Analyse and Research of Radiated Emission on PCBs

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***Abstract*-This paper presents a study of radiated emission's mechanism and radiated electromagnetic field estimation. Based on the electric dipole module, two sorts of module which could explain the mechanism of radiated emission are proposed. Furthermore, through utilizing EMSCAN system, a simple approach is presented for estimation of radiated electromagnetic field generated by radio frequency current in the cable. This paper also summarized an EMI diagnosis method. According to this method, we could easily find the source of radiated emission, which is the basic and important part of EMC improvement. The experimental research shows that radiated noises decrease obviously after circuit improvement. Therefore, the presented approach proves effective and efficient.**

Key words: EMC; EMSCAN; PCB; EMI

I. INTRODUCTION

Nowadays, with the development of PCBs, the EMC problem is becoming more and more serious. Therefore, a lot of electronic devices will be required to pass the standard test of EMC which is quite strict. EMC is composed of EMI which includes RE and CE and EMS which includes RI and CI. This paper focuses on how to solve the radiated emission problems.

II. COMMON MODE RADIATION ON THE CABLE

The common mode radiation is produced by common mode voltage, and it can be divided into two sorts according to the difference of the production mode. One is the noise voltage between the cable and the ground, which is produced by the differential mode circuit due to some special reasons, and the other one is the noise voltage which is inducted on the cable by dimensional electromagnetic radiation. The former is mainly caused by the badness of PCB design, and the latter belongs to the problem of environmental noise. This paper mainly focuses on the former.

The problem of electromagnetic radiation on the cable, caused by PCB's common mode noise voltage, could be described by a electromagnetic radiation model as Fig. 1[1].

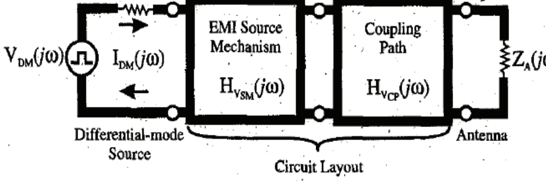

Fig.1. Electromagnetic radiation model

There are two sorts of production form about the common mode noise voltage on the PCBs. One is the voltage drop formed in the returned path because of time-varying current (differential mode current). The other one is directly from the differential mode voltage of the circuit(such as IC's some pins or the differential mode voltage in the connector). The modes whose common current is caused by these two kinds of noise voltage are named as current-steering mode and voltage-steering mode respectively[2]. These two kinds of mode could well explain the reason why the common mode current will be produced.

A. Current-steering mode

Fig. 2 can explain the current-steering. V_{DM} represents the differential driving voltage in the circuit. L_{signal} is the equivalent inductance of signal cable in the circuit. L_{return} is the equivalent inductance of signal cable in the returned circuit. R_l is the load. C_{ant} is the stray capacity between the extension cable. The left conductor (can be imagined as the metal shell of the controller)and the circuit(represents the circuit of the controller) constitute a controller, and the right conductor is the cable which connects with the controller. Both the conductor of the cable and the metal shell of the controller has the stray capacity refer to the GND[3]. The total capacity is C_{ant}. C_{ant} decides the impedance that the common current will meet. As the current frequency is 1GHz, the impedance of a 1pF capacity is more or less 160Ω.

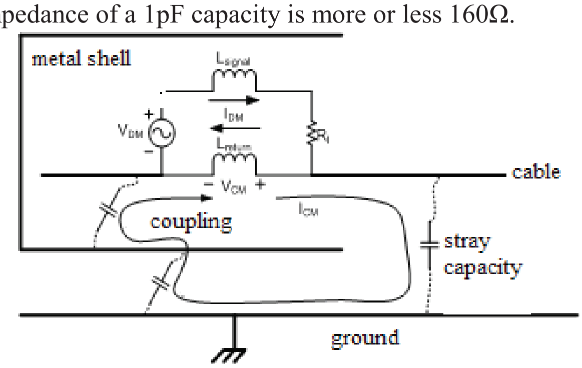

Fig.2. current-steering mode

The time-varying signal current di/dt(probably includes differential mode noise current) will run back to the signal source through the load along the returned path, and the returned current will produce the voltage fall V_{CM} on the inductance along the returned path(The returned path is uncertainly the ground, because for the current which has above 100KHz frequency, the returned current will choose the nearest conductor from the signal cable as the returned path)[4].

$$V_{CM} = L_{return} \frac{di}{dt} \qquad (1)$$

As the conductor (that is the dipole antenna as radiation emission antenna) drived by the common-mode source, V_{CM} can produce I_{CM}. C_{ant} provides the returned path for I_{CM}.

