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Research on the magnetic property of high-speed PCB design

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ABSTRACT

The design of the electronic system mostly enters the area of nano-sized high-sized high-speed. The clock frequency becomes higher and higher, which makes even a very short wire becoming the transmitting antenna possible. Then the wire radiates to the space as to form the electromagnetic interference(EMI). Along with the constantly improving of electronic system property, the problem of electromagnetic property of PCB will be the key to the success of high-speed circuit system design. In order to conquer the problem of electromagnetic interference(EMI) and explore rational way of high-speed PCB design, the paper, using the field theory as the analysis method, together with the electromagnetic simulation software Designer and HFSS and SI-wave, it carried on the theoretical research and the simulation analysis of the essence and condition of the cause of EMI in high-speed PCB and the method of restraining interference. It selected the minimum control system of PCB built by TMS320VC5416 chip of IT Company as the research object, conducted researches on the electromagnetic property. In the end, using the actual high-speed circuit, a minimum control system of PCB built by TMS320VC5416 chip, the paper did field simulation analysis and got the current distribution pattern and the EM near-far field distribution pattern. Based on the analysis, PCB design is optimized to obtain products with better electromagnetic property. It provide a fantastic approach to the high-speed PCB design.

Key words: Electromagnetic Property; Field Analysis; Designer; High-speed PCB Design

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INTRODUCTION

As the information technology has a high-speed development, the electronic system has finish its high-speed circuit design, along with the increase of clock frequency and integration level of integrated circuit as well as the increasing nature of multilayer PCB technology, because of which the electromagnetic interference problem appears inevitably[1]. Nowadays, the clock frequency of mostly electronic system has been over 600MHz,the rising/failing edge became more sharp together with a great number of high-frequency harmonic interference included in electronic system or device themselves, all of these cause the difficult in the design of system or device's electromagnetic property performance[2]. Traditional "designing-processing-testing-modifying" design flow cannot meet the standard of electromagnetic property performance of modern high-speed electronic system or device[10]. So, on the early stage of electronic system or device's design, it is the future research orientation to forecasting、simulating、optimizing and improving the electromagnetic property performance.

BASIC ELECTROMAGNETIC PROPERTY ANALYSIS AND METHOD IN HIGH-SPEED PCB DESIGN

Electromagnetic property mainly studies the electromagnetic compatibility performance of electrical and electronic device. Electromagnetic compatibility (EMC) mainly refers to the situation that electrical and electronic system or device may not only radiate electromagnetic field but receive electromagnetic field interference from outside[5]. Electromagnetic property performance design is to make the electromagnetic field system or device radiated will not go beyond the normative standard and can function well as expected with the electromagnetic field interference of others.

Electromagnetic compatibility contains two aspects:(1)system or device must have the anti-interference ability when working in a specific electromagnetic environment;(2)when a system or device working they cannot cause irresistible electromagnetic interference to other device working in the same environment. Thus, it separates the EMC into electromagnetic sensitivity (EMS) and electromagnetic interference(EMI), EMI also includes external interference and internal interference. Internal interference is mainly resulted by inter-coupling of adjacent circuits in transmission line and field effect coupling between internal components and high-frequency signal's decay along with the transmission line. The high-frequency harmonic wave of high-frequency periodic signal or clock signal mainly results the radiation problem of external interference. Internal interference sensitivity problem reason has close relationship with energy which couples to the I/O wire then conducts to the internal components of integrated circuit[12].

Coupling line includes radiation coupling channel and transmission coupling channel[11]. The former is that energy from EMI source transmits to the sensitive system or device in form of electromagnetic field radiation. The later is that there is complete path connection between interference source and sensitive system or device. According to the electromagnetic interference coupling line it can come up with three basic ways to restrain the electromagnetic interference problem: (1) Restraining the radiation interference intensity of electromagnetic wave radiation source or transmission source, thus its radiation energy will not cause unnecessary interference to other system or device working in the same environment. (2) Cutting off coupling line between electromagnetic wave radiation source or transmission source and sensitive system or device, thus there is no transmission way for high-frequency noisy signal. (3) Enforce the receiver's anti-interference ability in electrical system or device.

Electromagnetic property analysis in electronic system design field is: forecasting the electromagnetic property performance and anti-EMI ability of electronic system or device. According to the difference of studying on electromagnetic theory basis, it separates the method of studying high-speed PCB electromagnetic property into: field and path and field&path. The paper mainly studies field&path method, that is extracting the circuit's equivalent electromagnetic model parameter firstly, then doing time-domain analysis to the extracted equivalent circuit model using the path method. On the one hand field study method has accurate calculation but it is a great burden for the computer RAM, on the other hand path study method consumes little computer RAM but its result is not that accurate, combining the two method can gain high uniform in both accuracy and period.

HIGH-FREQUENCY ELECTROMAGNETIC RADIARION INTERFERENCE IN HIGH-SPEED PCB

There are some components which can be equivalent to transmitting antenna in most electronic system or device's hardware PCB in a specific environment; they transmit energy through electric field and magnetic field coupled with circuit. The antenna can not only radiate electromagnetic field but also receive electromagnetic measure data from outside. There are near-field and far-field as for electromagnetic field, in the same way electromagnetic measurement can be separated into near field and far field measurement. Radiation effect mainly appears in far field environment and induction effect in near field environment, they both belong to EMI radiation. It usually takes $\lambda / 2\pi$ as the demarcation point of far and near field in practical engineering application, field which is far beyond $\lambda / 2\pi$ belongs to far field and within near field[4].

