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Suppression of Common Mode Noise Caused by Unbalanced Return Currents of Redundant Power Lines

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ABSTRACT

Reliable and uninterrupted operation of military avionic systems is vital for ensuring flight safety and especially for mission critical situations. For this reason, redundant structures are established in almost all units used in avionic systems. Redundant power system architectures are widely used to provide redundancy and reliability against possible failures. In avionics systems, unbalanced return currents may occur due to factors such as unbalanced load distributions and different line impedances caused by the internal architecture of multiple redundant power systems. This situation may cause common-mode noise on avionics systems. MIL-STD-461 standard is used to determine acceptable noise levels in terms of electromagnetic interference (EMI) in avionics systems. The CE102 test, which is part of this standard, is specifically applied to evaluate the common-mode components of conducted emissions in the frequency range from 10 kHz to 10 MHz. In this paper, the CE102 test is applied to the redundant power system of a military avionic control unit and a multi-input common-mode coil design is used to equalise the total current and noise levels of all redundant power system lines to reduce the common-mode noise to acceptable levels under MIL STD-461 emission limits in the 10 kHz - 10 MHz frequency band. The experimental results of this optimisation study are presented.

1. Introduction

Electromagnetic Interference is defined as the effect of the noises (in other words, interference signals) emitted by an electronic system while it is operating on other electronic systems or being affected by the noises in the environment, resulting in loss of performance or becoming completely inoperable [1]. The suppression of these radiated noises or the protection of the systems from the noise in the environment is called electromagnetic compatibility [2].

Electromagnetic interference is one of the most important issues to be considered before the design of the electronic circuit, taking into account the location and conditions of the platform where it will be used [3]. With the developing technology, especially in switching power supplies, high level harmonics are generated due to high frequency switching of current and voltage [4, 5, 6]. These high-level harmonics cause an increase in the conducted emission level of the system, causing the system to emit noise both to its own operation and to the surrounding systems [2, 6].

Electromagnetic noise occurs as a result of the electronic equipment used in military avionics systems converting the energy level provided by the aircraft with DC-DC

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converters according to different voltage levels inside the device. With the increase in the quantity and variety of these systems, the electromagnetic compatibility requirements of the systems are increasing [7].

Electromagnetic noise has two different modes. Common-Mode noise, which flows simultaneously and in the same direction in each of the conductors, and Differential-Mode noise, which occurs in one direction in one conductor and in the opposite direction in the other. Common-mode noise is the main reason why conductors and power cables act as monopole antennas, which leads to the formation of Conducted Emission [8, 9, 10, 11, 12].

Redundancy in military avionic systems is vital for ensuring flight safety and especially for mission-critical situations. For this reason, DC-DC converters used in the systems are designed in a redundant structure. Space and size constraints in the aircraft create various difficulties in the design and production of electronic boards. Even if the DC-DC boards produced are equivalent to each other, the distance between their location and the source causes unbalanced load distribution [13, 14, 15].

MIL-STD-461F is a standard that describes how to perform electromagnetic compatibility tests of military electronic systems, including electromagnetic susceptibility and emission tests [2]. The CE102 test is the standardised method of conducted emission testing of avionic systems defined within the scope of these standards [2].

In the literature research, common-mode noise problems in power systems are generally addressed. In a patent registered with the European Patent Office with the number EP0626767B1, it is proved that balanced multi-wired telecommunication lines suppress common-mode noise with multiple windings on a single ferrite core, but this study has not been studied for redundant lines. In another article, the importance of suppressing electromagnetic noise in avionics systems was mentioned, but the redundancy structure was not mentioned. In this paper, the MIL-STD-461F CE102 test results of a military avionics unit with redundant power supply will be analysed and the solution to the problem of unbalanced load will be given.

2. CE102 Test Procedure

CE102 is applied to verify whether the electromagnetic noise generated from an electronic equipment exceeds the threshold value specified in the standard. This test is carried out on the power lines to the positive and negative terminals that supply energy to the sub-units of the equipment.

The equipment to be tested is tested in a semi-anechoic chamber, which largely prevents further electromagnetic interference from the external environment. Set up of the the test environment is as described in [2] (Figure 1). An important part of the test setup is the Line Impedence Stabilisation Network (LISN). Thanks to the LISN, the noises in the power supply feeding the equipment are filtered and only the transmitted emissions from the equipment to be tested are measured.

