Simulation and Design of Printed Circuit Boards Utilizing Novel Embedded Capacitance Material

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Abstract—the effects of a novel embedded capacitance material on PI-Power integrity, SI-Signal integrity and EMC-Electro Magnetic Compatibility were simulated and measured by comparing a multilayer board with embedded capacitance to a conventional multilayer board utilizing conventional FR-4 material. SIwave software was used to simulate electrical properties and EMC of the embedded capacitance material board and conventional FR-4 material board up to a frequency of 4 GHz. Finally, the application prospects of embedded capacitance materials are analysed.

I. INTRODUCTION

The ever increasing rising speed and power and decreasing voltages of high speed digital products create more and more issues with PI, SI and EMC. These problems have gradually attracted widespread attention of research engineers. New technologies and new tools such as embedded capacitance and the SI, PI and EMC simulation tools have been developed to solve these problems.

The need for embedded capacitance technology is induced by the following factors: The first is the wide application of products with high speed chips. Low voltage chips with high speed and high power consumption raise very high requirements for the PCB power distribution system, such as fast response characteristic of the power distribution system, low voltage ripple, low impedance, low voltage drop, etc. The second is high density on the board due to the miniaturization and complexity of products which limit the quantity and location of the discrete capacitors. The third is the electric performance limit of conventional discrete capacitors. Very high requirements of the capacitance density, wide-band filtering, and high frequency filtering capability and response time of the capacitors are needed for high speed IC chips. Conventional discrete capacitors have a narrow frequency filtering band due to the limitation of the discrete capacitor parasitic parameters and PCB parasitic parameters. Additionally, the functionality of conventional discrete capacitors is very limited when they are used for frequencies more than 2GHz.

Figure 1 shows the comparison of the frequency response curves of the conventional discrete capacitors and embedded capacitors. It is very clear from this figure (red curve) that discrete capacitor has a narrow frequency *filtering* band. The combination of many discrete capacitors is necessary to form a wide frequency filtering band. But potential risks could be induced if no detailed simulation analysis is carried out since lots of anti-resonance frequency points could be formed by the combination of the discrete capacitors. The blue curve is the frequency response curve of the embedded capacitor obtained by SIwave simulation. It shows us that the embedded capacitor has a wide frequency filtering band up to 4 GHz.

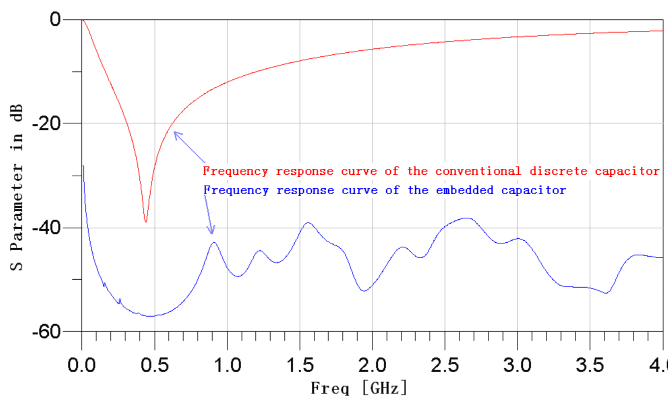

Fig.1. Comparison between the frequency response curves of the conventional discrete capacitor and embedded capacitor

In the PCB layout formed by the conventional FR-4 materials, the plate capacitor is formed by the coupling of neighbouring power plane and ground plane. This plate capacitor has a low capacitive density due to the limitation of the thickness and the dielectric constant of conventional FR-4 materials. The embedded capacitance materials are thin core materials and have higher dielectric constant (DK value) (Fig .2.). Their capacitive density is much higher than the conventional FR-4 plate capacitor. At the same time, the distributed inductance of the embedded capacitor is very low, which causes it to like an ideal capacitor with wide frequency filtering band. Especially, the high frequency filtering characteristic of the embedded capacitor is very outstanding.

