Analysis on an Electromagnetic Compatibility Engineering Trouble Shooting Case of Electric Vehicle

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***Abstract*—In the situation that an electric vehicle tested in accordance with GB/T 18387-2017 and GB 14023-2011 but not meets the requirements of the standards, the motor controller (PMU) and air conditioning compressor (ACCM) are proved to be the main electromagnetic disturbance sources according to the scientific elimination method. The mechanism of electromagnetic disturbance is also analyzed and studied. Considering the key factors affecting mass production of vehicles, an engineering optimization solution is proposed to enable radiation emission of the electric vehicles meet the requirements of national standards.**

Keywords—electric vehicle; electromagnetic disturbance; mass production; optimization solution

1 INTRODUCTION

large number of high power devices such as motor controller (PMU), air conditioning compressor (ACCM)etc.are integrated in the narrow space of vehicles, making the electromagnetic environment inside the vehicles more complicated[1]. In such a case, it is very important for reducing the electromagnetic disturbances below certain limits to ensure the quality and safety of the vehicles.

The electromagnetic radiation emission of the vehicle finally meets the limit requirements of GB 14023-2011 and GB/T 18387-2017 by applying this solution.

2 TESTANDANALYSIS

An electric vehicle is tested according to GB 14023-2011 and GB/T 18387-2017. When tested in accordance with GB 14023-2011, the narrowband test results of the antenna vertical polarization(LVmode) and antenna horizontal polarization(LH mode) exceed the limit lines with the antenna located on the left side of the vehicle. The test setup is shown in Fig. 1. The test results of LV mode are shown in Fig. 2. When tested in accordance with GB/T 18387-2017, the magnetic field test result at a vehicle speed of 16km/h exceeds the limit line with the antenna located on the left side of the vehicle and parallel to the vehicle(L-X-16 mode), as shown in Fig. 3. Thus, trouble shooting of narrowband test and magnetic field test are performed.

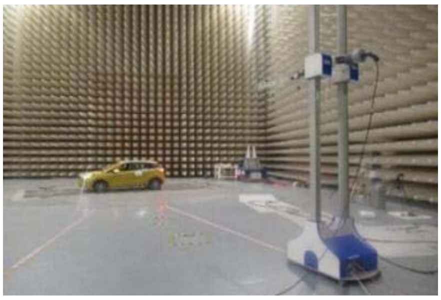

Fig.1 Test setup

It can be seen from Fig. 2 that the frequency of the peak point in area A. The peak point level exceeds the limit line of about 16 dB.Combining the spectrum characteristics of Fig. 2 , it can be seen that the frequency band from 45 MHz to 200 MHz exhibits narrowband disturbance characteristicsand the entire frequency band has a risk of exceeding the limit line.

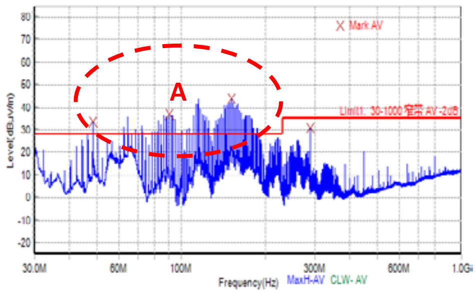

Fig.2 LV test result

As shown in Fig. 3, there are two areas of the magnetic field test results exceed the limit line. The frequency of the envelope in area B is about 13MHz. The level of the envelope exceeds the limit line of about 1.5dB. Two single frequency points of 26MHz and 28MHz in area C exceed the limit line. According to the analysis of area Band area C, the narrowband disturbance characteristics are also exhibited. According to the spectral characteristics of area A, B and C, it can be preliminarily determined that the radiation emission exceeds the limit lines in area A, B and C is caused by the same circuit topology and the radiation emission exceeds the limit line in area B is caused by another.

