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EMC Study and Testing of the Vehicle Management System in Clean Energy Automotive

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***Abstract*—Today, Electromagnetic Compatibility seems to be one of the major constraints of powertrain and especially for Clean Energy Automotive.The major purpose of paper is to get the veracity and repeatability of the testing results, and then to study the theory of RFI/EMI to resolve the interference resource and cut the interfering path. This paper will carry on the theory analysis and design analysis and EMC study aiming at the vehicle management system, at the same time introduce five imperative EMC tests of automotive components in details and analyse the measured results.**

***Keywords*—Vehicle Management System; RFI/EMI Testing; EMSCAN; EMC; Powertrain**

I. Introduction

Electromagnetic compatibility environment of the auto electrical equipment may be coexistent and noninterferential, which calls for the system having good EMI and EMS characteristics. Three factors are indispensable to lead to electromagnetic interference which would degrade the function of electrical equipment or make it lapse: interference source, coupling path and sensitive equipment. And in order to solve the problem of EMC fundamentally, various ways must be taken to inhibit interference source, intercept the coupling path and enhance sensitive equipment Immunity. In the pages we carry on the analysis and study aiming at the vehicle management system EMC of Clean Energy Automotive, and at the same time introduce imperative EMC tests of important automotive components in details and analyse the test results.

II. EMC Analysis in Clean Energy Automotive

In Clean Energy Automotive, the vehicle borne disturbance sources are the fuel cell engine, the fuel cell stack high-pressure system, the DC / DC, the charge and discharge of auxiliary battery, and the powertrain system, etc. The fast transient of voltage and current will generate radiation and noise, so the electronic equipment close to these devices may be in disorder. In particular the rapid rectifier, motor start and high pressure radiation of motor drive modules will cause conduction and radiation disturbances with higher field strength.

Therefore, when designing the EMC in Clean Energy Automotive, we can research on the theory of primary interference source, sense organ and pipeline based on the theory of electromagnetic field initiation and propagation, and then we can build up mathematics model of EMC in automotive environments. According to the model research and simulation analysis, we can provide expected indicators of EMC of practical automotive systems.

A. Mathematics model of EMC in automotive environment

The mathematics model of EMC is built up based on the mathematical equation of spatial electromagnetic field distribution which is established according to the electromagnetic field characteristics, Maxwell equation, and automotive appearance, etc. The model requires that some data, such as the shape parameters, and the number, location (location in and out), frequency and intensity of the interference sources, can be changed easily. The function of local electromagnetic screen and the effect of multiple reflection and refraction (transmission) of the automotive covering should also be considered.

B. The automotive EMC simulation analysis

The simulation analysis of primary interference source, sense organ, etc based on the mathematics model of automotive EMC shows the spatial electromagnetic field distribution and confirms the amplitude frequency characteristic curve. The output of various methods of contrast curve can be based on the advantages and disadvantages of researching various EMC preventive methods in automotive working environment and the measures of restraining the disturbance initiation and propagation.

The mathematical model established needs more than 3 simulation analyses of practical systems. Simulation analysis results should consist with the actual test results, and the maximum error of specific point cannot be beyond± 5 dB.

Further FCV EMC design is based on this. The initial study of electromagnetic compatibility design should be conducted:

The analysis of the interference source (the initiation, nature and characteristic of interference);

The transmission mode and approach of interference signal;

Interference Effects (the corresponding response characteristics between equipment and interference signal);

Methods and measures to limit interference;

The measurement and calculation of interfere;

Simulation of interference (reappearance of interferencecondition and simulation of interference mechanism);

Immunity test expected (limit of interference, testing method and evaluation criteria).

There are two kinds of interference sources in driving vehicles. One is the radiation disturbance source outside vehicles, and the other is inside. Its manifestation is mainly based on the spectrum characteristic of the interference source, for instance, the narrow band interference sources, such as radios, receivers, industrial high-frequency generators, etc; The intermittent broadband interference sources, such as the internal combustion engine vehicles passing by, high-altitude (underground) high-tension lines, rectifier motors , etc; the transient broadband interference sources, such as electrostatic discharge, LEMP (Lightning Electro Magnetic Pulse), etc.