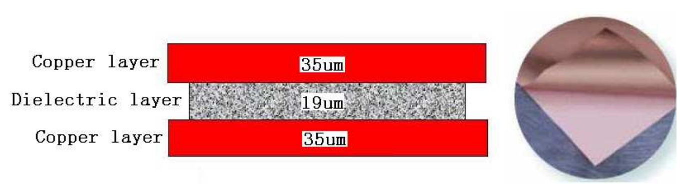

Fig. 2. Schematic diagram of 3M embedded capacitance material

Table 1 is the comparison of the electrical performance parameters between the 3M C-PLY19 embedded capacitor and the conventional FR-4 plate capacitor. It is very clear from the table that the embedded capacitors have much higher dielectric constant, much thinner core and much larger capacitive density compared with the conventional FR-4 plate capacitors.

Materials name / Parameters	FR-4 (PCB plate capacitor)	3M C-PLY19 (Embedded capacitor)
Composite	FR-4	Epoxy/Ceramic filler
Dielectric constant (DK)	≦4.0~4.5	21
Dielectric consumption (DF)@1GHz	≦0.02	0.03
Dielectric thickness (um)	≥68	19
Capacitance density ($nF/inch^2$)	≤0.3	6.2

Table 1. Comparison of electronic parameters between 3M C-PLY19 embedded Capacitor and the conventional FR-4 plate capacitor

II. Comparison of the Simulation of the Embedded Capacitance Material Board and the Conventional FR-4 Material Board

To verify the application effect of the embedded capacitors for PI, SI and EMC, we have designed two boards with the conventional FR-4 materials and 3M C-PLY19 embedded capacitance materials respectively. The active circuit on each board was the same clock circuits, which were the clock circuits with the frequency is 50 MHz and 125 MHz respectively. Two boards were both 6-layer boards except that the difference existed between the L3 and L4, one board has around 4 mil conventional FR-4 materials while another had 0.75 mil 3M C-PLY19 embedded capacitance materials. Their layouts are shown in Fig 3.

Layer name	Layout figures	Layout explanation
L1		TOP (GND)
	pp(FR4)	
L2		SIGNAL
	core(FR4)	
L3		POWER
	pp(FR4) or 3M c-ply19	
L4		GND
	core(FR4)	
L5		SIGNAL
	pp(FR4)	
L6		BOTTOM (GND)

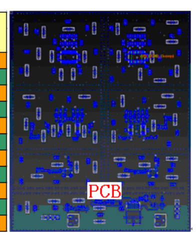

Fig. 3. Layouts and PCB figures of the conventional FR-4 and embedded capacitance material boards

Before testing, detailed PI and EMC simulation analysis was carried out with SIwave software to verify the electronic characteristic difference between the embedded capacitors and the conventional FR-4 plate capacitors, SIwave software was chosen because its high accuracy and applicability. The simulation accuracy of this software on S, Y, Z parameters was proved by our product boards. Fig 4 is the comparison of the s parameter curve of SIwave simulation and testing.

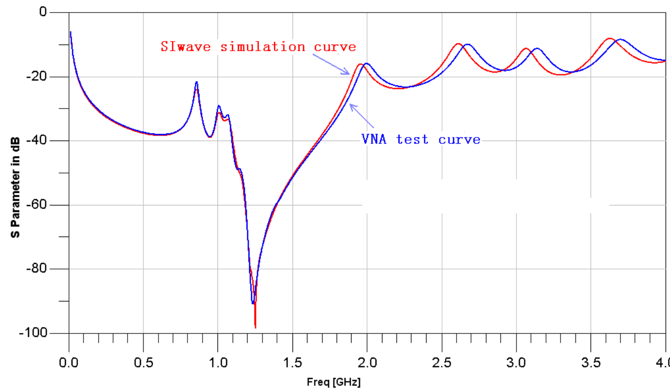

Fig. 4. Comparison of the S parameters curves of SIwave simulation and testing

Many connectors at the same place were put to compare and analyse the experimental boards of these two materials. For example, in Fig 5, impedance port and voltage probe was added on the same connector J33, and the same voltage excitation source was added at the same site of U5 clock device. The voltage excitation source was a clock power frequency noise source. Although this frequency noise source could not reflect the power noise of the U5 device, the relative electronic characteristic difference between the embedded capacitance material board and the conventional FR-4 material board could be compared by simulation at the same noise excitation source.