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When the cables power size is on the small side (less than 0.1 times wavelengh), I_{CM} will distribute nearly evenly along the cable. Thus, we can write down the expression of the common-mode current according to the traditional circuit theory.

$$I_{CM} = j\omega C_{ant} V_{CM} \quad (2)$$

Because V_{CM} is produced when the differential-mode current flow through the impedance in the return path. Thus,

$$V_{CM} = j\omega L_{return} I_{DM} \quad (3)$$

Suppose the load impedance R is far bigger than the returned signal circuit inductance L_{loop} $L_{loop} = L_{signal} + L_{return}$) , provided that the signal frequency do not reach the resonant frequency, thus,

$$I_{DM} = \frac{V_{DM}}{R} \quad (4)$$

In this way, we get a final expression of common-mode current:

$$I_{CM} = -\frac{\omega^2 C_{ant} L_{return} V_{DM}}{R} \quad (5)$$

From the expression(5), we can see that the differential signal voltage and the load has been decided by the circuit design demand, the stray capacity which is part of the returned path has been also decided by the placement of the controller, dummy load box and the ground. As a result, the only way to control the common-mode current is supplying a returned path which has low impedance for the signal. That means reducing L_{return} as much as possible.

B. Voltage-steering mode

The voltage-steering mode can be explained by Fig. 3. The differential voltage could drive the common-mode circuit directly and, in this way, the common-mode current is produced.

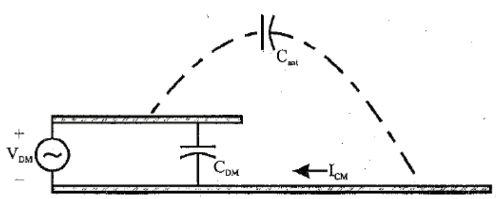


Fig.3. voltage-steering mode

There are two pieces of conductor. The top one and the part of the below one which is just below the top one can be considered as the interior of the controller. The extending part of the below conductor can be considered as the conductor of the radiation emission's antenna. As Fig.3 shows, V_{DM} is the differential mode voltage between the two parts of the controller, and C_{DM} is stray capacity between them, and this two pieces of conductor constitute a differential mode returned path. There is some stray capacity between the conductor with the reference ground. Otherwise, there is also some stray capacity between the above conductor and the surrounding of the controller. Therefore, the returned path is composed of the stray capacity Cant between the cable and the above conductor. When the impedance of the returned path is less than the one of the differential mode returned path provided by CDM, VDM will produce the common mode current in this returned path. The current flows from the cable, then returns to the voltage source through the stray capacity.

III. EMSCAN SYSTEM

EMSCAN is a world leading developer of fast magnetic near-field measurement tools which can access to all the Electromagnetic information of EUT(Equipment Under Test).EMSCAN system (see Fig. 4) contains a customer workstation (PC/laptop), ISM Scanner Module, a Nexus Plus Controller, Agilent E4403B spectrum analyzer and a Nexus Plus EMSCAN user interface software. Controller controls the acquisition of data from the scanner module, measurement of data by the spectrum analyzer and transfer of data to the customer workstation. Spectrum analyzer measures the radio frequency (RF) signal received from scanner module. Customer workstation receives data using Ethernet link from controller and Nexus Plus software enables user to interact with the controller to gather, display and store scan data. Controller builds in high speed digital / analog converter card to transfer RF signal into digital signal at a high speed of 30,000 per second which greatly improves the accuracy. ISM Scanner Module is composed of 1280 H-field loops, arranged in 32×40 array. Each of the loops is located in the 7.6mm×7.6mm rectangular grid, ordered by chevron.

Fig.4. EMSCAN Nexus Plus system

EMSCAN is thousands of times faster than traditional method such as current probe measurement and is a powerful diagnostic for the EMC engineer enabling him to quickly identify problem areas on the PCB due to switching on one of the loops and the RF voltage automatically. By mapping both the path and intensity of every high frequency current flowing on a PCB at a user-selected frequency, EMSCAN can test time-dependant EMC problems, called time-synchronous measurement[5].