There is no active protective measure for the outside interference sources, so the EMC design for the vehicle is a passive protection design, namely, the transmission modes and defensive capabilities. For the interference sources in vehicles, interference sources of the interference parts can be restrained by the usage of screen, buffers, and soft-switching.

There are several ways of electromagnetic coupling approaches, which include electrical couplings with resistive and capacitive characteristics, magnetic couplings with inductive characteristics and radial couplings with the characteristics of high-frequency radiation. Interferences in vehicle, such as the start-up and acceleration of the fuel cell engine, the charge and discharge of the auxiliary power supply and the motor driver power of the powertrain system, will interfere with the devices nearby with the mode of electrical couplings or emit conduction disturbances to interfere with power lines, as well as other parts of communications and entertainments like radios in vehicles. The devices, such as the high-pressure fuel cell stack system and DC / DC, will have strong RF radiation in the work mode conversion. If the standard limit is exceeded, a radial pollution will be generated to outside.

In Clean Energy Automotive, a number of radios, audio entertainment systems, navigation equipments and some low-voltage, micro-signal controllers are electromagnetic sensitive devices and may be damaged by the transient interference or electrostatic discharge. According to the characteristics of the interference source, the methods of screen, spectrum spread and common grounding can be taken to enhance electromagnetic defensive capabilities.

III. EMC DESIGN OF VEHICLE MANAGEMENT SYSTEM IN CLEAN ENERGY AUTOMOTIVE

VMS, namely, the powertrain controller, as the vehicle management center, mainly includes functions, such as the control of driving torque, the optimization control of braking energy, the automotive energy management, the maintenance and management of CAN network, the diagnosis and treatment of fault, the surveillance of automotive state and etc. It plays a role in controlling the operation of vehicles.

There are serious interferences in the VMS applicable environment where a variety of noises and coupling approaches exists. Therefore the VMS has not only perfect functions but also strong anti-jamming capability. The following EMC design methods can be used to inhibit it.

A. Grounding

The grounding of VMS primarily aims at resisting the outside interferences, so it is a signal grounding. It adopts a "full grounding" approach, which means all of the places are grounded, except the room occupied by transmission wires and components, to reduce the resistances and also to play a role in screen. The distance between the earth wire and the signal wire is only the distance among the wiring board layers. The high-frequency circuit always chooses the shortest path of signal loop to flow. Therefore, the actual current always flows in the surface the earth wire below the signal wire. Thus the smallest signal loop is formed naturally to reduce the difference-mode radiation.

B. Isolation

The electromagnetic isolation of VMS adopts the whole photoelectric isolation of input and output. Because of the optocoupler with a low impedance input (generally 100Ω to 1KΩ) and a strong interference, the interference voltage transmitted to the optocoupler becomes low. Because the internal resistance of interference source is very high, the interference voltage with low energy could only produce weak current, which is not strong enough to make the diode light; although it has very high voltage, the interference could not generate enough energy to make the diode light; therefore, the interference is restrained. The optocoupler operates in a sealed tubal crust, so it doesn't suffer from the outside influence.

C. Filter

The main factors that cause the VMS out of work are the sensor fault and external interference signal. For analog signals, the normal output is in a certain scope, so when designing the EMC, we usually adopt low pass filters to stop the high-frequency signals.

Additionally, the high-speed jumping digital signal will produce the impedance noise, so when designing the EMC of the VMS, the method of adding filters to the power ports is usually used to suppress the power noise. The large-capacity capacitor is used as the high-pass filter, and the small one as the low-pass filter.

D. PCB design

The circuit template of the VMS adopts the design of six layers of circuit board, compared with the double-sided PCB, adding up the earth layer and power layer. The power plane should be closed to the grounding plane and below the grounding plane. Thus the grounding plane can play a shielding role to the radiation current distributed on the grounding plane. The power layer and the narrow space between the signal wire and the grounding wire can reduce the common-mode impedance and inductance coupling. Because of the little crosstalk between signal wires of two layers and the narrow space between the power layer and the grounding layer, the impedance is very low and suitable for power noise decoupling.

