Analysis and Rectification of Power Line Conducted Emission Test Exceeding Standards

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Abstract. The power transmission emission test (CE102) is the key to electromagnetic compatibility (EMC) testing. The device exceeded the limit at multiple frequencies in the CE102 test. The analysis was performed to locate the curve. The filter was selected based on the frequency characteristics of the filter components and the DC-DC conversion was performed. The harmonic emission of the switching frequency of the converter was analyzed and effectively suppressed. The filter module circuit was set according to the characteristics of the interference source, the key parameters of the filter module were calculated, the rectification method was formulated, and CE102 test was performed again to determine the accuracy of the rectification plan.

1. Overview
A certain device is a key component of the combination machine. In the ground simulation system, the device must meet the anti-interference ability, and the interference to other devices in the system should be minimized. During the electromagnetic compatibility test of this device, the power transmission line and the positive and return lines of the power line both exceeded the standard. Through analysis and calculation, an effective rectification idea was formulated.

Regarding CE102 is mainly used to test the impact of the EUT conducted emissions on the outside world, the U.S. military standard MIL-STD-461F standard makes clear the reference limit of CE102. When performing CE102 test, the measurement receiver generally needs 20dB attenuator. As shown in Figure 1, the equipment in this article uses 220V AC power supply, which is relaxed by 9dB according to the standard curve limit.

Figure 1. CE102 limit reference curve.
The positive line test curve chart of the device during CE102 test is shown in Figure 2 below. According to the test result curve chart, specific frequency bands that exceed the standard can be obtained. In the frequency band of 0.25MHz to 10MHz, the standard is severe, and there is no difference in lines.

![Figure 2. Positive test curve.](image)

2. Analysis and rectification of electromagnetic interference

2.1. Analysis of conducted interference mechanism

In the switching power supply, the influence of parasitic parameters such as parasitic capacitance and parasitic inductance is also affected by the on and off of the MOSFET, so a large number of interference sources are generated at its ports. The power, ground, and communication lines in the device form an antenna. Common-mode interference is caused by interference currents. A large number of parasitic capacitances exist on the sensor and chip of the device, and the cables also have a variable amount of parasitic inductance. These interference sources will interfere with sensitive devices. When the MOSFET is turned on and off at high speed, the generated interference source forms a common-mode interference between the interference path and the ground. According to the interference characteristics of the signal source, it is divided in the 10kHz-10MHz frequency band. Among them, differential mode interference is the main under 5MHz, and common mode interference is the main over 5MHz.

The filtering circuit is not the higher the order, the better the filtering effect is, but the selection of filtering parameters to form the common mode and differential mode impedance, as far as possible to cause impedance mismatch between the DUT interference source port and the impedance network, the size of the filtering circuit must also be considered, Weight and rated current and other performance indicators, so as not to cause the filter to lose the significance of practical application. During application, the filter should be installed at the power inlet as much as possible, and the input line and ground should be avoided to prevent the filter from performing poorly or failing.

The working current of a digital circuit is transient. Although decoupling capacitors are installed on the bypass and circuit of each circuit chip, a part of the transient current is still reflected in the power supply, which is transmitted along the power supply or passed through the nearby coupling causing CE102 conduction to exceed standards. The schematic of conduction and internal space coupling is shown in Figure 3 below.
CE102 exceeding the standard is usually implemented by adding a filter circuit at the power inlet. Appropriately increase the X safety capacitor to suppress the differential mode and the Y safety capacitor to suppress the common mode. The parameters of the device need to be matched with the actual circuit. At the beginning, CE102 rectification used a common performance filter circuit in front of the power inlet, and added several X capacitors and Y capacitors. The test curve was adjusted to obtain the following figure 4, as shown in Figure 4. Rectification needs to continue.