The CE102 test frequency range is from 10 kHz to 10 MHz (Figure 2). This range is considered to be the most characteristic region for switching frequencies in power supplies used in military systems. Noises at frequencies from 10 kHz to 10MHz are analysed and recorded during the test.

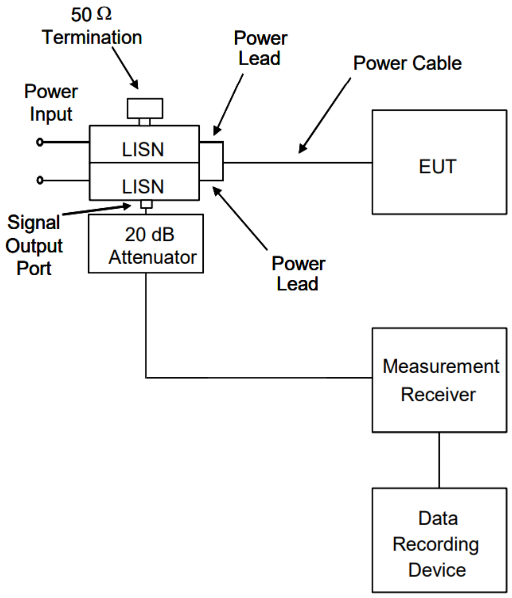

Figure 1. General Test Setup for MIL-STD-461F [2]

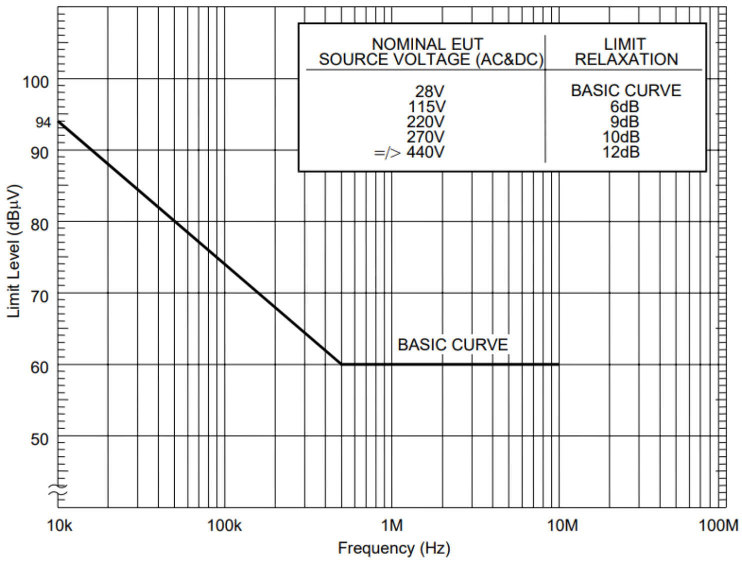

Figure 2. CE102 Testing Area [2]

3. Definition of the Problem

Common-mode noise is a type of electromagnetic noise carried simultaneously and in same phase at the positive and negative ends of a signal line. The noise is detected by measuring the rotation of the positive and negative ends of the line over ground, rather than between the positive and negative ends of the line (Figure 3). Especially DC-DC converters cause this noise due to their switching frequencies [16].

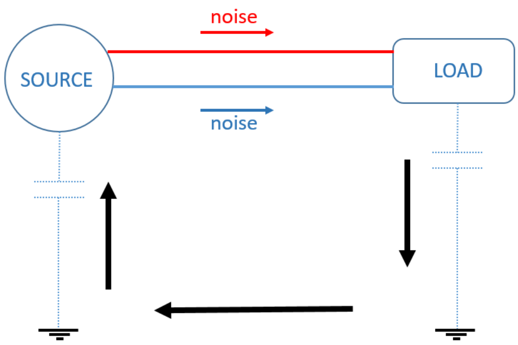

Figure 3. Common-Mode Noise Flow Direction

These noises in electronic boards are usually resolved by common mode chokes [16]. It is based on the principle of magnetic field damping each other that the magnetic field generated by winding positive and negative lines on a ferrite core in opposite directions but with the same number. This principle allows the common mode noise to be eliminated by inductance (Figure 4).