The electric dipole model is shown as Figure1(a), it is a short current carrying wire which is also called current element, its length Δl and lateral dimension is far shorter than electromagnetic wave length. Suppose that the current intensity is uniform along the Δl orientation, on account of that the length of Δl is much shorter than that of from any point to electric dipole in electromagnetic field, so it can consider that the length is same from any point to electric dipole in the electromagnetic field. Due to that the length of Δl is much shorter than wave length or radiation radius of field, it can use the electric dipole model as equivalent when measuring and calculating the electromagnetic radiation problem along a certain signal transmission path in PCB. Figure 1 shows the principle of electric dipole radiation. It separates the field around electric dipole into near field and transmission field and far field according the length from observation point to electric dipole[6]. For near field:

$$\left.\begin{aligned} H_\varphi &\approx \frac{I_m \Delta l}{4\pi r^2}\sin\theta\cos\omega t \\ E_\Gamma &\approx \frac{I_m \Delta l}{2\pi\omega\varepsilon r^3}\cos\theta\sin\omega t \\ E_\theta &\approx \frac{I_m \Delta l}{4\pi\omega\varepsilon r^3}\sin\theta\sin\omega t \end{aligned}\right\} \quad (1)$$

For far field:

$$\left.\begin{aligned} H_\varphi &\approx \frac{-kI_m\Delta l}{4\pi r}\sin\theta\sin(\omega t - kr) \\ E_\Gamma &= H_\Gamma = H_\theta = E_\varphi = 0 \\ E_\theta &\approx \frac{-k^2 I_m \Delta l}{4\pi\omega\varepsilon r^3}\sin\theta\sin(\omega t - kr) \end{aligned}\right\} \quad (2)$$

Magnetic dipole model is shown in Figure 1, it is a linear magnetic element which is also called electric current loop. From the electromagnetic field theory it is known that electric field with changing current produces magnetic field, magnetic-south pole and magnetic-north pole exist at the same time, there is no magnetic monopole, but it can take a finite small current loop as a magnetic dipole. As for different study object, it supports that when the current loop radius is r（$2\pi r << \lambda$）,the current is in uniform distribution. It takes place currentelement to current loop, puts origin point of rectangular coordinate system at the same position with center of current loop, makes z-axis perpendicular to the current loop plane[7].

$$\left.\begin{aligned} H_\varphi &\approx \frac{-I_m r^2 k^2}{4\pi r^2}\sin\theta\cos(\omega t - kl) \\ E_\Gamma &\approx E_\theta = H_\Gamma = H_\varphi = 0 \\ E_\theta &\approx \frac{-I_m r^2 k^3}{4\pi\omega l}\sin\theta\cos(\omega t - kl) \end{aligned}\right\} \quad (3)$$

The main radiation source in high-speed PCB is: routing in PCB and I/O wire. In addition, the foremost radiation source is from wire radiation. Though the frequency of some transmission signal in wire is low, the wire is the sending antenna possessing great ability of radiation, so it may generate high-frequency radiation with great intensity when the high-frequency signal transmitting in PCB couples to the wire. High-frequency radiation can be divided into common-mode radiation and differential-mode radiation on the standard that how interference current transmit in wire[9]. As for the common-mode radiation and differential-mode radiation, it can analyze using the equivalent electric dipole and magnetic dipole model according to the difference of current's transmission path in PCB. In practical engineering application, EMI in PCB mainly comes from radiation of common-mode current.

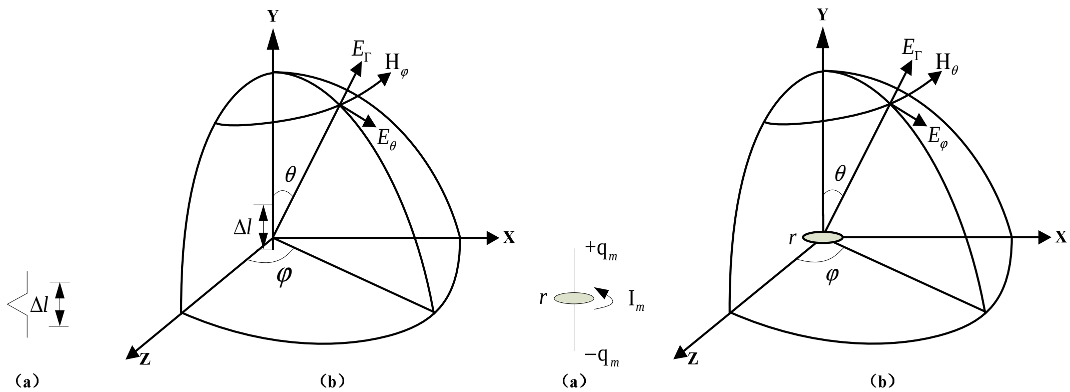

Fig.1: The principles of electricand magnetic dipole radiation

SIMULATION ANALYSIS AND OPTIMIZATION OF HIGH-SPEED PCELECTROMAGNETIC PROPERTY

The paper dose simulation analysis to electromagnetic property of high-speed PCB using the combination of Cadence、Designer、SI-wave and HFSS. The original minimum control system PCB board(main frequency is 160MHz,clock frequency is 6.67ns) is from TMS320VC5416 chip from TI[3]. The paper dose simulation analysis and forecast to the electromagnetic property problem in the PCB caused by current radiation interference. It also improves the electromagnetic property performance of PCB according to the simulation current distribution and electromagnetic field near field figure.