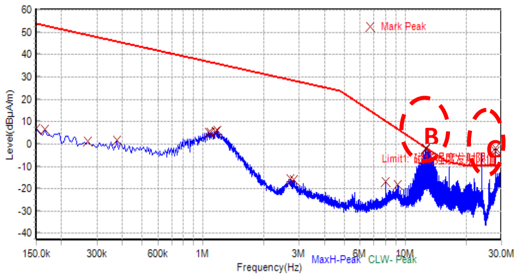

Fig.3 L-X-16 mode test result

3 LOCATION OF RADIATION EMISSION DISTURBANCE SOURCE

In the narrowband test mode[2], the electrical systemsof the vehicle are in normal operation, all continuously operating devices with built-in oscillators or repetitive signals greater than 9 kHz are in normal operation. When tested in LV mode, the vehicle should be in "READY" state and the gear should be in N position. The electrical components in operation include wiper motor, double flash, headlight, radio, blower, battery management system(BMS), power battery, DC/DC converter, PMU, ACCM, etc. The exclusion method is used to find the electrical components that cause the radiation emission in Fig. 2 to exceed the limit line.

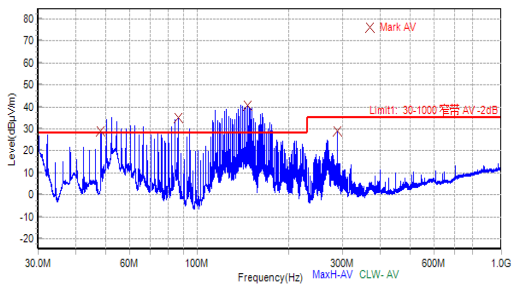

Fig.4 LV mode test result with the wiper motor, double flash, headlight, radio and blower turned off

Firstly,the wiper motor, double flash, headlight radio and blower should be turned off one by one. The test result is shown in Fig. 4. excluding the possibility that the above electrical components cause the radiation emission to exceed the limit line.

Secondly, according to the component layout of the vehicle, the high-voltage components are inspected one by one. The power battery and the motor system should be in normal operation in order to make the vehicle in "READY" state. The low voltage connectors of other high voltage electrical components are disconnected one by one. The test results are still not significantly changed compared with Fig. 2.Only the motor system is currently in operationand all the other high voltage components have been disconnected. In order to determine whether the motor system is the electromagnetic disturbance source, the low voltage connector of the PMU should be disconnected. The vehicle cannot be in "READY" state without the connection of PMU low voltage connector and the corresponding test result in LV mode is shown in Fig. 5. that the radiation emission in area A of Fig. 2 is significantly reduced. As the radiation emission exceeds the limit line in area A, B and D maybe caused by the same circuit topology, PMU is determined as the main electromagnetic disturbance source.

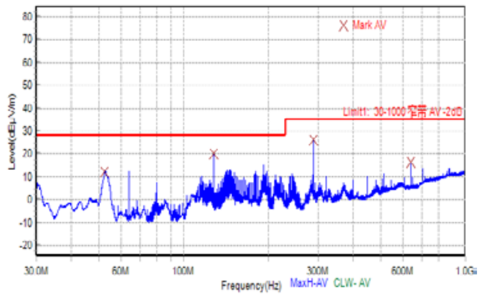

Fig.5 LV mode the result without the connection of PMU low voltage

With the purpose of verifying the rationality of the above judgment, the low voltage connector of the PMU should be connected. Radiation emission test should be carried out using the probe under the condition that the low voltage harness is added with magnetic loops. The results are shown in Fig. 6.

As the radiation emission in area A is lower than the limit line with the magnetic loops added, it can be concluded that the main electromagnetic radiation source in area A of Fig. 2 is the low voltage harness of PMU.Therefore, the PMU is the main component that causes the radiation emission to exceed when tested according to GB 14023-2011.

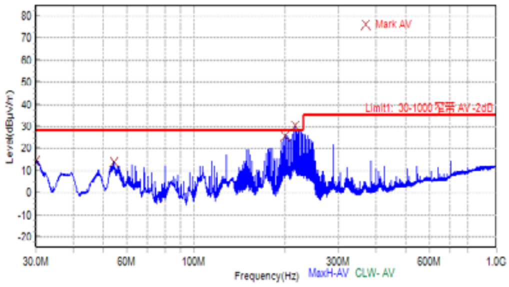

Fig.6 Test result with PMU low voltageharness added magnetic loops

Next, As the radiation emission exceeds the limit line in area A, B and C maybe caused by the same circuit topology, directly disconnect the PMU low voltage connector to verify whether the radiation emission in area C of Fig. 3 decreases. The test result is shown in Fig. 7.