E. Other methods

The highly integrated circuit components can reduce the number of components on the PCB and simplify the layout of the PCB. As a result it can greatly reduce the failure rate and the probability of interference.

Another one is the derating use of components. The derating design means the components working in lower rated stresses, and the stresses impacting the system operation include: electric stresses (voltage, current, power, frequency and etc.), temperature, mechanical stresses. When the working stress is higher than rated stress, the failure rate will increase. A reasonable derating is an effective method to improve the reliability of the components and parts.

IV. EMC Testing of Vehicle Management System in Clean Energy Automotive

A. Emission measurements

According to the transmission routes, emissions can be divided into conduction emission and radiation emission. Both of the emission measurements follow the standards of GB18655 and CISPR 25:"Limits and Methods of Measurement of Radio Disturbance Characteristics for the Protection of Receivers used on Board Vehicles".

1) Conduction emission

The purpose of the test is to verify whether the controller will generate interferences beyond limits which may interfere with the other vehicle electronic components through the same power supply loop. The frequency measuring range is from 0.15 MHz to 108 MHz. The test layout is shown in Figures.1: the external lines of the controller should be well connected to meet the test conditions, and the power line length is 0.2 m.

The test is based on GB18655-2002, chapter 4 of the first part, "General Requirements of Emission Measurement for Vehicles and Components/Modules"; chapter 6, "Test Equipments only for Components/Modules Test" and chapter 11 of the third part, "Conduction Emission of Components / Modules"; chapter 12 of the third part, "Limits of Conduction Disturbance of Components". And the test is used to measure the interference intensity of conduction electric field produced by the power line of ECU, and ensure it under the set limits (TABLE Ⅰ).

The test results are shown in Figures.2: parts of the results in the low frequency around 600k overstep the limit of class 1, and in the high frequency from 30M to 108M, they all overstep the limit of class 1.

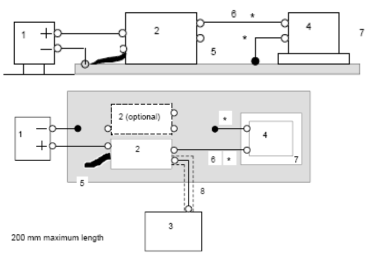

Figure 1. Test layout of conduction emission

1—storage cell; 2—line artificial-mains network and load; 3—measuring instrument; 4—controller; 5—grounded plane; 6—testing line pencil; 7—insulating layer (50mm); 8—coaxial cable(50Ω)

TABLE I.
LIMITS OF CONDUCTION EMISSION

class	Limits of conduction emission (dB/μV)				
	0.15MHz-0.3MHz	0.53MHz-2.0 MHz	5.9MHz-6.2MHz	30MHz-54MHz	70MHz-108MHz
	P	P	P	P	P
1	90	66	57	52	42

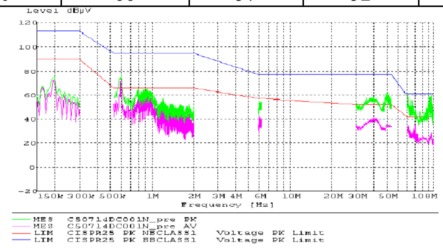

Figure2. Conduction emission measurement

2) Radiation emission

The purpose of the test is to detect whether the radiation disturbance will interfere with the vehicle wireless communications and other electrical devices. The frequency measuring range is 0.15 ~ 960 MHz. The testing layout is shown in Figure.3: the peripheral circuit of the controller should be well connected to meet the test conditions. The length of the power line and signal wire is 1.5m.

The test follows the standard of GB18655-2002, chapter 4 of the first part, "General Requirements of Emission Measurement for Vehicles and Components / Modules"; chapter 6, "Test Equipments only for Components / Modules Test" and chapter 13 of the third part, "Radiation Emission of Components / Modules"; chapter 14 of the third part, "Limits of Radiation Disturbance of Components". And the test is used to measure the interference intensity of radiation electric field of ECU, ensure it under the set limits (TABLE Ⅱ) and simultaneously avoid interfering with other electrical systems inside the vehicle.