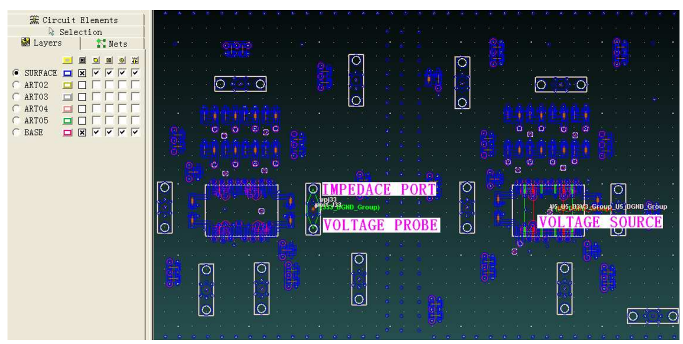

Fig. 5. Simulation setup of the embedded capacitance material board and the conventional FR-4 material board

1) Comparison of the Impedance Simulation of the Embedded Capacitance and the conventional FR-4 material boards

The impedance comparing curves of the connector J33 between the embedded capacitance and the conventional FR-4 material boards were shown in Fig 6. Fig 6 showed us that the impedance of the embedded capacitors is all less than that of the conventional FR-4 plate capacitor within 30MHz~4GHz. The impedance difference is very obvious when the frequency is higher than 1GHz. additionally, the inhibition of the board-level resonance by the embedded capacitors is obviously better than that of the conventional FR-4 plate capacitors from the impedance curves.

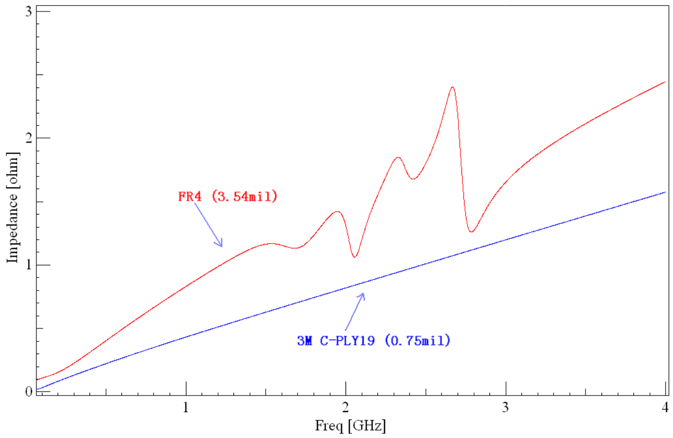

Fig. 6. Comparison of impedance curves between the embedded capacitors and the conventional FR-4 plate capacitors

2) Comparison of the Power Noise simulation of the Embedded Capacitance and the conventional FR-4 material boards

The voltage probes on the connector J33 were analysed within 30 MHz to 1GHz frequency at the same frequency noise excitation. The simulation results of the embedded capacitance and the conventional FR-4 material boards were shown in Fig 7. From figure7, it is not hard to tell that the inhibition of the power noise by the embedded capacitors is much better than that of the conventional FR-4 plate capacitors.

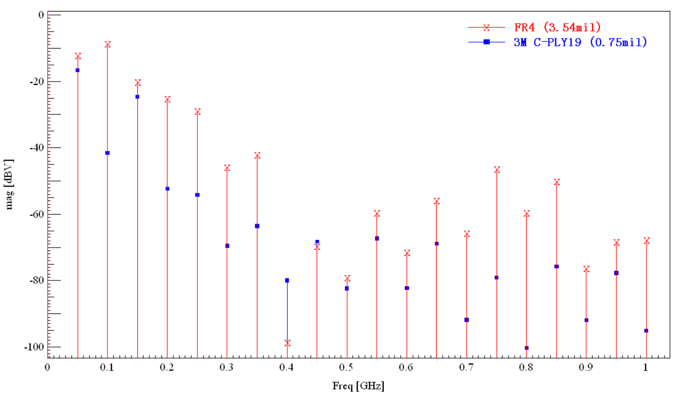

Fig. 7. Comparison of the power noise frequency sweep simulation results between the embedded capacitance and the conventional FR-4 material boards

3) Comparison of the EMC Simulation of the Embedded Capacitance and the conventional FR-4 material boards

EMC simulation of the embedded capacitance and the conventional FR-4 material boards within 30MHz~1GHz was analysed at the same frequency noise excitation. The results of the 3m field radiated emission were shown in figure 8. This figure shows that the result of the embedded capacitance material board is obviously better than that of the conventional FR-4 material board within 30MHz~1GHz.