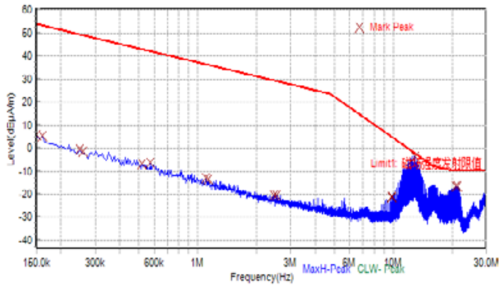

Fig.7 Test result with PMU low voltage connector disconnected

It can be seen from Fig. 7 that the radiation emission in area C meets the requirements of the standardand the correctness of the inference is proved.However, the radiation emission in area Bof Fig. 3 has not changed.Finally, through a new round of troubleshooting, it is found that the component that causes the radiation emission in area B of Fig. 3 to exceed the limit line is ACCM. Disconnect the ACCM high voltage connector and the test result is shown in Fig. 8.

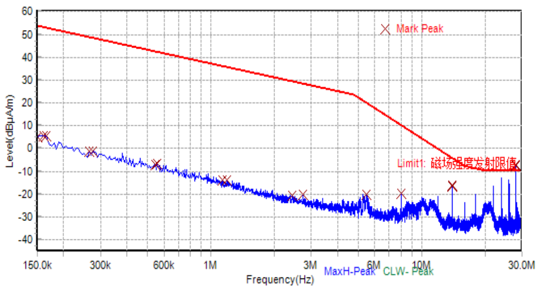

Fig.8Test result with ACCM high voltage connector disconnected

It can be seen from Fig. 8 that the radiation emission in area B has been significantly reduced. At this stage, the trouble shooting is all over. PMU mainly includes electronic control module,drive system and power conversion module.ACCM mainly includes switching power supply.it is determined that the non-isolated BUCK switching power supply inside the electronic control module of PMU and the auxiliary switching power supply of the ACCM are the main reasons for the radiation emission of area A, B, C exceeding the limit line.

4 TROUBLE SHOOTING OF RADIATION EMISSION DISTURBANCE SOURCE

The loop diagram of the BUCK circuit is shown in Fig. 9, including loop 1 and loop 2. In loop 1, current flows from the input bypass capacitor Cin1, then passes through the high-side MOSFET, the inductor and the output bypass capacitor Co1 during turn-on, and finally returns to Cin1. Radiation is generated by theloop and then coupled to the low voltage harness of the motor controller for radiation emission.In loop 2,the energy stored in the inductor flows through the output bypass capacitor Co1, the low-side MOSFET, GND and finally return to Co1 during turn-off of high side MOSFET and turn-onof low side MOSFET.

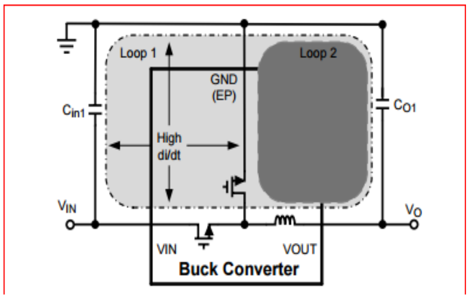

Fig.9 Loop diagram of BUCK circuit

The PCB design of the BUCK switching power supply on the PMU internal control board is shown in the blue part of Fig. 10. Since the GND-12V and GND are not electrically connected in the design, the ground reference plane is incomplete, resulting in the radiation emission exceeding the limit line.

The radiation emission of the switching power supply is related to the current, the loop area of the circuit and the frequency of the signal[3],as shown in (1).

$$E = 263*10^{-16}(f^{2}AI)(1/r) \qquad (1)$$

E represents the limit of radiation emission field strength. f represents the frequency of the signal. A represents the area of the loop. I represents the current of the signal and r represents the distance between the loop and the test antenna.As the frequency f and current I of the signal as well as the distance r can hardly be changed after the product design is completed, changing the loop area is a more feasible solution.