The test results are shown in Figures.4, Figures.5 and Figures.6: The tested ECU measures up to the standard limit in the low frequency band, while around 80M and 400M in the high frequency band, vertical polarization, it oversteps the limit of class 3.

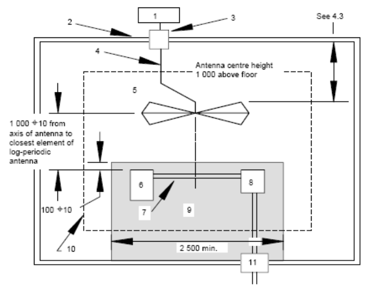

Figure3. Test layout of radiation emission

1—measurement receiver; 2—absorbing shielding room; 3—separator connector; 4—double layers shielding coaxial cable; 5—antenna; 6—controller; 7—testing line pencil; 8—line artificial-mains network; 9—experimental table; 10—radio frequency absorbing materials; 11—power filter

TABLE Ⅱ
LIMITS OF RADIATION EMISSION

class	Limits of radiation emission (dB/μV)									
	0.15MHz-0.3MHz		0.53MHz-2.0 MHz		5.9MHz-6.2MHz		30MHz-54MHz		70MHz-960MHz	
	P	QP	P	QP	P	QP	P	QP	P	QP
3	76	63	67	54	48	35	48	35	37	24

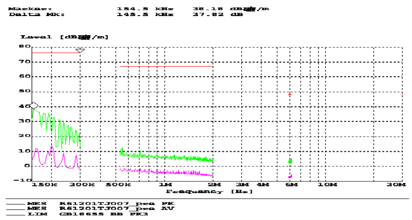

Figure4. Radiation emission measurement in low frequency band (0.15~30MHz)

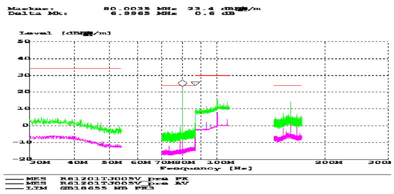

Figure5. Radiation emission measurement in high frequency band （30~300MHz; horizontal polarization）

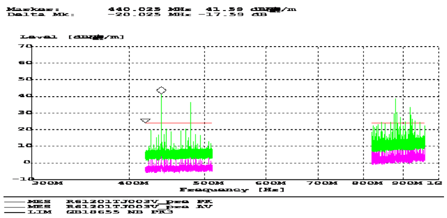

Figure6. Radiation emission measurement in high frequency band （300~1000MHz; vertical polarization）

B. *Immunity measurements*

1) Bulk current injection

The purpose of the test is to detect whether the discharge and strong magnetic radiation from the other vehicle controllers will make the control performance depreciation or lapse. The testing standard is ISO11452:"Road ISO Vehicles-Electrical Disturbances by Narrowband Radiated Electromagnetic Energy-Component Test Method". The current frequency range is 1~400MHz, continuous sine wave modulation, 1KHz 80% and current residence time is longer than 1 second. Testing distance is 1.5 m. The testing layout is shown in Figure.7: the test is done by the usage of the set current class and increasing the induction signal frequency, and the current injection probe is induced on the connection line pencil directly.

As the controller is metal sealed, the whole controller has a good anti-interference screen. It has a strong immunity against the outer electromagnetic radiation, so the most probable interference for the controller is the radiation or conduction interference produced by various feedback lines.

According to part 4 of ISO11452:"Bulk Current Injection", the test is to verify the immunity of the ECU when the interference is a common mode current produced by radiation electromagnetic field. Test result is A, shown in TableIII.

2) Electrical transient conduction immunity

The purpose of the test is to verify the ability of every working controller to resist the interference of varied transient pulses which would appear when controllers work in the same power supply circuit, such as charge and discharge of the power; high-power motor start; engine start, etc. The testing standard is ISO11452:"Road Vehicles-electrical Disturbances by Conduction and Coupling". The testing layout is shown in Figure.8. The controller meets the testing conditions. Then the following tests have been done by simulating various vehicle field interferences:

① The test for the power lines is designed by five methods, 1, 2a, 2b, 4 and 5 of ISO7637.