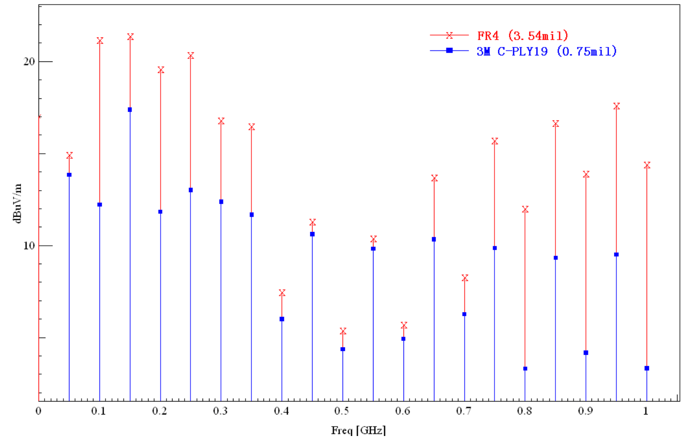

Fig. 8. Comparison of the EMC simulation curves between the embedded capacitance and the conventional FR-4 material boards

III. COMPARISONS OF THE TESTING RESULTS BETWEEN EMBEDDED CAPACITANCE AND THE CONVENTIONAL FR-4 MATERIAL BOARDS

The comparing testing of time domain power noise, frequency domain power noise, RE (3m field radiated emission) testing and SI was carried out after assembling the embedded capacitance and the conventional FR-4 material boards.

1) Comparison of the Power Noise Testing results between Embedded Capacitance and the conventional FR-4 material boards

Comparison of the power ripple noise testing results on the J33 connector were shown in figure 9. It is visually clear that the power ripple noise of the conventional FR-4 material board is 155.52 mV while that of the embedded capacitance material board is only 24.28 mV. The power ripple noise of the conventional FR-4 material board is much higher than that of embedded capacitance material board. This trend is consistent with the impedance simulation results.

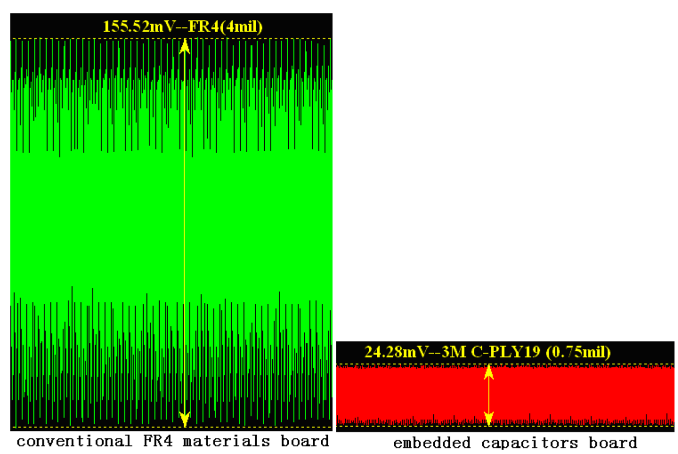

Fig. 9. Comparison of the power ripple noise of the embedded capacitance and the conventional FR-4 material boards

Comparison curves of the power noise frequency spectrum between embedded capacitance and conventional FR-4 material boards were shown in figure 10, the power noise frequency spectrum is measured on the connector J33 by using high bandwidth frequency spectrometer. It's very clear that the noise frequency spectrum amplitude of the conventional FR-4 material board is higher than that of the embedded capacitance material board within 10MHz~4GH. Especially, almost no harmonic of the clock signal was seen in the power noise frequency spectrum of the embedded capacitance material board at more than 1.5 GHz frequency. This trend is consistent with the previous frequency sweep simulation results.