As the DSP harmonic wave frequency performs as radiation interference only when it is at high frequency stage (30MHz-1GHz), so it sets the simulation frequency threshold as 200MHz-1GHz. It builds a new engineering project in Cadence 16.3 and draws the PCB schematic diagram, then convert it to PCB hardware diagram, shown as Figure 2. It converts the PCB hardware diagram into .brd file which can be recognized by Allegro then transforms the .brd file into DXF format file which is needed when building the electromagnetic simulation model of PCB in Ansoft Designer、HFSS[8].

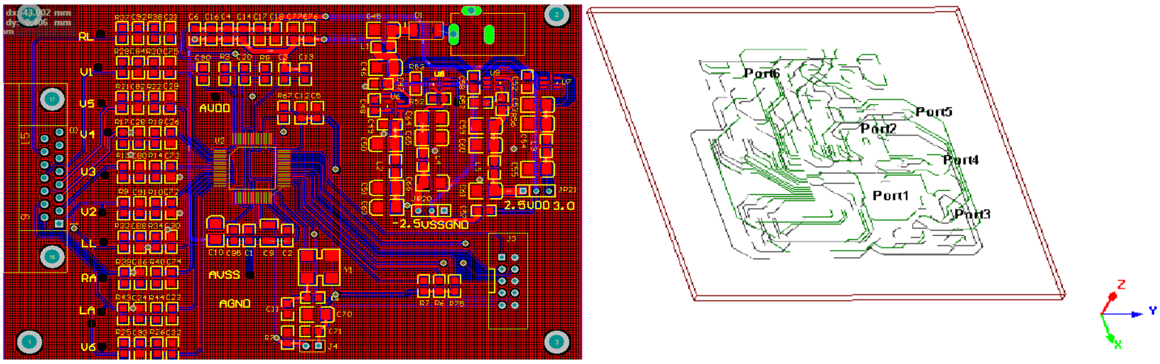

Fig.2: ThePCB layout of DSP control circuitand simulationmodel in Ansoft Designer

Imports the DXF file into Ansoft Designer and builds a new Planar EM project, then sets the excitation source and scanning frequency of model, adds a 2.5D via hole according to the position and actual size. The electromagnetic simulation model of PCB built in AnSoft Designer is as Figure 2. It sets six excitation sources(Port1~Port6) the type of which is Single Strip Gap Source, the current amplitude of Port1~Port6 are 3A、1A、0A、2A、0A、2A. The frequency scan mode is linear stepped case, the starting scanning frequency is 100MHz and off frequency 1.5GHz, the step length is 100MHz, 15 frequency points totally.It imports the electromagnetic model of PCB into SI-wave, harmonic distribution with different frequency are shown in Figure 3.

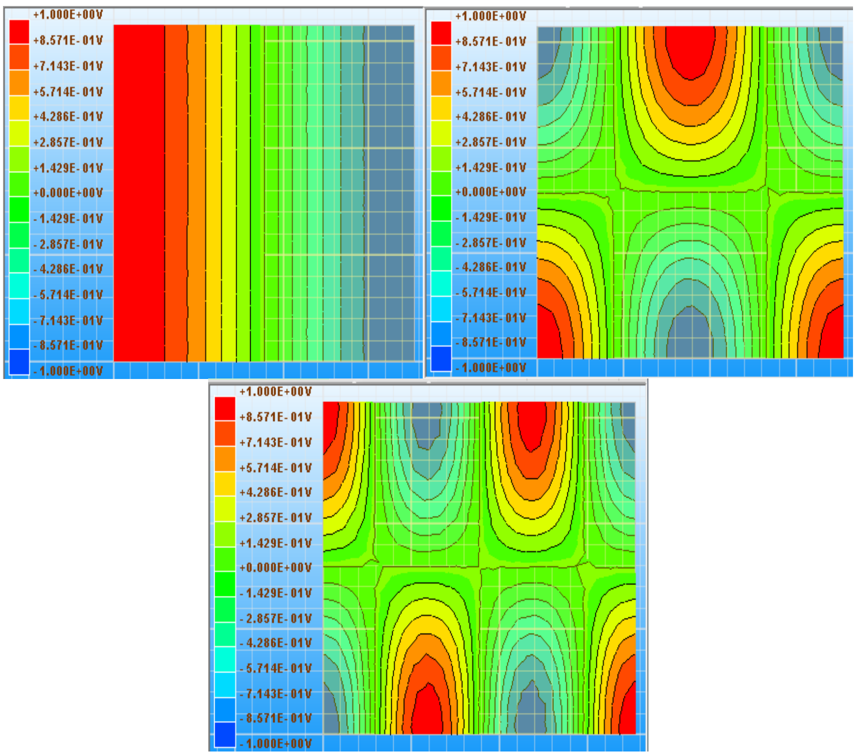

Fig.3: The resonance graphs of 1.5GHz、3.6GHz and 5.1GHz

From the harmonic distribution figure it can be seen that harmonic situation is not that serious,the main harmonic region is on the overlap part of upper and sub layer routing.