This paper uses the F-55 current probe based on Ampere's law to measure common mode current. The F-55 is usable from 10KHz to 500MHz, produced by FCC corporation. It is an electrical device having two jaws which open to allow clamping around an electrical conductor. Once passing a conductor carrying power through the probe, the current produces the magnetic field around the jaws. According to Faraday's law, the induced electromotive force (EMF) in the closed circuit is equal to the time of rate of change of the magnetic flux through the circuit. This allows properties of the electric current in the conductor to be measured, without having to make physical contact with it, or to disconnect it for insertion through the probe.

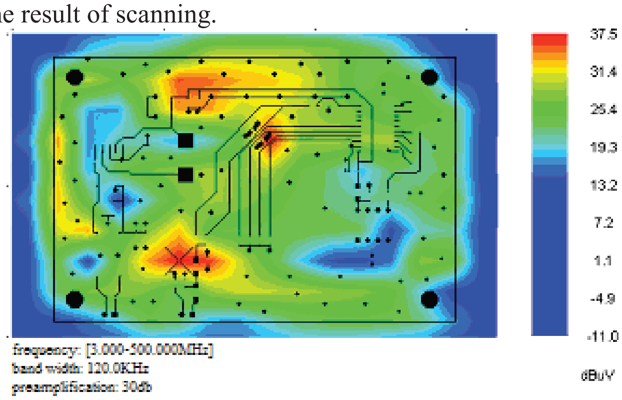
IV. Experiment Result and Analysis

A. *Current-steering mode*

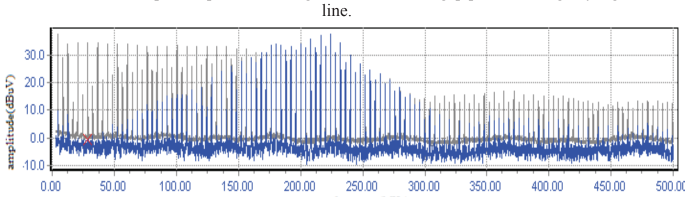
This experiment uses a two-layer board. A 4MHz crystal oscillator provides a square wave signal to four input pins of 74HC540. 74HC540 inverts the signal, and is connected to a 65-Ω resistor by a long cable, while the other input pin is pulled low, and the corresponding output pin will export a high level signal of 5V. The back of the board contacts with the ground. However, there's a gap near the edge of the board and the cable connector while the level signal of 5-volt passing through the gap. Each of the signal conductor and signal ground connects with a decoupling capacitor of 10nF in parallel. The other side of the capacitor connects to the ground.

The high level signal of 5V and GND are connected with a 10-KΩ resistor by a cable of 1.3m. A battery of 9V supplies the power of the circuit board in order to avoid power supply equipment and power cable affecting the results of experiment. Current probe is placed at a stationary location to measure the common mode current carried by the two cables, and connected with spectrum analyzer which can directly display the frequency spectrum by a coaxial cable of 50-Ω.

First of all, EMSCAN measurements of circuit board at work are performed in the near-field regions.Fig.5 illustrates the result of scanning.



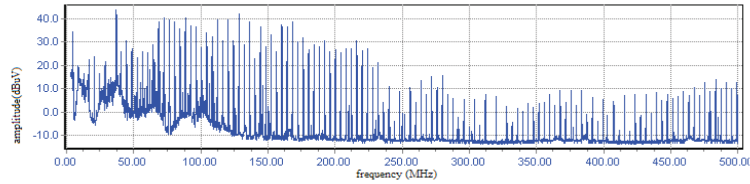
a. Near-field composite spatial scan. Signal × refers to the gap passed through by signal line.



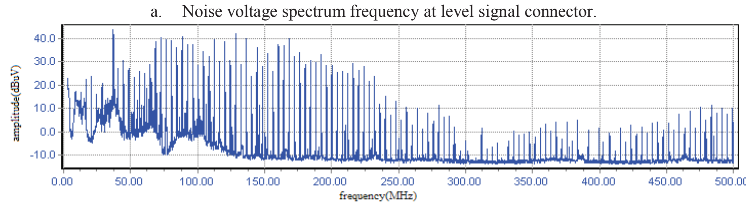
b. Comparison of spectrum frequency of the mark point and whole circuit board.