② The test for CAN and I/O port is designed by the methods of 3a and 3b of ISO7637.

Other electrical apparatus (or equipments) in the same power supply circuit would produce transient disturbance pulse group when working, and the turnon or turnoff of certain high-power motors would produce transient disturbance pulse surge, which may reduce the voltage of the whole power system. All these interferences may make the controller lapse. In addition, engine starter motor excitation would lead to voltage drop of the entire power supply system and directly interfere with the controller. Therefore, this test must be done to verify the immunity.

According to part 2 of ISO7637:" Commercial Vehicles with Nominal 24V Supply Voltage-Electrical Transient Conduction along Supply Lines Only", the testing item is to verify the ECU immunity against transient conduction electromagnetic field interferences.

Figure.9 shows the transient voltage interference waveform, and the measured results are eligible, shown in TABLE Ⅴ.

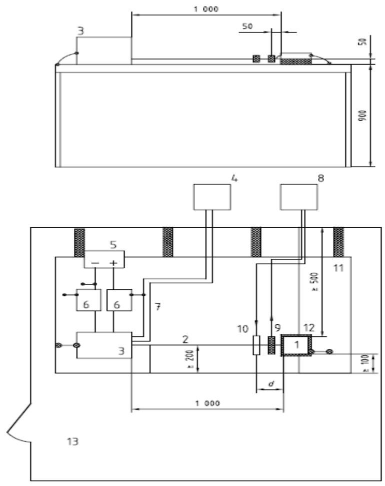

Figure7. Test layout of bulk current injection
1—tested controller; 2—testing line pencil; 3—analog load; 4—observation device; 5—power supply; 6—line artificial-mains network; 7—optical fiber; 8—radio frequency transmitter; 9—radio frequency feedback probe; 10—radio frequency injection probe; 11—grounded plane; 12—insulator; 13—shielding room;d—distance between tested controller and radio frequency injection probe

TABLEIII
TEST RESULTS OF BULK CURRENT INJECTION

Testing state of specimen: normal （fan loads）		Dwell time: 3s	Working voltage of test: DC + 13.5V	
Stepping:1~10MHz:1MHz; 10~200MHz:2MHz; 200~400MHz:20MHz		Modulation：CW；AM，80%		
Class (mA)	Distance to EUT （mm）	Frequency range （MHz）	Perform-ance criterion	Testing result
100	120,450,750	1~400	A	Accord

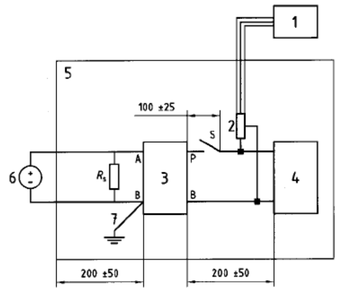

Figure8． Test layout of electrical transient conduction immunity

1—waveform generator; 2—voltage probe; 3—line artificial-mains network; 4—tested equipment; 5—grounded plane; 6—power supply; 7—grounding line

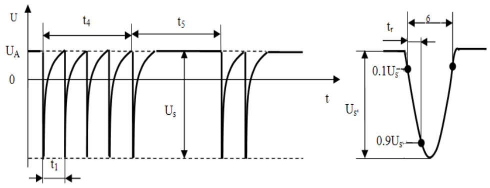

Figure.9 transient interference waveform

TABLEⅣ
PARAMETERS IN FIGURE.9

parameter	12V system
Us	-112V — -150V
Ri	50□
t6	$(0.1_0^{0.1})$ us
tr	5ns ±1.5ns
t1	100
t4	10ms
t5	90ms