The typical value of the switching frequency of the DC-DC converter is 125kHz, which corresponds to the frequency exceeding the standard. It can be judged that the working frequency of the DC-DC converter is 125kHz and the noise level of its higher harmonics is high. DC-DC converters have high di/dt and dv/dt variations in the operating state. When the power is turned on, the instantaneous peak current and the peak voltage generated during power conversion will affect the stability of the system.

![Figure 3. CE102 conduction and internal space coupling diagram.](image)

2.2. Interference suppression method

By analyzing the interference source of the device to cut off its coupling path, the electromagnetic interference problem can be effectively solved. Add resistance and capacitance to the converter to suppress it. Because the module itself is an independent chip, it cannot be effectively processed. By analyzing the circuit of the device, the interference path is isolated to reduce the sensitivity of the DC-DC converter Electromagnetic interference from equipment.

Selecting a suitable filter circuit can effectively solve the conduction problem of the device. The classic filter circuit shown in Figure 5 below is divided into a common performance electromagnetic disturbance filter circuit and an electromagnetic disturbance filter circuit enhanced for differential mode suppression. The first rectification was a common-performance electromagnetic interference filter circuit. The combination of the common-mode inductor and the two common-mode capacitors can effectively suppress common-mode interference. There must be differences in the winding of the

![Figure 4. The first rectification of the CE102 test curve.](image)
common-mode inductor, and the difference between the coils on both sides The value generates a certain amount of leakage inductance, and the generated leakage inductance and two differential mode filter capacitors are used to eliminate the differential mode interference signal together. According to the results after the first rectification, it is seen that the ordinary performance electromagnetic disturbance filter circuit has sufficient suppression effect on common mode signal interference, and the 250-kHz differential mode interference generated by the DC-DC converter is not sufficient. The filter circuit is listed in Figure 5. Based on the comparison of the insertion loss diagram of the differential mode enhanced electromagnetic interference filter circuit at 250 kHz, the insertion loss is higher than that of the ordinary performance electromagnetic interference filter circuit. The differential mode enhanced electromagnetic interference filter circuit is used for suppression.

2.3. Calculation of key parameters
The specific data on interference noise is analyzed by calculating the insertion loss (IL), and the power ratio after adding the filter circuit and without the filter is compared. CE102 stipulates that the insertion loss in the 10kHz-10MHz frequency band is 30dB ~ 60dB, and 6dB safety margin needs to be added in engineering applications. Through the graph of the bottom test, the specific attenuation value is reached through theoretical calculation, as shown in Table 1 below.

| F(MHz) | 0.125 | 0.250 | 0.775 | 1.5  | 2.255 | 5.760 |
|--------|-------|-------|-------|------|-------|-------|
| LLCM(dB)| 55    | 65    | 80    | 80   | 80    | 80    |
| LLDM(dB)| 60    | 70    | 75    | 75   | 75    | 75    |

The equivalent circuit after the filter is added is shown in Figure 6 below. The insertion loss IL is given by equation (1).

$$\text{IL} = 10\log \left( \frac{P_1}{P_2} \right) = 10\log \left( \frac{U_1^2}{R_1} / \frac{U_2^2}{R_2} \right) = 20\log \left( \frac{U_1}{U_2} \right)$$

2. The differential mode equivalent circuit and common mode equivalent circuit of the differential mode enhanced filter circuit are shown in Figure 7.
Equations (2) and (3) are replaced with equations (4) to obtain equations (5) and (6), and the final differential mode and common mode IL are obtained.

$$IL_{CM} = 20 \log \left| \left( 1 - w^2 L_{CM} C_y \right) R_L + jw L_{CM} + jw C_y R_S R_L + R_S \left( R_S + R_L \right)^2 \right|$$

$$= 10 \log \frac{w^2 (1 + w^2 C_y)^2 L_{CM} - 2w^2 R_S^2 C_y L_{CM} + (R_S + R_L)^2 + w^2 R_S^2 R_L^2 C_y^2}{(R_S + R_L)^2}$$

$$IL_{DM} = 20 \log \left| \frac{R_L + jw L_{DM} + jw R_S R_L C_x + (1 - w^2 L_{DM} C_x) R_S}{(R_S + R_L)^2} \right|$$

$$= 10 \log \frac{w^2 (1 + w^2 C_x)^2 L_{DM} - 2w^2 R_S^2 C_x L_{DM} + (R_S + R_L)^2 + w^2 R_S^2 R_L^2 C_x^2}{(R_S + R_L)^2}$$