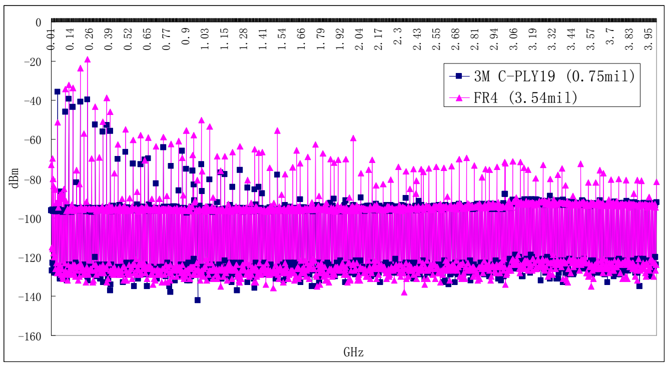

Fig. 10. comparison of the power noise frequency spectrum of the embedded capacitance and the conventional FR-4 material boards

2) Comparison of the RE Testing Results between the Embedded Capacitance and the conventional FR-4 material boards

By using the standard full wave darkroom, RE testing with bare boards of the embedded capacitance materials and the conventional RF4 materials within 30MHz~2GHz was carried out, the results were shown in figure 11. It is very clear from this figure that the RE amplitudes of the conventional RF4 board are higher than that of the embedded capacitance material board, which is similar to the previous EMC simulation analysis trends.

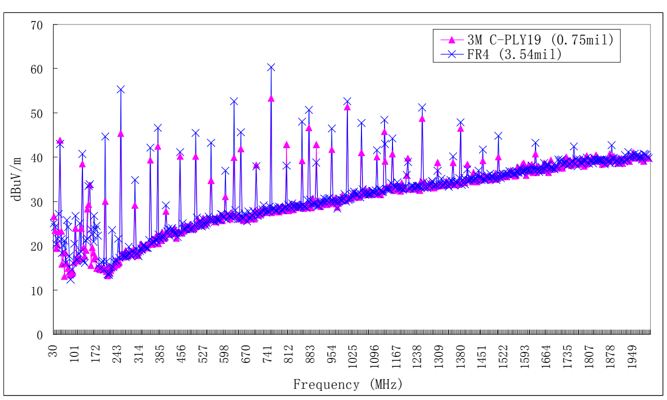

Fig.11. Comparison of the RE testing results of the embedded capacitance and the conventional FR-4 material boards

3) Comparison of the SI Testing results between the Embedded Capacitance and the conventional FR-4 material boards

All the circuits on the experimental boards are the clock circuits which are mainly 50MHz and 125MHz clock signal. Figure 12 is the measured signal wave at the receiving end of the same 50 MHz clock signal. It is obvious from Figure 12 that the signal qualities including ringing, noise margin and duty cycle of the embedded capacitance material board are slightly better than those of the conventional FR-4 material board. Figure 13 is the FFT results from figure 12. From figure 13, because the second and the fourth harmonic amplitudes of the 50 MHz clock signal of the embedded capacitance material board are smaller than those of the conventional FR-4 material board. So the duty cycle of the embedded capacitance material board are smaller than that of the conventional FR-4 material board. Additionally, the amplitude of the first, the third harmonic noise coupled from125 MHz clock circuits through using the same PCB power distributed system of the embedded capacitance material boards is much less than that of the conventional FR-4 material board. The root cause of the signal qualities differences mentioned above is that the inhibition of power noise by the embedded capacitance material board are better than that of the conventional FR-4 material board.