Fig.5. Near-field spectrum frequency of Circuit board

The result of scanning presents that strong near-field radiation really occurs at the gap which means noise current exists. This current will generate noise voltage on the ground, coupling with cable voltage. It can be detected by voltage probe that the frequency spectrum of coupling noise voltage at cable connector (see Fig.6).



a. Noise voltage spectrum frequency at level signal connector.



b. Noise voltage spectrum frequency at signal ground connector.

Fig.6. Noise voltage spectrum frequency at signal line connector measuring by voltage probe using a bandwidth of 120KH from 300MHz to 500MHz

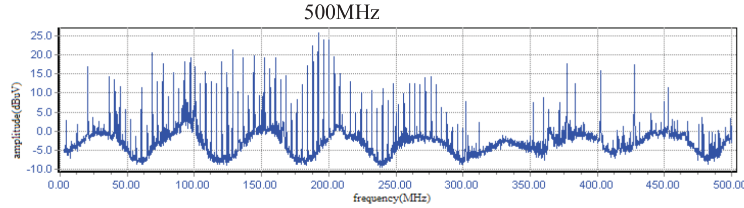
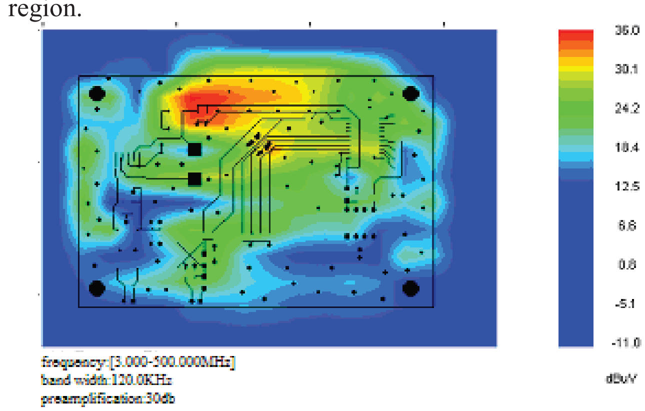


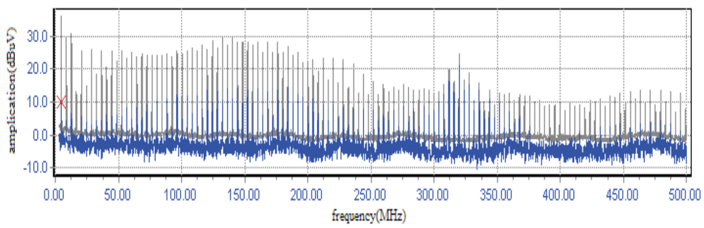
Fig.7. Common mode current spectrum frequency at cables measuring by voltage probe using a bandwidth of 120KH from 300MHz to 500MHz

Fig.7 presents the scanning result of frequency spectrum of common mode current at the cable. It shows that the frequency spectrums of common mode current and noise voltage at cable connector don't correspond exactly which may be due to that cables can't radiate emissions to noise voltage at some frequencies and the common mode current at the cables generated by noise voltage may be much less.

In order to verify that the noise voltage at the gap generates common mode current at the cables, we insert a capacitance of 220-pF near the signal cable in the gap. Two ends of the capacitance are connected to the ground. Set up a near-field scan again and the results are showed in Fig.3.18. It's evident that the users composite spatial view shows near-field radiation at the gap has already been reduced by 20dBμV at 200MHz. Although near-field radiation emission of the whole are still strong (see the grey part in Fig.8b), peek amplitude at 200MHz are much lower than before. It means noise voltage at the gap generated the near-field radiation emissions in this region.



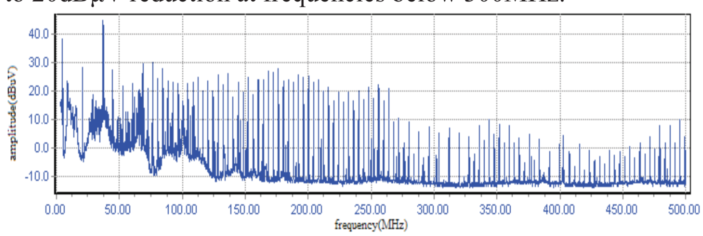
a.Near-field composite spatial scan. Signal × refers to the gap passed through by signal line.



