EMI Radiation Mechanism and Experimental Research of Power Battery System

YUN WANG, YIFU DING, WEIDONG YANG, XU ZHANG and LI JIANG

ABSTRACT

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KEYWORDS

EMC; Power Battery; Radiation Filter

INTRODUCTION

Power battery system contains a large number of power electronic switching components, such as IGBT, MOS, etc. When in working state, these switching components may produce loud noise. The switching mode power supply of battery management system (BMS), such as BUCK circuit, BOOST circuit or BUCK-BOOST circuit, have abundant high frequency harmonics, which can produce serious electromagnetic radiation. The internal wireless harness of power battery is a little complex, including high voltage wiring harness, low voltage wiring harness and various signal acquisition wiring harness. Complex EMI noise may be formed Due to mutual coupling between all kinds of wiring harness, complex EMI noise may be formed. Moreover, owing to the existence of high voltage wireless harness and the huge volume of battery, the electromagnetic coupling paths is complicated, which may put forward higher technical requirements and challenges for engineers.

In this paper, to study the EMC of electric vehicle battery system, 13 battery manufacturers are randomly selected to run an EMI radiation test. The results show that only four of them passed the third level limit of standard, CISPR25: 2016, which is the most commonly used limit for original equipment manufacturers (OEMs). The other nine all have different degrees out of the standard limits, especially in the frequency band 150kHz to 450MHz. Compared narrowband signal and the broadband signal, the former is more obvious at the resonant frequency. Above 500 MHz, all of the 13 manufactures meet the third level specified by CISPR 25:2016. The test results are shown as Figure1.

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PRINCIPLE OF EMI RADIATION

The inference source, coupling approach and sensitive components are the three elements of EMC. As the test method in GB/T 18655-2010, the inference source refers to battery system. The free space of echamber is the coupling approach. And the receiving antenna can be seen as sensitive components. The testing arrangement is shown in figure 2.

The function of BMS is complex. In hardware circuit even very short circuit wiring is also likely to be a transmitting antenna and EMI radiation is produced when the electromagnetic wave into space. In general, the noise of the power source and the ground will cause the common mode radiation, and the large backflow path will increase the differential mode radiation, which is the main source of EMI radiation.

Differential Mode Radiation

Differential mode radiation generated when the differential current flows through a conductor loop of the circuit. The loop corresponds to a small ring antenna that we use small ring antenna (magnetic dipoles) model to analyze the differential mode radiation [3].

The ideal magnetic dipole antenna is made up of a small current ring, which radius is $a<<\lambda$. And the components of electromagnetic fields are shown as follows.

\[
E_{\varphi} = -j \frac{\eta S_{\varphi}}{4\pi r} \left[ jk + \frac{1}{r} \right] \sin e^{-jkr} \quad (1)
\]

\[
H_{\theta} = \frac{jS}{4\pi r} \left[ -k^2 + \frac{jk}{r} + \frac{1}{r^2} \right] \sin \theta e^{-jkr} \quad (2)
\]

\[
H_{r} = \frac{jS}{2\pi r^2} \left[ jk + \frac{1}{r} \right] \cos \theta e^{-jkr} \quad (3)
\]

The corresponding amplitude is

\[
|E_{\varphi}| = -\frac{\eta S_{\varphi}}{r\lambda^2} \sqrt{1 + \frac{\lambda^2}{4\pi^2 r^2} \sin \theta} \quad (4)
\]

\[
|H_{\theta}| = \frac{jS}{r\lambda^2} \sqrt{1 - \frac{\lambda^2}{4\pi^2 r^2} + \frac{\lambda^4}{16\pi^4 r^4} \sin \theta} \quad (5)
\]

\[
|H_{r}| = \frac{jS}{r\lambda^2} \sqrt{1 + \frac{\lambda^2}{4\pi^2 r^2} \cos \theta} \quad (6)
\]
Where, \( E \) is electric field strength, \( H \) represents magnetic field strength, and \( \eta = 120\pi \Omega \) is the characteristic impedance of free space, \( S \) is the area of the loop, \( R \) is the distance from one point of space to the center of the current loop, \( \theta = \frac{2\pi}{\lambda} \) is equal to the angle between the vector and the z axis.