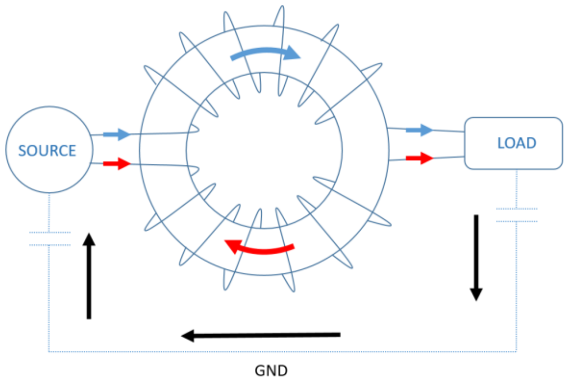

Figure 4. Common-Mode Choke Structure

Using of seperated common-mode chokes for avionics equipment which is using a redundant power supply in design phase is common practice. However, as a result of the fact that connecting of these redundant power supplies to a single backplane in the equipment and their physical placement distances are not the same creates the difference in current values returning from the negative lines. This difference creates a load imbalance. This imbalance causes the individual common-mode chokes to be unable to effectively suppress the common-mode noise.

The ability of a common-mode choke to attenuate the electromagnetic noise level passing through its terminals depends on the balance of the current level passing through its terminals. A single common-mode choke wound on a single ferrite core can not attenuate common-mode noise in lines carrying unbalanced currents at different levels. This causes the electromagnetic compatibility requirements of military avionics systems to be unmet.

4. Experimental Set Up and Proposed Design

4.1 Traditional Seperated Common Mode Coil Design

A military avionic equipment with redundant power supply, manufactured with a common-mode choke design to prevent each seperated common-mode electromagnetic noise generation, was subjected to CE102 testing (Figure 5). The Common-Mode Choke design of the equipment is as shown in Figure 6 and Figure 7.

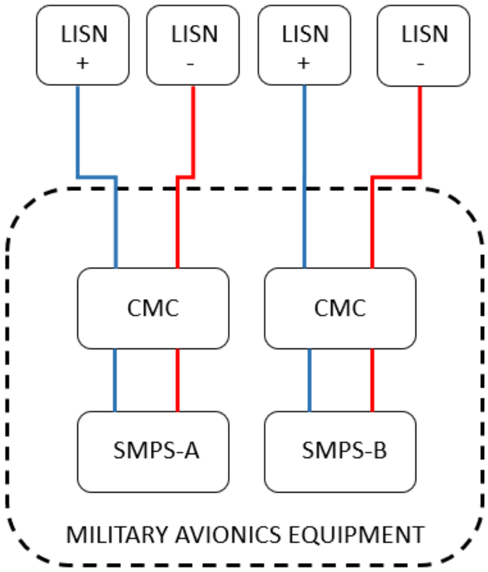

Figure 5. Equipment Seperated Common-Mode Choke Design

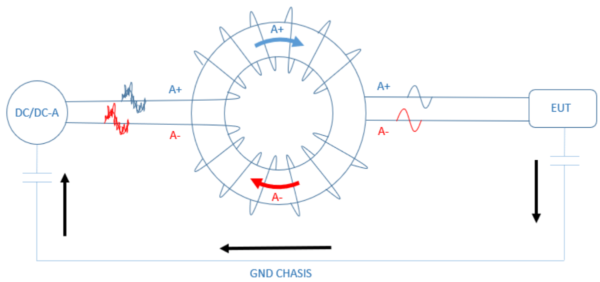

Figure 6. Power Supply –A CMC Filtering Design

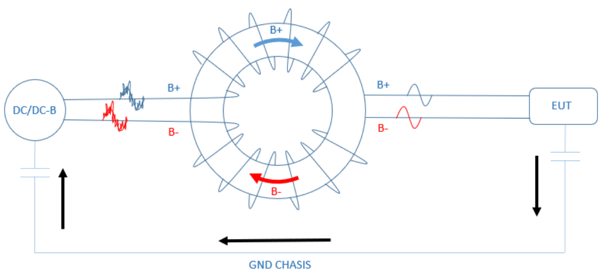

Figure 7. Power Supply –B CMC Filtering Design

For Conducted Emission test, scanning was performed according to MIL-STD-461F Table II [2]. In the test set up prepared according to Figure 1, the devices in Table 1 were used.