TABLEⅤ
TEST RESULTS OF ELECTRICAL TRANSIENT CONDUCTION IMMUNITY

Testing state of specimen: normal operation (fan loads)				Working voltage of test: DC + 13.5V （pulse 4 is12V）	
Coupling line: power line				Coupling approach: CDN	
Testing waveform	Class /polarity	Pulse number	Testing time	Pulse cycle	Performance criterion
Pulse 1	-75 V	1000	/	2s	B
Pulse 2a	+35 V	1000	/	1s	A
Pulse 2b	+10 V	10	/	5s	B
Pulse 3a	-112V	/	1800s	100ms	A
Pulse 3b	+75 V	/	1800s	100ms	A
Pulse 4	-6 V	1	/	2s	B
Pulse 5	+65 V	1	/	45s	A

3) Electrostatic discharge

The test is to verify whether the heavy current and strong magnetic field produced by body contaction or object discharge nearby will damage the controller. The reference standard is ISO10605:” Road Vehicles-Electrical Disturbances from Electrostatic Discharge”. Testing voltage, discharge times and discharge interval separately are ±15KV, 3 times and 5 seconds. The test layout is shown in Figure.10: make sure the controller is out of work and adopt indirect discharge. The discharges to the coupling plate near the tested object are carried out by the discharge gun. Test result is show in TABLE Ⅵ.

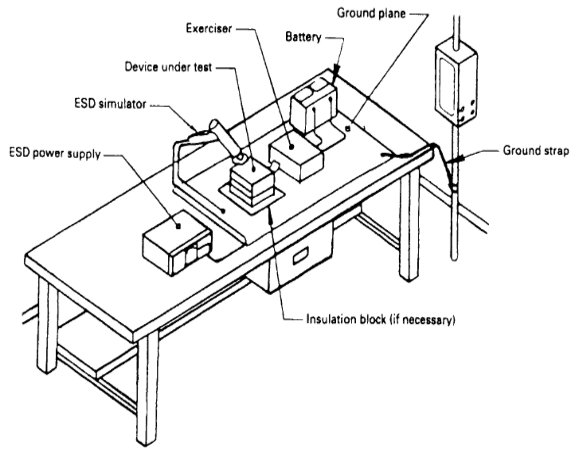

Figure10． Test layout of electrostatic discharge

TABLEⅥ
TEST RESULTS OF ELECTROSTATIC DISCHARGE

Testing state of specimen: no electric charges			Power type: DC 12V	
Discharge times: 3 times plus and minus / position			Discharge interval: 5s	
Discharge mode	Discharge position	Class (KV)	Testing phenomenon	Performance criterion
Direct discharge (air discharge)	Stitch	15	Normal work after electified	B

The high voltage electrostatic discharge may produce heavy current, high voltage and strong magnetic field when the body or other objects closing to or contacting the surface of the electrical equipment, which may make the electrical equipments ineffective or even lose their functions. In other words, electrostatic discharge may interfere with the working equipments or systems and even damage them, so it is necessary to do the immunity test for electrostatic discharge for the VMS.

According to part 5 of ISO10605:” Test Procedure for Electronic Module”, the purpose of the test is to verify the ECU immunity to resist electrostatic discharge produced by body. The measured result satisfies the standard.

V. CONCLUSIONS

The test results of conduction and radiation emission overstep the class 2 limits. The improvement measures are based on the measured results and analyses.

A. Analyses and improvements for conduction emission

The reasons for the over standard of conduction disturbance emission might include: 1. The DC / DC converter working in the switching power supply circuit at pulse state would lead to strong interference; 2. The working current of the digital circuit in the controller circuit board is transient. Although decoupling capacitors are set on every circuit board and beside every circuit chip, part of the transient current will still interfere with the power supply, transmitting along the power line. 3. The internal circuit board of the controller will likely generate radiation, whose energy will be induces into power lines and power supply circuit itself, forming conduction emission.

In order to improve characterization of conduction emission, power line filters with better high-frequency performance should be installed at the entrance of the power line; otherwise it would lead to the problem of radiation emission. To find the possible jamming areas of high-frequency currents and radiations, we use near-field probe and spectrum analyzer or specialized near-field scanner (e.g., EMSCAN) to scan the circuit board. We fix suitable decoupling capacitors and improve the circuit board layout to solve these problems. The modified controller satisfies the class 2 limits and the test result is shown in Figure 11.