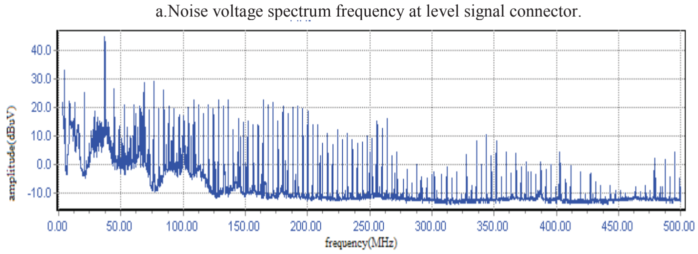
b.Comparison of spectrum frequency of the mark point and whole circuit board.

Fig.8. Near-field spectrum frequency of Circuit board

Decoupling capacitor inserted provides a returned path of low impedance along the signal line for the high-frequency current of signal lines. Thus noise voltage of the impedance on the returned path is reduced. It's also proved by the spectrum frequency of noise voltage at the signal connector measuring by voltage probe (see Fig.9), with the peak amplitude from 10 to 20dBμV reduction at frequencies below 300MHz.



a.Noise voltage spectrum frequency at level signal connector.



b.Noise voltage spectrum frequency at signal ground connector.

Fig.9. Noise voltage spectrum frequency at signal line connector measuring by voltage probe using a bandwidth of 120KH from 300MHz to 500MHz

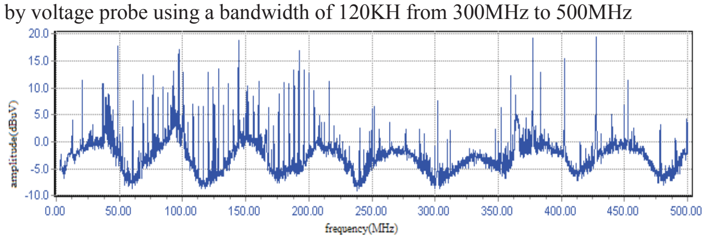


Fig.10. Common mode current spectrum frequency at cables measuring by voltage probe using a bandwidth of 120KH from 300MHz to 500MHz

Fig.10 shows spectrum frequency of the common mode current at cables. Compared to the last scan, reduction of common mode current reduced a lot at the range of 150MHz to300MHz where the reduction of near-field radiation amplitude happened. It further confirmed that the noise voltage generates the common mode current measuring before decoupling capacitance inserted at these frequencies. And the noise voltage is produced by the differential-mode current flows through the impedance in the returned path. So we can figure out that this kind of common mode current is current-steering mode.

B. Voltage-steering Mode

There're two signals in the Prototype circuit interface of VMS: Digital I/O 1 and Digital I/O 2, using to transfer information between two controllers. A filter capacitance of 10nF is connected in parallel so the signals can be obtained directly from the I/O pin of the SCM without passing through any other circuits. These signals will couple with strong noise inside the SCM and produce common mode noise voltage. It's proved that high noise voltage really exists on the pins by measuring voltage of the two signal pins using voltage probe.
Spectrum analyzer shows the peeks at 360MHz before and after the aerial cable touching the digital I/O 1 and 2 measuring by a current probe. Compare the two peeks and we can find a 19dBμV increase in the common mode current, which indicates that the coupling noise voltage causes the increased common mode radiated emission. As a result of noise voltage deriving from the SCM, it can be concluded that voltage drives to generate the common mode current on the connecting cable.

A principle of designing circuit board can be obtained from the above case that SCM pins can be connected to the cable connector pins only after filtering such as concatenating LPF near the SCM.

V. CONCLUSION

This paper analyzes the produced mode on the circuit board of the common-mode current which contributes a lot to the radiated emission. That is voltage-steering module and current-steering module, which provides the theoretical basis for restraining the common-mode current. Based on this, a diagnosis method on radiated emission is proposed. The experimental research shows that radiated noises decrease obviously after circuit improvement according to the method. Therefore, the presented approach proved valid and efficient.

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