Table 1: Test devices which are used

Brand	Model	Explanations
Rohde Schwarz	ESW44	EMI Receiver
SOLAR	8116-50-PJ-100-N	LISN
Pasternack	PE7464-20	20dB Atteunetor

4.2 Proposed Multi Input Common Mode Coil Design

The equipment was subjected to CE102 test again after the supply inputs directed to each sub-unit were wound on a single common mode coil in the opposite direction and with equal winding amount so that the common mode coils designed specifically for the power supplies in the equipment were bypassed (Figure 8). The Common Mode Choke design of the equipment is as shown in Figure 9. The visuals of the design applied to the equipment are as shown in Figure 10 and Figure 11.

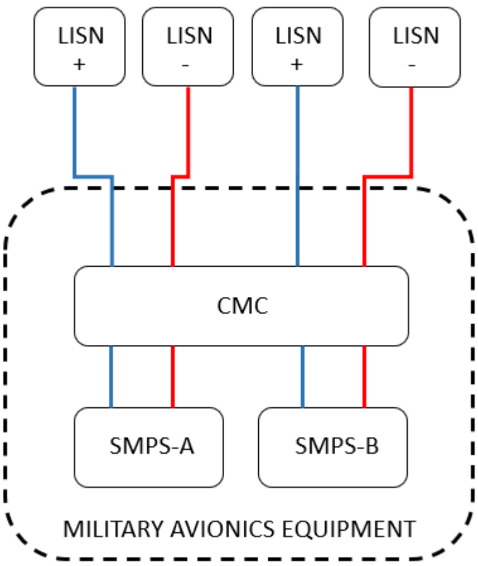

Figure 8. Equipment Multi Input Common-Mode Coil Design

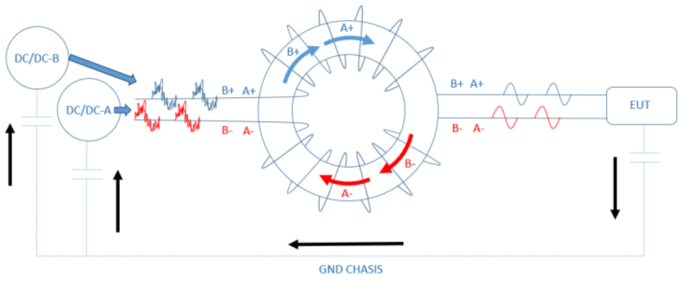

Figure 9. Multi Input Common Mode Coil Filtering Design

Figure 10. Multi Input Common Mode Coil Application

Figure 11. Multi Input Common Mode Coil Application-2

For Conducted Emission test, scanning was performed according to MIL-STD-461F Table II [2]. In the test set up prepared according to Figure 1, the devices in Table 2 were used.

Table 2: Test devices which are used

Brand	Model	Explanations
Rohde Schwarz	ESW44	EMI Receiver
SOLAR	8116-50-PJ-100-N	LISN
Pasternack	PE7464-20	20dB Atteunetor

5. Results and Discussion

The CE102 test results applied to the positive and negative terminals for power supply A and power supply B of the equipment with redundant power supply designed with conventional split common mode coil design are shown in Figure 12, Figure 13, Figure 14 and Figure 15.

When the results of the conventional seperated common-mode choke design are analysed, it is observed that the noise level emitted by the equipment for both positive and negative ends, especially in the range of 160 kHz to 550 kHz, is above the CE102 noise level limits.

The CE102 test results applied to the positive and negative terminals for power supply A and power supply B of the equipment with redundant power supply designed with multiple input common-mode coil design are shown in Figure 16, Figure 17, Figure 18 and Figure 19.