The optimized solution is found through the analysis of the circuit principleand the analysis of the PCB circuit connection, as shown in the red part of Fig. 10. Ground the earth wire at multiple points first, then connect the above points to the same point, which is GND-12V

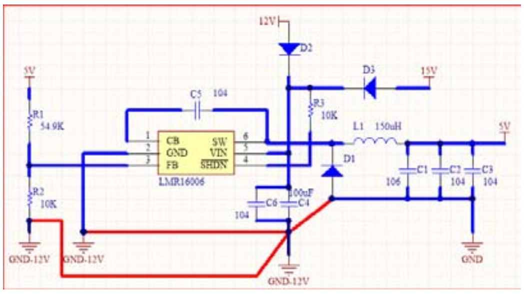

Fig.10 PCB design before and after trouble shooting

For the reason that the radiation emission in area B exceeds the limit line, it is analyzed that the ACCM is not well grounded, so that the common mode interference generated by the switching power supply is nowhere to be released[4]. After trouble shooting, the picture is shown in Fig. 11 and the red line is the ground wire.

Fig.11 ACCM after trouble shooting

Based on the current trouble shooting measures, the PMU and ACCM have been redesigned to meet the requirements of mass production. It can be seen from the figures that the radiation emission of the vehicle meets the requirements of the standards are shown in Fig. 12-13.

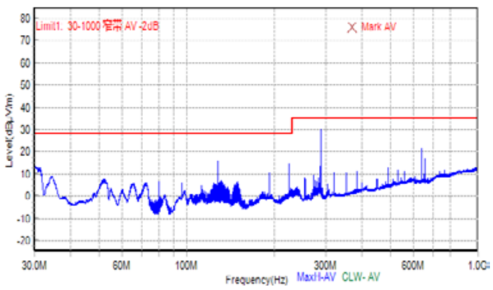

Fig.12 LV mode test result

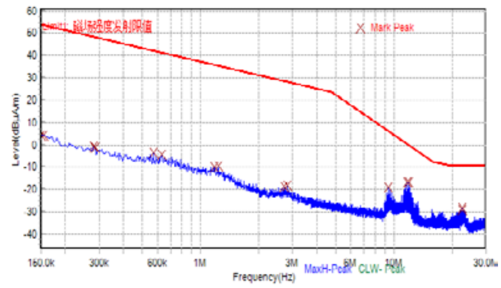

Fig. 13 L-X-16 mode test result

5 CONCLUSION

Theoretical research is conducted to guide engineering practice, through the analysis of the circuit principle and PCB design, combined with the near field test method and other methods, it is obtained that the radiation emission exceed the limit line because of the grounding problem of switching power supplies and effective trouble shooting measures are proposed. As the size of switching power supplies decreases and the power densityincreases, the EMC problem has become a key factor in the stability of the switching power supply. In the design of switching power supply, the electromagnetic compatibility can be effectively improved by comprehensive use of various electromagnetic disturbance suppression technologies and truly meet the needs of various occasions.

REFERENCES

[1] Chung Y N, Chiu M S, Hsu C H, et al. The Development and Analysis of Electromagnetic Compatibility for Vehicles[C]. International Conference on Smart Vehicular Technology, Transportation, Communication and Applications. Springer, Cham, 2018: 42-50.

[2] GB 14023-2011,Vehicles,boats and internal combustion engine-Radio disturbance characteristics-Limits and methods of measurement for the protection of off-board receivers[S].Beijing:Standards Press of China, 2011.

[3] Zuo P, Yan L, Xu Y, et al. Near-Field Radiation Estimation and Its Reduction Using a Novel EBG for PCB[J]. IEEE Transactions on Components Packaging & Manufacturing Technology, 2018, PP(99):1-7.

[4] Yang X, Dong C, Qu Z. Design and dynamic analysis of a novel double-swing vane compressor for electric vehicle air conditioning systems[J]. International Journal of Refrigeration, 2017, 76:52-6.