After setting the parameter in AnSoft Designer, it dose analysis to the simulation model and gets the current diagram whose initial phase are all 0° of corresponding frequency current distribution diagrams with frequency 200MHz~1GHz are shown as Figure 4.

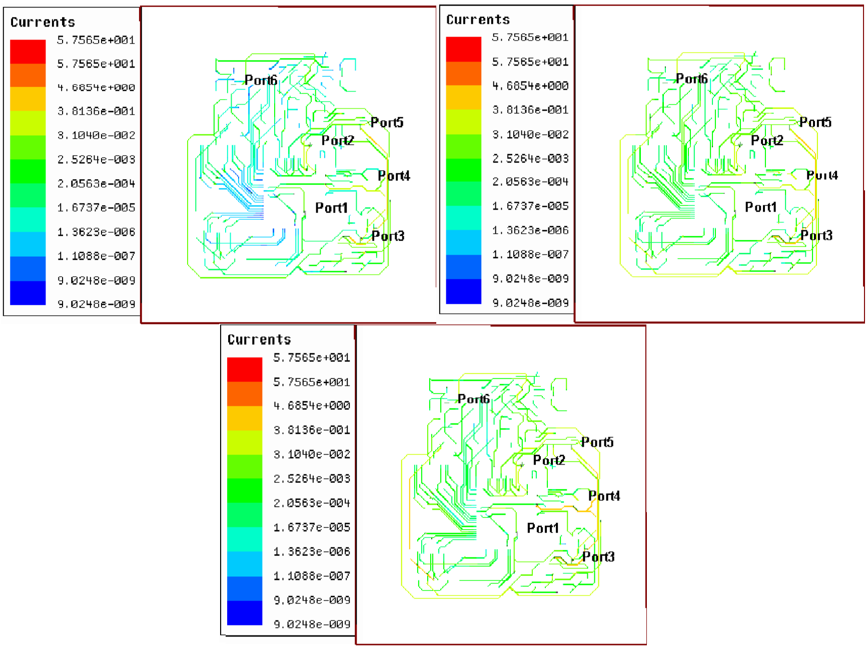

Fig.4: The current graphs of 200MHz、600MHz and 1GHz

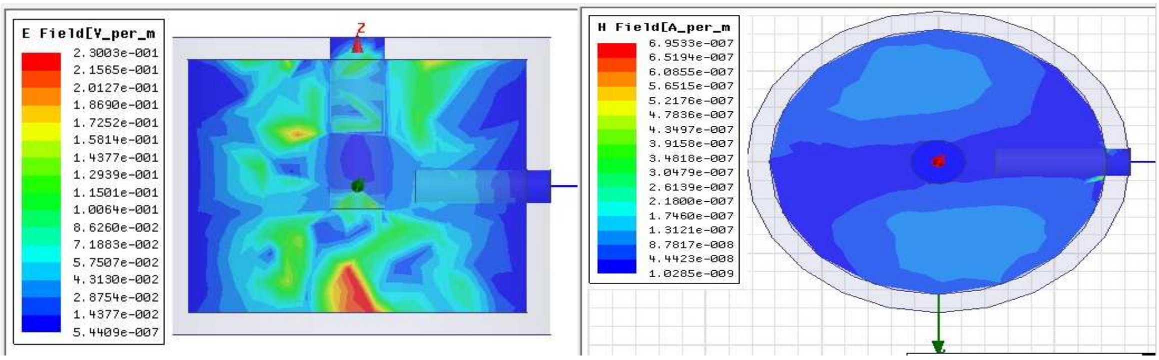

Fig.5: The near field electric field and magnetic field distributions of 200MHz

The near field electric field and magnetic field distribution of each excitation source when the frequency is 200MHz~1GHz are as Figure 5-Figure7.