Due to the impedance matching problem in the filter circuit, it needs to deal with interference noise. The larger the capacitor value, the more obvious the filtering effect. It is verified through experiments that the larger capacitor has the best suppression effect on the device. The final common mode capacitor uses 22nF and the differential mode capacitor uses 0.68uF.

According to the theory, the electromagnetic disturbance filtering performance is proportional to the inductance of the common mode inductor LCM, and the cut-off frequency will decrease with the increase of the common mode inductance, and the corresponding distributed capacitance will also increase accordingly. High-speed changing current passes through the distributed capacitor, which makes its ability to suppress high-frequency noise worse. In the actual design, a common-mode inductor of 2mH ~ 50mH is generally used. The increase of the differential mode inductance also results in serious heating. It is necessary to use a differential mode inductor with a small inductance to effectively control the temperature parameters of the filter circuit. (6) and Table 1 can get the common mode and differential mode inductance values in Table 2. By comparing and calculating the filtering effect, the final common mode inductance uses 32mH, and the differential mode inductance only uses 33uH.

| F(MHz) | 0.125 | 0.250 | 0.775 | 1.5 | 2.255 | 5.760 |
|--------|-------|-------|-------|-----|-------|-------|
| LCM(mH)| 8.9   | 5.6   | 14.8  | 1.9 | 0.8   | 1.6   |
| LDM(uH)| 34    | 25    | 19.5  | 9.6 | 5.6   | 2.3   |
2.4. Test verification
After adjusting the filtering parameters for specific practice, 22nF common mode capacitors, 0.68uF differential mode capacitors, 32mH common mode inductors, and 33uH differential mode inductors are used. After redesigning the welding and testing, the test curve is shown in Figure 8.

![Figure 8. CE102 test curve.](image)

The final qualified specific data is shown in Table 3 below. The margin meets the requirements. The data used by the filter and the data obtained from the previous formula can effectively suppress the effect and reach the final rectification plan.

Table 3. CE102 peak calibration table.

| Number | Frequency (MHz) | MaxPeak (dBuV) | Corr. (dB) | Result (dBuV) | Limit (dBuV) | Margin (dB) |
|--------|----------------|----------------|------------|---------------|--------------|-------------|
| 1      | 0.125          | 7.65           | 20.24      | 27.89         | 82.21        | 54.32       |
| 2      | 0.250          | 35.66          | 20.12      | 55.78         | 69           | 13.22       |
| 3      | 0.775          | 18.69          | 20.05      | 38.74         | 69           | 30.36       |
| 4      | 1.5            | 17.89          | 20.26      | 38.15         | 69           | 30.85       |
| 5      | 2.255          | 31.53          | 20.04      | 51.57         | 69           | 17.41       |
| 6      | 5.760          | 29.01          | 20.19      | 49.20         | 69           | 19.8        |

Note: Result=MaxPeak+Crr., Margin=Limit-Result

3. Conclusion
The stability of the equipment's electromagnetic compatibility determines the reliable performance of the aeronautical system, and selecting the appropriate filter circuit has also become the key to solving the electromagnetic compatibility problem. The test curve was analyzed to determine the source of the problem, and an effective solution was developed for the DC-DC converter in the device. The parameters of the filter circuit was analyzed based on theoretical knowledge, the key parameters of the inductor and capacitor in the circuit were calculated, and the reliability of the device was verified through actual tests. It is determined that the designed differential mode enhanced filter circuit can meet the engineering application of the device.

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