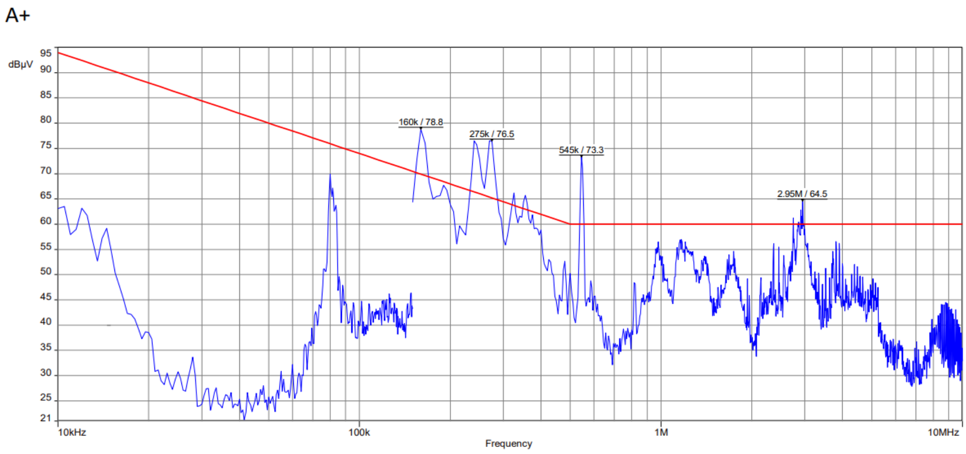

Figure 12. Power Supply-A Positive Line

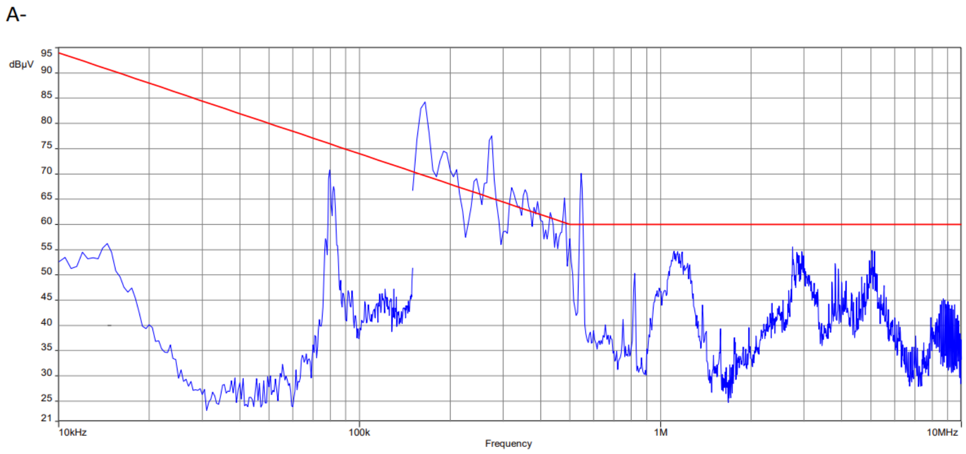

Figure 13. Power Supply-A Negative Line

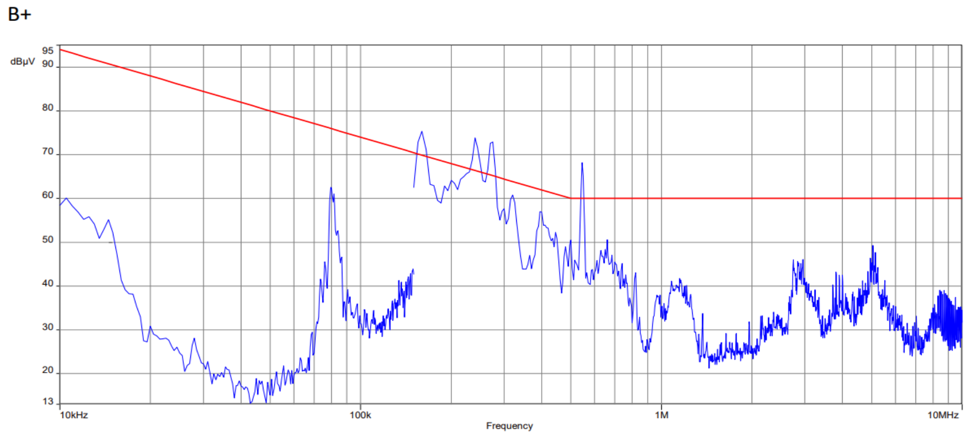

Figure 14. Power Supply-B Positive Line

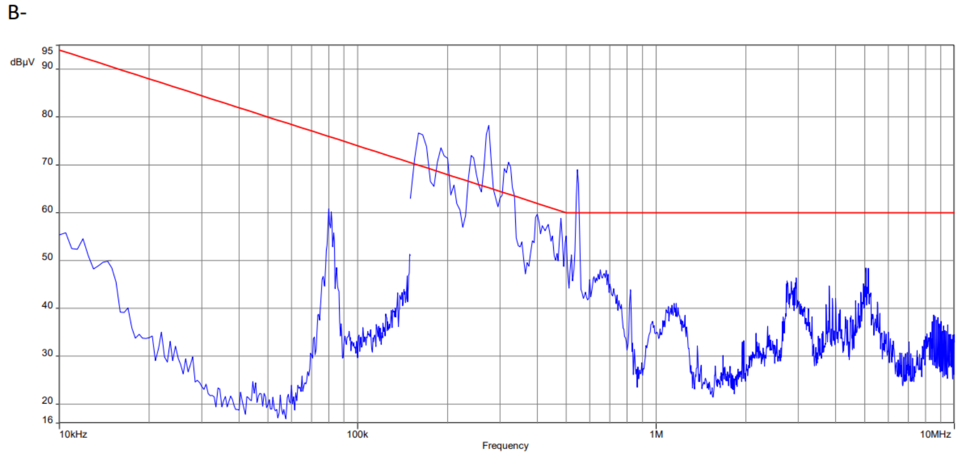

Figure 15. Power Supply-B Negative Line

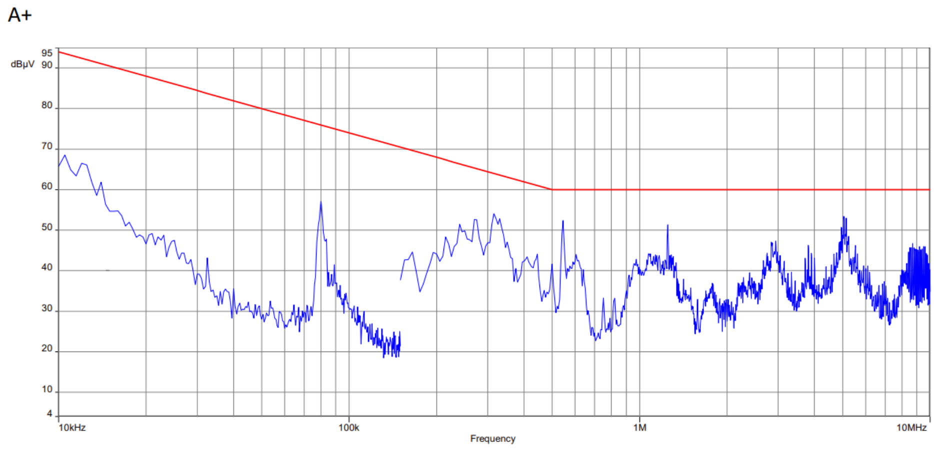

Figure 16. Power Supply-A Positive Line

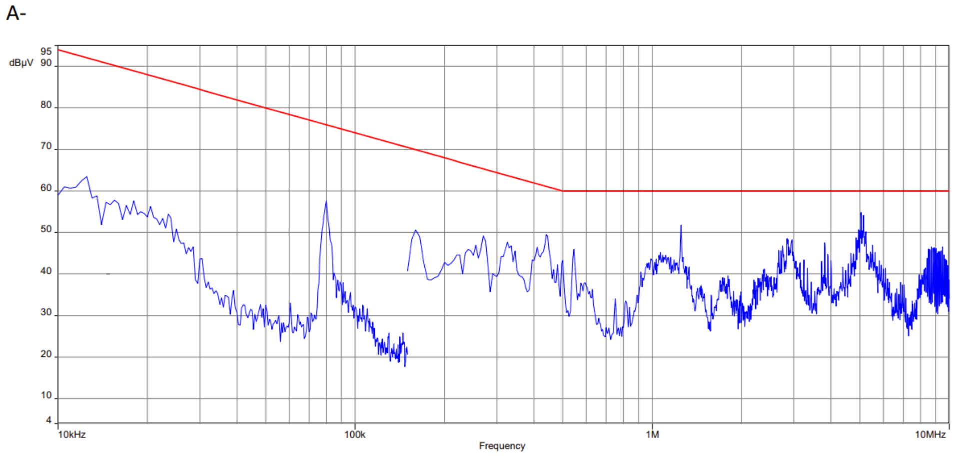

Figure 17. Power Supply-A Negative Line

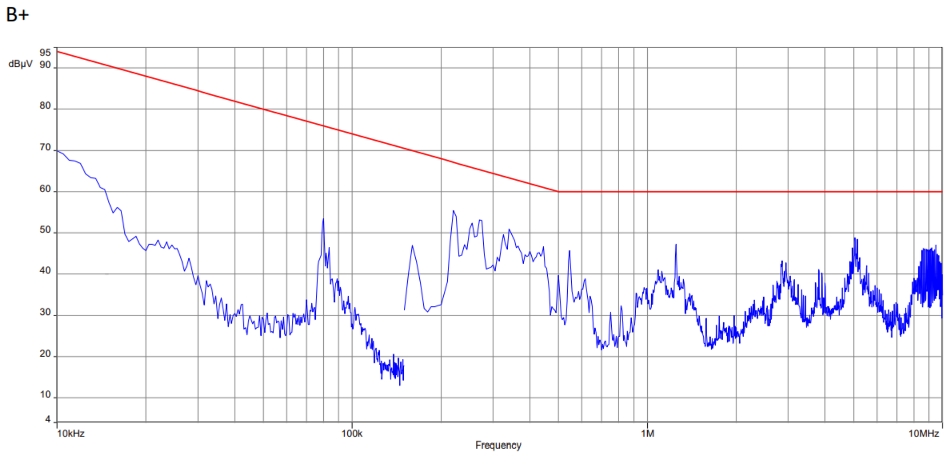

Figure 18. Power Supply-B Positive Line

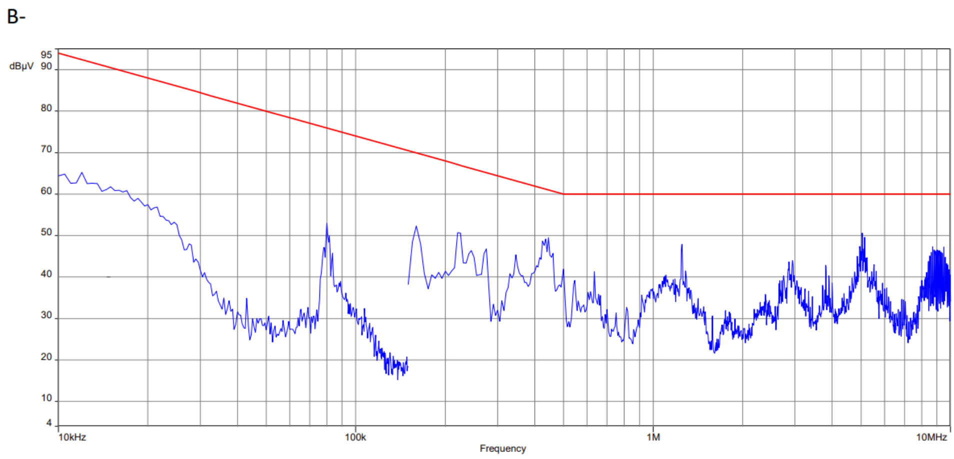

Figure 19. Power Supply-B Negative Line

When the results of the multiple input common mode coil design were analysed, it was observed that the CE102 test results were within the limits for all positive and negative lines of the equipment.