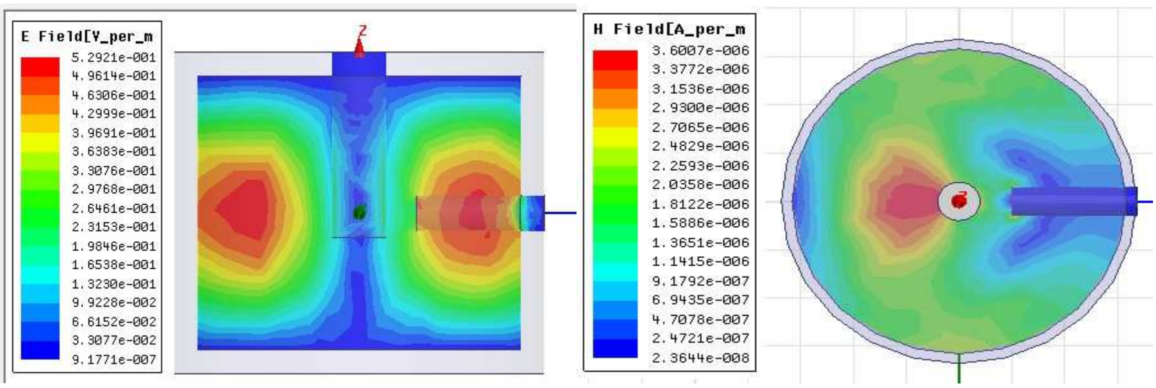

Fig.6: The near field electric field and magnetic field distributions of 600MHz

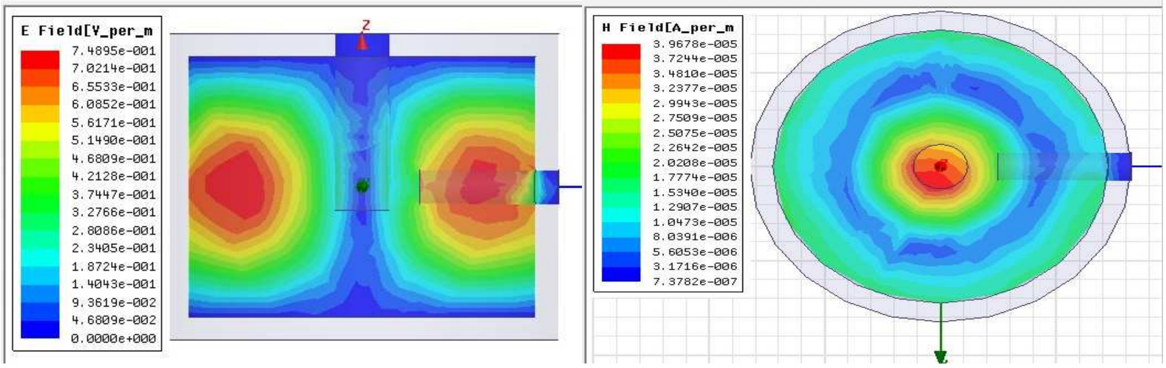

Fig.7: The near field electric field and magnetic field distributions of 1GHz

From the above figures it is known that there are two regions with high intensity electromagnetic field in the PCB, that is there are high-frequency signal wire radiation and high-frequency property components; By comparing the E and M near field distribution figure simulating in different frequency, it can be seen that when the simulation frequency is higher the electromagnetic radiation intensity of near field is greater and the region of field intensity is bigger and its effect to components and circuit around is bigger and more comprehensive. The region with maximum intensity in near field may shift when it is on different frequency points; the region where the wiring density is big has higher electromagnetic field near field radiation intensity; electromagnetic field intensity is bigger as the increasing of frequency and coupling wire effect gets greater in the region where wiring distance is long. Taking the frequency point of 1GHz with maximum electromagnetic field intensity as the study object, it can be seen that Port3 and Port5 in current distribution figure forms a 5.7564e+001 excitation current intensity, they has a great interference to neighboring signal, the current intensity radiated by the max-interfered signal wire is 5.7564e+000.

