7 were performed. Measurement results are showed on Figure 15 and Figure 16, respectively.

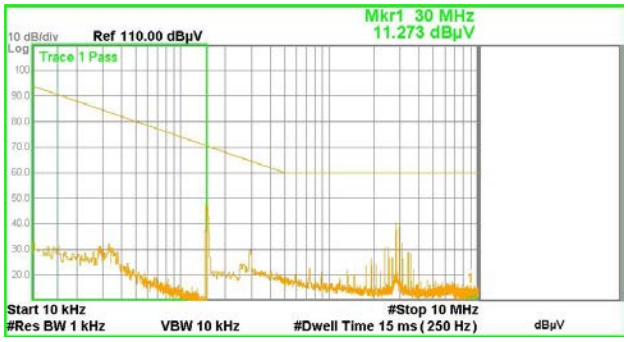


Figure 14. DM interference after filter implementation

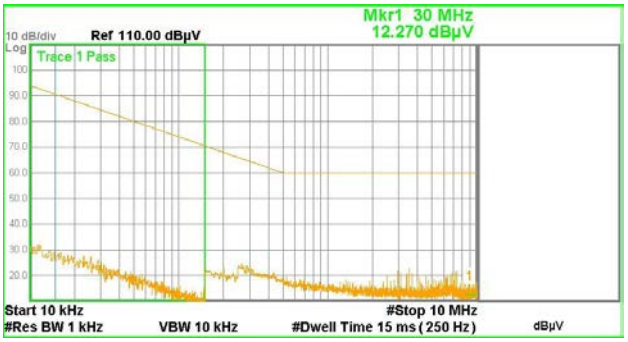


Figure 15. CM interference after filter implementation

Figure 14 and Figure 15, shows that analysis and calculation from previous chapter was correct.

Last test, that was carried out, for demonstration, that this methodology was correct, was test as shown on Figure 5, after a filter.

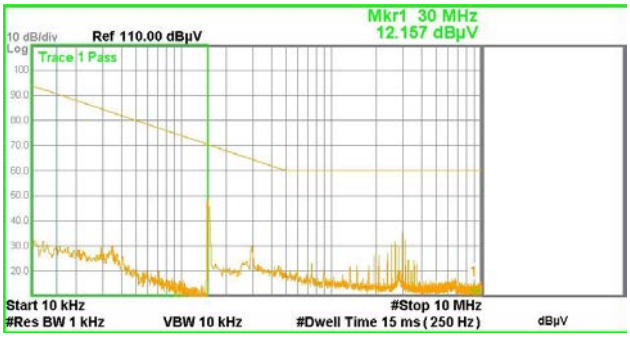


Figure 16. Conducted interference after filter implementation

On Figure 16, was shown that, also methodology proposed by MIL-STD-461, Figure 5, verified results. Only with expanded methodology, as proposed in this paper, and as showed on Figure 6 and Figure 7, is possible to manage each type of conducted interference separately.

5. CONCLUSION

This paper presents a measurement based methodology for the analysis of conducted electromagnetic interference, starting from the appropriate configuration of measurement equipment acquisition of conducted emission data, followed by spectral analysis and separation of the measured interference into DM and CM components. The obtained results are used to identify the dominant noise mode over investigated frequency range to determine required level of suppression. Further, based on required level of suppression and the dominant type interference, appropriate filter for implementation was selected. Finally, after the implementation of the filter, a final verification was performed to confirm that that the interference is within the limits defined by standard.

The future extension of this paper would include the design of filter, according to the data obtained by the methodology and measurement in order to optimize the filter for a specific device. Generic filters are usually not optimal, they cover wider frequency ranges, with certain suppression that could be much greater then is needed and because of that are certainly larger in size, heavier in mass and in higher price range. The designed filter would represent an optimal solution, would have required suppression, would be smaller in size, lighter and in lower price range.

Acknowledgement

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References

[1] ANTONIJE R. ĐORĐEVIĆ, DRAGAN I. OLĆAN: *Ispitivanje Elektromagnetske Kompatobilnosti*, Univerzitet u Beogradu Elektrotehnički fakultet, Beograd, 2012.

[2] MIL-STD-461: https://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=35789, last accessed 2026/08/09

[3] https://www.com-power.com/products/single-phase-lisns/li-3100, last accessed 2026/08/09

[4] https://www.tekbox.com/product/tblm2-lisn-mate/, last accessed 2026/08/09

[5] https://www.unitest.com/pdf/5990-7421EN.pdf, last accessed 2026/08/09

[6] https://www.keysight.com/us/en/product/909A/coaxial-termination-dc-18-ghz.html, last accessed 2026/08/09

[7] https://www.keysight.com/us/en/assets/7018-02033/data-sheets/5990-3453.pdf, last accessed 2026/08/09

[8] https://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=FN409&DocType=Data%20Sheet&DocLang=English&DocFormat=pdf&PartCntxt=819398-SF, last accessed 2026/08/09

[9] https://www.normservis.cz/download/view/iec/info_cispr17{ed2.0}b.pdf, last accessed 2026/08/09