B. Analyses and improvements for radiation emission

The reasons for the over standard of radiation disturbance emission might include: 1. The external non-shielded cable of the controller, without filtering, may become radiation source because of its potential common mode current; 2. Power lines with undesirable high-frequency filtering may be caused by power line with no filters or the filters with bad high-frequency performance; 3. The shielded cable with bad shielding layer terminations may be caused by misconnecting the shielding layer or not contacting the terminals in accordance with the principle of 360° termination; 4. Leaks will be formed by the cracks or holes in the shielding shell of the controller.

The following measures are taken: the layers of PCB increase from 6 to 8 and the high-frequency noise is decoupled by the coupling capacitance formed between integrated power supply and ground；meliorate the layout of the circuit board and place the components more reasonably to prevent the interference between different circuits; some electromagnetic interference suppression components are added. The test results of the radiation emission before and after revised are shown in Fig.12. They show that these measures greatly reduce the intensity of radiation and improve the electromagnetic compatibility.

Frequency scanning result of the revised circuit board is shown in Fig.13: the harmonic order is quite high, and the highest one based on 40MHz is 25th or even more. The reason is that the data bus and address bus between U26 [CY7C1347B] and U1B [MPC555LFMZP40] do not take into account impedance matching and EMC. And the impedance matching between A2-A20 and D0-D31 should be added (Propositional resistance is 33ohm and it should be adjusted according to the actual test result). And Figure14 shows that the controller has measured up to the class 2 limits.

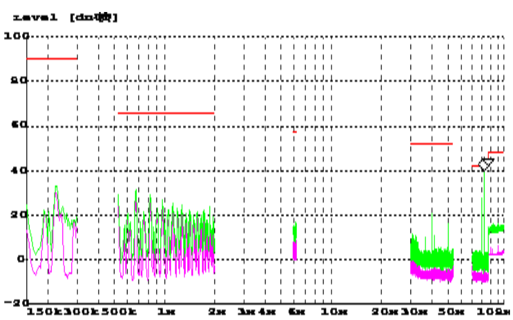

Figure11. Final conduction emission measurement

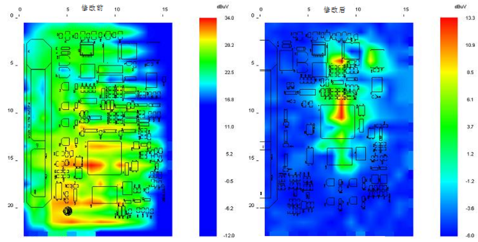

Figure12. Radiation emission measurement (the right one is the modified one)

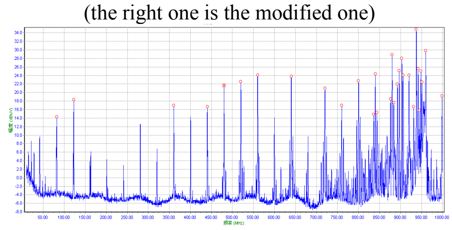

Figure13. Frequency scanning on the revised circuit board

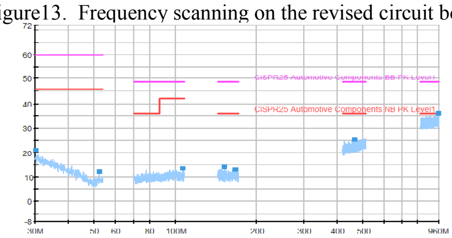

Figure14. Final radiation emission measurement in high frequency band （vertical polarization, wideband）

C. Rectification measures

Aiming at the analyses of the tests above, the following improvement measures for the controller PCB are adopted: 1. A common mode filter (ACM1211 produced by TDK) for the power line, is fixed at the entrance of the PCB power (12V supply); 2. In the power circuit, a magnetic bead (HF××575018 produced by TDK) is fixed at the entrance of the circuit transforming 5V into 3.3V; 3. A special common mode filter for CAN (ACT45B-510-2P produced by TDK) should be added to the bus interface. With the above measures adopted, tests can be passed.

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