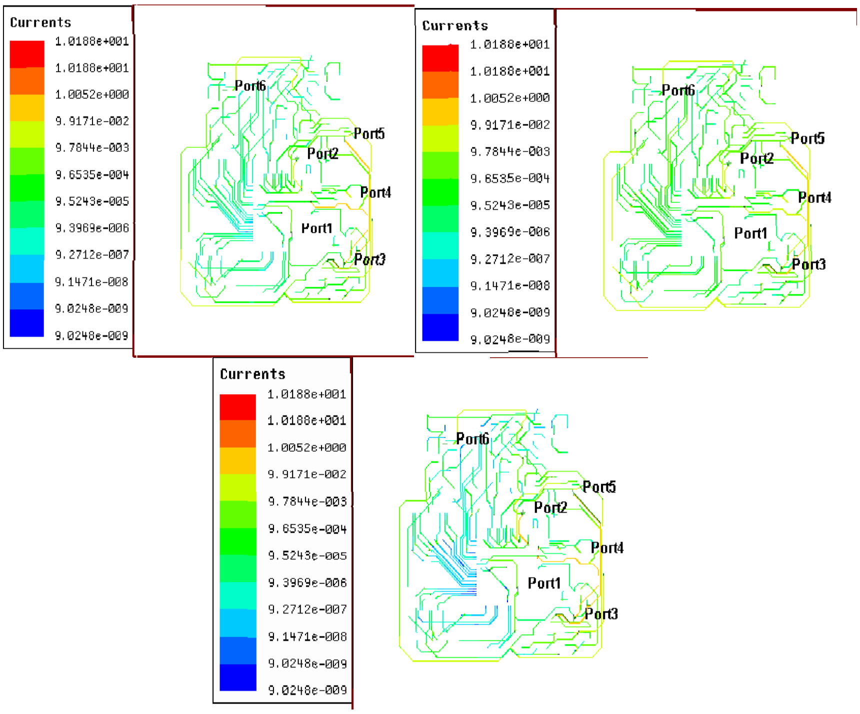

Fig.8: The current graphs of 200MHz、600MHz and 1GHz after optimal wiringdesign

Taking the 1GHz current distribution figure and electromagnetic field near field distribution figure with maximum radiation intensity as compared objects, it improves the distribution appropriately and adjusts the position of signal wire and sensitive components that are in the above region with relatively great electromagnetic intensity in PCB simulation schematic diagram, making them far from that tow region with high electromagnetic intensity. It adjusts the high-frequency excitation signal wires position, making them move to PCB board edge slowly and far from the signal wire which is easy to be interference, it also increases the length between signal wires and decreases the rate of bend design. If there must be a bend, it makes the bend smoothly. The PCB current distribution figures designed according to above principles are shown as Figure8.The near field electric field and magnetic diagram of PCB are shown as Figure 9-Figure 11.

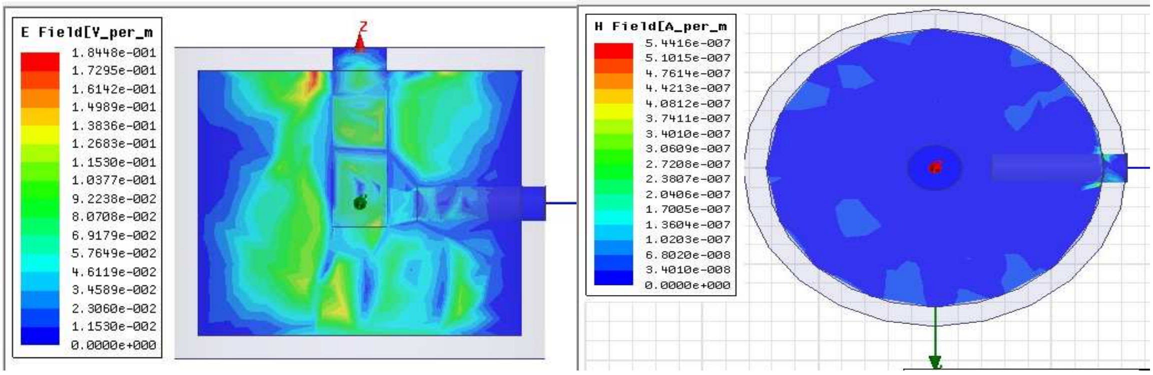

Fig.9: The near field electric field and magnetic field distributions of 200MHz after optimal wiringdesign

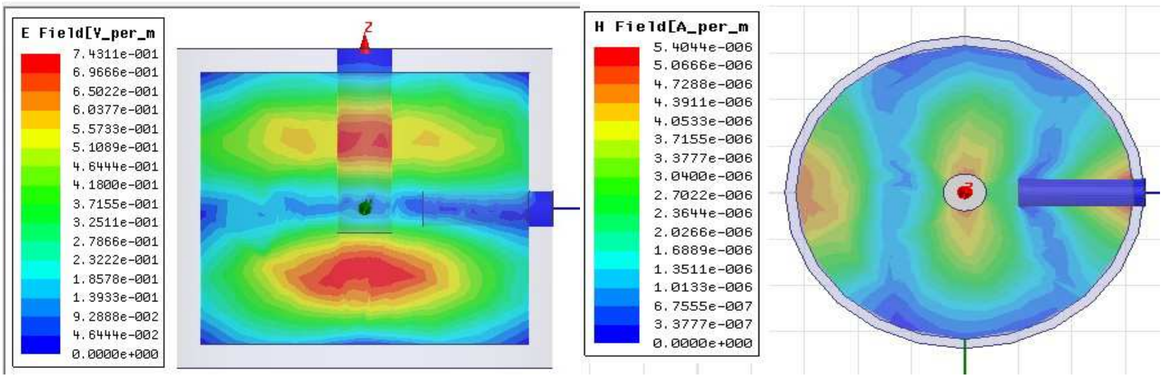

Fig.10: The near field electric field and magnetic field distributions of 600MHz after optimal wiringdesign

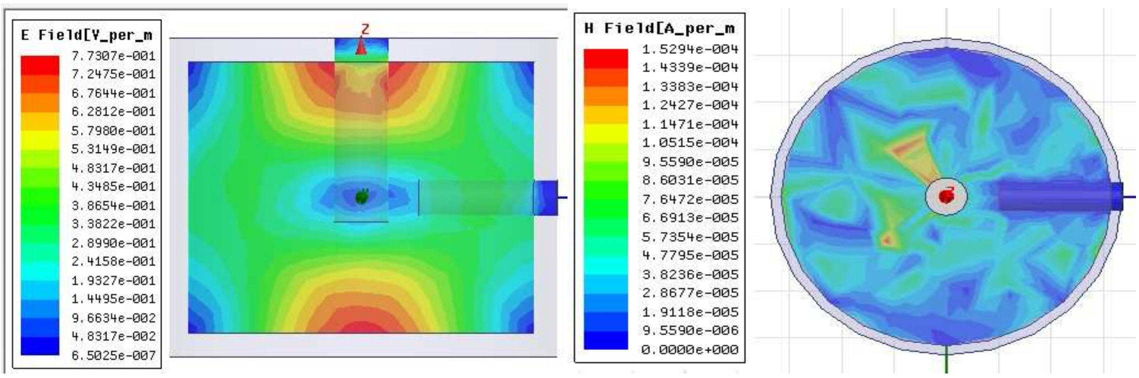

Fig.11: The near field electric field and magnetic field distributions of 1GHz after optimal wiringdesign