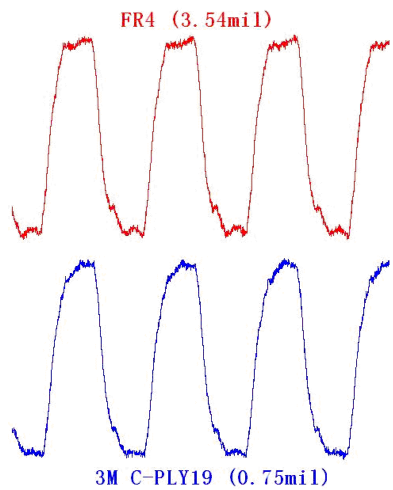

Fig.12. Comparison of the 50 MHz clock signal measured wave between the embedded capacitance and the conventional FR-4 material boards

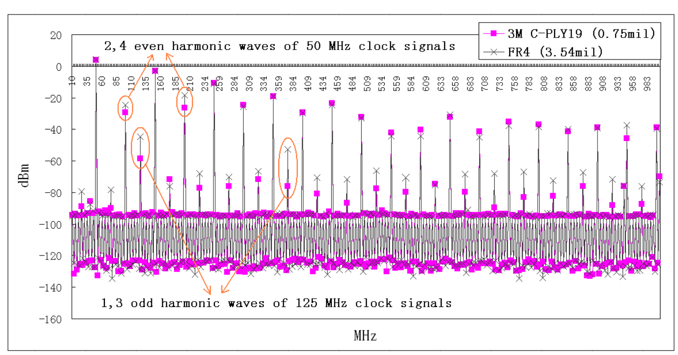

Fig.13. Comparison of the 50 MHz clock signal frequency spectrums between the embedded capacitance and the conventional FR-4 material boards

IV. THE APPLICATION PROSPECT OF THE EMBEDDED CAPACITANCE MATERIALS

The embedded capacitance materials could be used for the following aspects depending on their excellent properties on SI, PI and EMC.

1) Digital/analog Interference Design with Digital/analog Mixed Board

Part of the boards for the wireless communication products are the digital/analog mixed boards. The digital circuits and analog circuits share the same board-level power distribution system. These noises produced by the digital circuits interfere with the analog circuits.

The embedded capacitors could inhibit the noise induced by the digital circuit on the board-level power distribution system especially at high frequency, and so could decrease the interference times of the digital/analog mixed board, which is very important for the design quality and design period of the digital/analog mixing boards.

2) EMC Design of the Non-shielding Box-type Products with Plastics shell

The electronic products with strong competitiveness are those which are smaller, lighter, more excellent performance, lower cost and shorter design period. To improve the competition of the products, the plastic non-shielding shells are used more and more. In this case, the design focused on the board-level EMC design. Some EMC compulsory certification like CE, FCC and 3C become the threshold of the products into the market. Especially, the RE testing frequency will be enlarged from 30MHz~1GHz to 30MHz~6GHz after 2010. Research engineers focus on how to ensure the products passing the EMC compulsory certification shortly with the least editions.

The application of the embedded capacitors decreased the noise of the board-level power distribution system greatly， especially the high frequency noise of the board-level power distribution system. Even when the frequency is higher than 6GHz or even 10GHz， the electronic characteristic of the embedded capacitors are still good. Noise inhibition of the board-level power distribution system is superbly important for the board-level EMC design.

3) Power Integrity and Signal Integrity Design of the High Speed and High Density Board

More and more low voltage chips with high speed have been used in the products which demand much more for the board-level power distribution system, such as fast response characteristic of the board-level distribution system, low voltage ripple, and low impedance. The conventional FR-4 plate capacitors and conventional discrete capacitors could not meet these requirements. The embedded capacitors could meet the requirements of the low voltage chips with high speed and high power consumption greatly because of their thinner dielectric thickness, higher dielectric constants, lower distributed inductance and larger capacitive density. At the same time, they could replace most of the decoupling capacitors on the PCB boards to save more placement area and thus contribute to the miniaturization of the products.

The high speed signals on the boards now have the characteristics of lower voltage amplitude, steep signal edge and lower jitter. They could be affected easily by the noise of the board-level power distribution system, so that lower noise of the board-level power distribution system is very important to ensure the high speed signal qualities. The application of the embedded capacitors could reduce the noise of the board-level power distribution system and improve the signal integrity of the high speed signals. In this way, the stability and the reliability of the products could be greatly improved.

ACKNOWLEDGMENT

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