When both test results were compared, it was observed that the electromagnetic noise levels in the very low frequency region (10 kHz - 100 kHz) and high frequency region (1 MHz - 10 MHz) increased by an average of 20 dBµV but remained below the CE102 test limits, while the mid-frequency region (100 kHz - 1 MHz), especially for the noisy region between 160 kHz and 550 kHz, decreased by an average of 40 dBµV and fell below the CE102 test limits.

While the emission levels exceed the CE102 test limits due to the unbalanced load condition and the difference in return currents for separated common-mode choke design of the discrete DC-DC converters of the redundant military avionics equipment, the unbalanced load situation has been eliminated by winding and filtering all DC-DC converters through a single common mode coil. With this result, it has successfully passed from CE102 tests by keeping the emission level below the limits. At the same time, the positive and consistent results for both redundant power supply lines make the study even more valuable.

The unbalanced load induced electromagnetic noise suppression test can be performed for all redundant DC-DC converters regardless of the amount of redundancy. In avionic equipment with two or more redundant power inputs, it can be used by increasing the number of multiple inputs and outputs.

6. Conclusions

In summary, this study analyses the CE102 test results of military avionics equipment with redundant power supply and compares the CE102 test results of seperated common-mode choke design and multi input common-mode choke design. It is thought that the developed multi input common-mode choke design will contribute to possible hardware improvement in military avionic equipment with redundant power supply. The application has been carried out on military avionic equipment, further studies on the effects on medical or civilian equipment will enrich the level of knowledge in this field.

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