From the above figures, it can be seen that region with relative great intensity becomes small or shifts. There are basically no signal wire and sensitive component which is easy to be interference in present region with high electromagnetic field intensity. The magnetic field intensity on 1GHz frequency point decreases from $6.2986e-005$ to $1.3245e-005$, about five times. The excitation current intensity from Port3 and Port5 decreases to $1.1268e+001$ ，its effect to wire around becomes weak. The maximum electromagnetic current intensity radiated from current path decreases with a half. All of these show that the electromagnetic property performance of PCB improves a lot. Thedevelopment tendency of the maximal current intensity、electric field strength and magnetic field intensity along with the frequency variation after optimal wiringdesign are as Figure 12.The near field electric field distributions of 1GHz before and after optimal wiringdesign are shown as Figure13-Figure14.

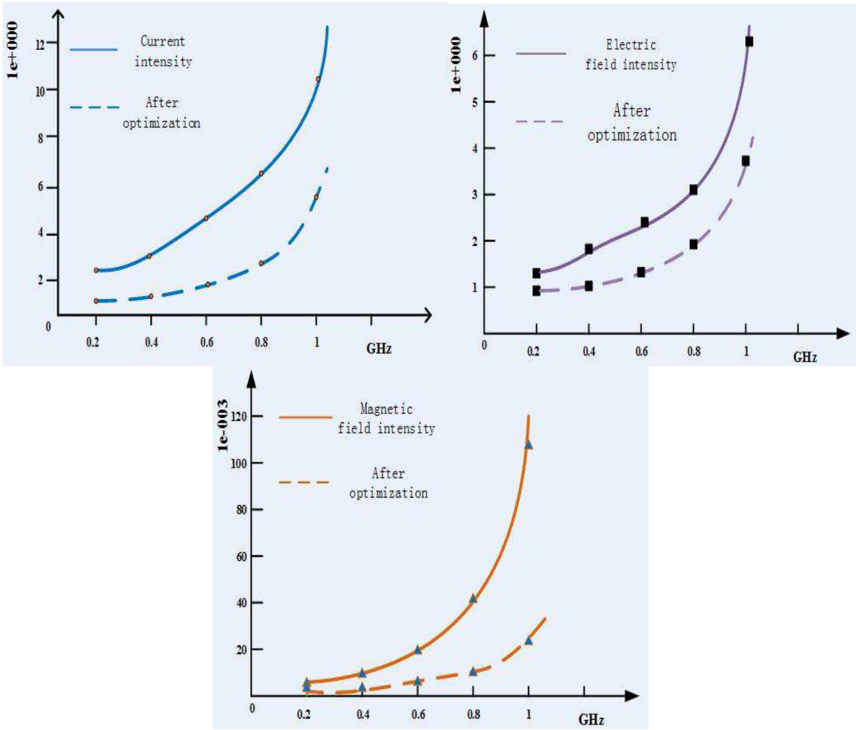

Fig.12: Thedevelopment tendency of the maximal current intensity、electric field strength and magnetic field intensity along with the frequency variation after optimal wiringdesign

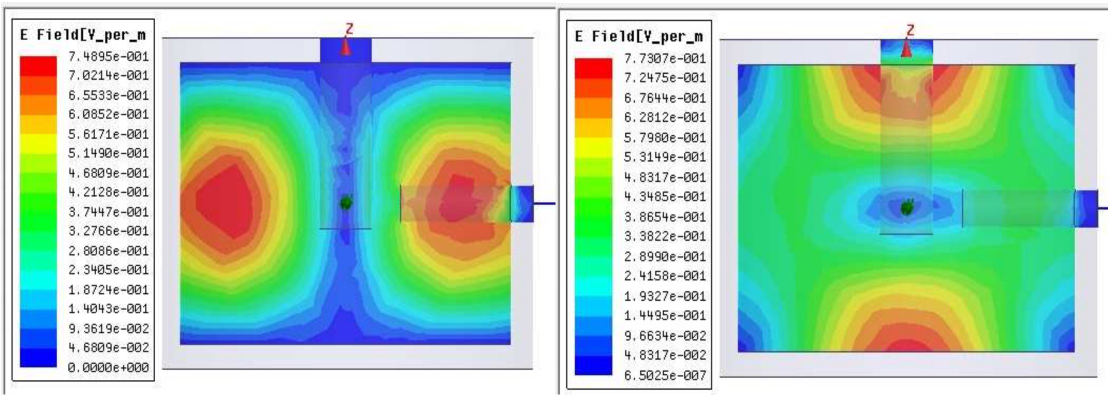

Fig.13: The near field electric field distributions of 1GHz before and after optimal wiringdesign