**Common-Mode Radiation**

Due to the voltage drop in the grounding circuit, some parts have high potential common-mode voltage. When external cable connects to these areas will be under the common mode voltage produced common-mode current, caused by common-mode radiation, equivalent to a short antenna, can electric dipole antenna model to analyze the common-mode radiation [3]. The ideal electric dipole antenna is composed of an isolated conductor of a radial line length \( d<<\lambda \), whose electromagnetic fields are components.

\[
\begin{align*}
E_r &= -\frac{i \omega \cos \theta}{2 \pi \omega r^2} \left[ j k + \frac{1}{r} \right] e^{-jkr} \\
E_\theta &= -\frac{i \omega \sin \theta}{4 \pi \omega r^2} \left[ -k^2 + \frac{jk}{r} + \frac{1}{r^2} \right] e^{-jkr} \\
H_\varphi &= \frac{i \omega \sin \theta}{4 \pi r} \left[ jk + \frac{1}{r} \right] e^{-jkr}
\end{align*}
\]  

The modulus value is:

\[
|E_r| = \frac{i \omega \cos \theta}{2 \pi r^2} \sqrt{\frac{k^2}{r^2} + 1} = \frac{i \omega \eta \cos \theta}{2 \pi r^2} \sqrt{1 + \frac{\lambda^2}{4\pi^2 r^2}}
\]  

\[
|E_\theta| = \frac{i \omega \eta \sin \theta}{2 \lambda r} \sqrt{1 - \frac{\lambda^2}{4\pi^2 r^2} + \frac{\lambda^4}{16\pi^4 r^4}}
\]  

\[
|H_\varphi| = \frac{i \omega \sin \theta}{2 \lambda r} \sqrt{1 + \frac{\lambda^2}{4\pi^2 r^2}}
\]

In near-zone, the wave impedance is much less than the vacuum wave impedance \( \eta \), which is the low impedance region. In the far field, the wave impedance is equal to the vacuum wave impedance. The intensity of the differential radiation and the intensity of the electric field are proportional to the area of the loop area. Common mode radiation indicates that the strength of the electric field and the magnetic field is proportional to the length of the current \( I \) and the length of the line.

**POWER BATTERY SYSTEM RADIATION EMISSION CHARACTERISTIC**

Power battery system has double properties of high voltage and low voltage system, when the BMS battery control system relay disconnect and suction moments, DC-BUS can make a big \( \text{du/dt} \) and \( \text{di/dt} \) value, the moment of the radiation energy is very big, the energy may be produce some serious interference in the vehicle.

the PCB of BMS is a typical interference source, the board typical interference sources as follows: 1, switching power supply of PWM switch drive pulse and higher harmonic, 2, the clock signal lines of the digital circuit, including the sampling clock
line, 3, a crystal vibration signal of MCU, 4, and the common mode and differential mode current on the power cable, etc. The current hardware circuit is generally high speed PCB, and for high frequency signal, the PCB line reactance is greater than resistance, and it presents the inductance characteristic, which in turn introduces the radiation. Electromagnetic radiation harassment is caused by high-frequency circuits in the battery management system, such as extreme conditions: open circuit - antenna effect. By this time should be followed to find a way to shorten the line, to find a way to reduce the high frequency signal loop area, eliminate any abnormal work need antenna, will not need to go line to remove; Therefore, the important task of reducing radiation disturbance is to reduce the area of high frequency current loop. Loop current, the higher the frequency, the more serious EMI radiation, the radiation field intensity and is proportional to the square of the current frequency, thus it can be seen, another way to reduce the radiation harassment is reduce frequency of the disturbance source of the high frequency current [4].

**Power Battery Differential And Common Mode Current Analysis**

The common mode current and differential mode current can be measured by the LISN and current probe.

A source of disturbance can form a common and differential mode coupling under different coupling paths. The problem of EMI can be solved by setting filter absorption differential mode or common mode current on the corresponding coupled path.

The high voltage and low voltage in the power system have two different types of ground, and the normal low-voltage system is applied to the ground. So Common mode noise and common mode noise can be present on the DC-BUS. The battery model is shown in figure 3, where R1 is the battery's internal resistance and R2 is the battery's discharge resistance [13]

Battery monomer through the form of parallel and serial eventually form the battery pack, monomer connection between the connection between the battery and battery pack, lead to parasitism inductance and parasitism capacitance, to form an impedance, and the impedance of the battery itself, the battery within the system will appear a lot of kinds of circuits. Battery voltage on the impedance of producing pressure drop, formed in the LISN connected load circuit, a part of the noise signal through the DC-BUS to the ground formed common-mode interference, the other part by load, often forms motor electric control circuit of the formation of differential mode interference, as shown in figure 4, the battery pack of common-mode differential mode in the path of the DC-BUS.

![Figure 3. The battery model.](image1)

![Figure 4. Battery system IDM and ICM analysis.](image2)
In addition, BMS function design is complex, the main function has voltage collection, current collection, temperature collection, balance management and communication. There are many ways to collect voltage and current, which leads to the need for a BMS circuit board. In PCB, there are different levels of crosstalk and conmodular interference between lines and lines.

RADIATION EMISSION TEST AND CORRECTIVE OPTIMIZATION

Before the actual test, general meeting PCB simulation, using SI wave and Designer to joint simulation of PCB, get the PCB level optimization, simulation environment is relatively closer to the ideal test environment, the actual test environment is relatively complex, including the influence of the grounding impedance, the antenna to the receiver of the cable attenuation and other complex parameters affect the actual results, therefore, the simulation is not a substitute for the actual test, the simulation can provide the direction for improvement optimization [5].

As shown in figure 5, the battery system radiation emission test layout in e-chamber.

The Technique of Filter

Adopts π filter design train of thought, the filter principle of π is the difference in the impedance of the shunt capacitance and inductance, the inductance has the very good partial pressure effect, so as to eliminate the effect of noise interference. With Y capacitor for common mode signal has good absorption effect, X capacitor is a good way to filter out differential mode interference signal, the common-mode inductor and the circular form common mode choke coil absorption common-mode interference signals. Because the filter is used for high voltage wiring harness, when selecting capacitance and inductance values to consider capacitance pressure values of inductance and current limit values, to ensure the filter design and filter the clutter signal at the same time will also be able to work in a reliable way. The design of filter is shown in figure 6 below.

The crossover frequency of the LC filter:

In the design of filter, the insertion loss and the turning frequency of the filter should be obtained. Due to the limited volume of inductance, the capacitance is restricted by the gauge, so it is reasonable to choose the inductance device. For the
more resonant curve, the multistage filter is adopted, and more turning frequency is obtained, and the signal of noise absorption is better.

The designed filters should be aware of the following questions when installing:

Filter should be installed in the metal shielding material box, the pick up location in the filter should be good contact and shells, and ensure the filter shell is also good to contact, and to ensure that the contact impedance is less than 100 mΩ. Filter of input and output port should be connect to the coaxial cable center, coaxial cable shielding layer should be connect to the filter metal shell.

**Test Data Comparison**

By table 1 and figure 7 test results show that the peak, 500 kHz will appear resonance point intervals, the resonance point of narrowband signal is stronger, here to determine the resonant peak is caused by switching frequency. In order to solve this problem, it is mainly aimed at the power supply design filter, which eliminates these spikes through the effect of filtering. You should also consider the effects of clock signals, so you should also add filters to some necessary clock signals.

In this, apply to two filters, DC-BUS and 12V low voltage supply lines. For high voltage wire and low voltage wiring harness the difference between voltage and current value, when selecting a capacitance and inductance values should choose appropriate pressure and current limiting value, on the one hand, to ensure a stable job, on the other hand consider the economy. According to the EMI filter design method to design reasonable filter, and ensure the battery system to place well grounded, DC-BUS wiring harness for shielding, low voltage wiring harness, CAN communication, test curve is shown in figure 10, 10 MHZ, the filter for narrow-band signal has very good absorption effect.

The design filter was validated and two sets of experiments were done.

Test 1, the pre-overhaul test curve is shown in figure 7

Test 2: The pre-overhaul test curve is shown in figure 9

![Figure 7. The pre-overhaul test.](image1)

![Figure 8. The pass test.](image2)

**TABLE 1. RE TEST DATA.**

<table>
<thead>
<tr>
<th>Frequency(MHz)</th>
<th>Peak (dBµV)</th>
<th>Average (dBµV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.494250</td>
<td>60.4</td>
<td>60.1</td>
</tr>
<tr>
<td>0.496500</td>
<td>65.6</td>
<td>65.4</td>
</tr>
<tr>
<td>0.498750</td>
<td>67.8</td>
<td>67.7</td>
</tr>
<tr>
<td>0.501000</td>
<td>67.2</td>
<td>67.0</td>
</tr>
</tbody>
</table>
Test results show that 105.75 kHz resonance point, resonant point of overweight is more noticeable, as do the corresponding processing and test 1, get below data after rectification.

Two test results show that the filter design of the resonant point has obvious filtering effect, use $\pi$ filter is a good way to absorb the resonance point of the clutter signal, is a good way to solve the switching frequency resonance problem.

Through the analysis of the data of two tests, to the problem of the resonance point narrow-band interference signal exceeds bid by designing $\pi$ filter, and based on the frequency of resonance point, choose the filter parameters, effective absorption of electromagnetic disturbance EMI, the EMI radiation value below the limit.

CONCLUSION

BMS as three electric control parts of electric vehicles, the features of the product is complex, PCB wiring is diversiform, have made the battery system EMI radiation problem is outstanding.

Analysis of radiation of common mode and differential mode radiation of model, understand the mechanism of radiation, and combined with hardware circuit analysis of power battery common-mode interference and the differential-mode interference of transmission. Design EMI filter to absorb differential noise and common mode noise to eliminate the interference of common and differential mode noise.

In the development process of battery pack, adopt a complete EMC design process is necessary, through the way of using software simulation analysis, the power integrity (PI) and the signal integrity (SI) is applied in EMC design of hardware circuit, and finally through the simulation and practical test method of combining the science of the end product of EMI problems, is an effective for EMC design.

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