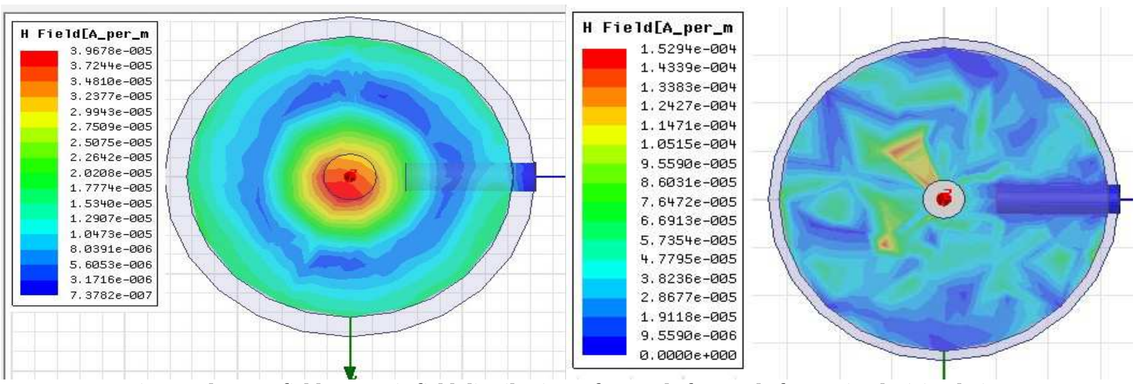

Fig.14: The near field magnetic field distributions of 1GHz before and after optimal wiringdesign

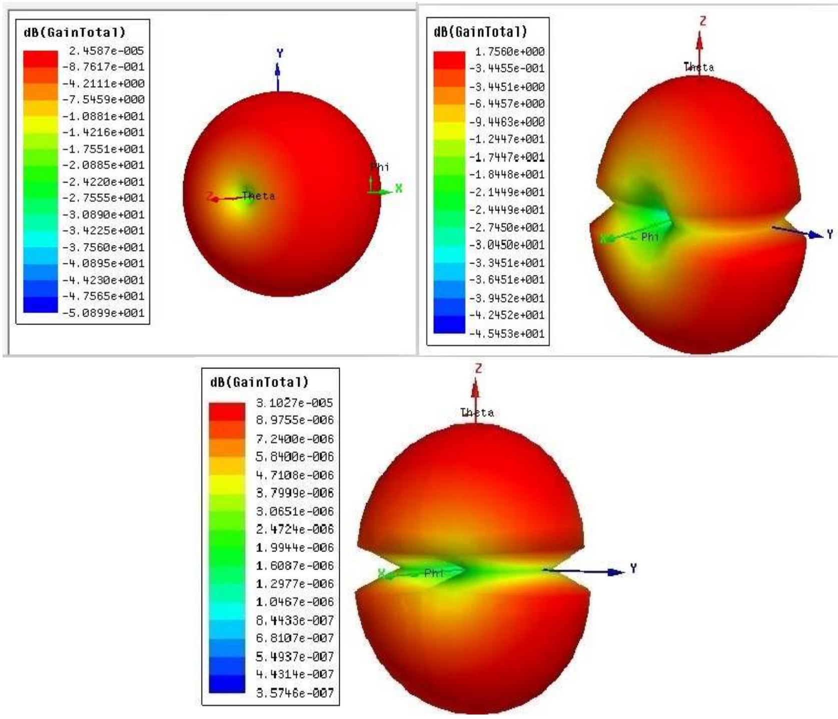

Fig.15: The far field electric field distributions of 200MHz、800MHz and 1GHz

It dose simulation analysis to the minimum control system PCB's far field distribution built from the TMS320VC5416chip from TI, the simulation results are as Figure 15.

Compared with the near field of electrical field simulation figure, it is known that the current intensity on both upper and sub layer is small, it is appropriate to place other PCB board in these region. In far field ,the tow direction upper and sub layer are the main radiation direction of PCB electromagnetic field, the maximum radiation value when frequency is 200MHz is $2.4587\times10^{-5}V/m$,that is $22.46dB\mu V/m$ close to $32dB\mu V/m$ --the testing threshold of electromagnetic property performance. In the same way, the maximum radiation value is $3.1027\times10^{-5}V/m$ corresponding to $28.69dB\mu V/m$,it also within the testing threshold of electromagnetic property performance.

CONCLUSION

From the above current distribution figure and electromagnetic far and near field simulation, it can be seen that they play a well guiding role in the optimization design of high-speed PCB electromagnetic property performance. After getting the electromagnetic radiation source position in PCB according to simulation current distribution and electromagnetic far and near field distribution figure, it guides the wiring design based on the high-speed electromagnetic property performance design principle. It adjusts the component and signal wire position with high radiation electromagnetic intensity, making them far from the high electromagnetic field intensity region. It designs the signal wire as short-wire and makes the length between wires not that small, thus avoiding the electromagnetic field radiation interference from adjacent wires. On this way, it can judge that if the designed PCB meets performance of system or device or not, according to current figure and electromagnetic far and near field distribution. If not, it goes back to repeat the above step until that the whole design satisfy electromagnetic property performance standard. This process can not only improve successful rate of PCB design but also raises the design efficiency and reliability. As a result, it decreases the design cost.

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