EMC Decoupling Capacitors Impact on PCB Radiated Emissions

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Abstract - **This paper focuses on the impact of the power-supply decoupling capacitors on the radiated emissions from a PCB. The purpose and the decoupling methods are discussed, and related to the board topology and the signal trace geometry. PCB circuitry implemented on two different boards is described. Anechoic chamber measurements of radiated emissions from the PCB with and without decoupling capacitors are presented and discussed.**

Index Terms – Decoupling capacitors, Electromagnetic compatibility, radiated emissions.

1. Introduction

Decoupling in printed circuit board (PCB) design refers to preventing energy transfer from one circuit to another in addition to enhancing the quality of the power distribution network. Three circuit types targeted by the decoupling schemes are power and ground planes, components, and internal power connections. There are two primary reasons for using decoupling between power and ground planes. The first reason addresses the functionality, and the other relates to the electromagnetic (EM) emissions from the circuit board [1].

When the decoupling capacitors are used for the functionality reasons one is primarily concerned with their charge-storage capability. When integrated circuit (IC) switches states, it draws addition current from the adjacent circuitry. The local decoupling capacitor provides this additional current. If sufficient current is not provided during the transition, the IC may experience a functional failure.

The second reason for using decoupling capacitors is to reduce the EM noise injected into the power and ground reference plane pairs, and thus to reduce the EM emissions from the circuit board.

In order to analyze the decoupling mechanism it is important to understand that decoupling is not a process of placing a capacitor adjacent to an IC , but rather it as a process of placing an LC network adjacent to the IC between the power and ground to supply the transient switching current [2]. This LC decoupling network will, at some frequency become resonant, and thus will not be effective beyond that frequency. It has been shown that a single capacitor, or two adjacent capacitors placed close to the IC power and ground pins could be effective up to 150 MHz frequency range. In the range 150-500 MHz many small capacitors spread around the IC prove to be more effective. Beyond 500MHz up to 5GHz, PCB embedded capacitance (inherent capacitance between power and ground planes) is the most effective decoupling approach [4].

This paper focuses on the impact of the power-supply decoupling capacitors and the board design on the radiated emissions from of a PCB in the 100 kHz – 500 MHz frequency range. Two types of PCB boards were used in our investigations: one with dedicated power and ground planes (Type I board) shown in Fig 1.1, the other with no dedicated planes (Type II board) shown in Fig 1.2. Both types of boards were tested under two scenarios: with no decoupling capacitors, and with decoupling capacitors. Decoupling capacitors pairs of values $0.1\mu F$ and $0.001\mu F$ were used in several locations indicated in Figures 1.1 and 1.2.

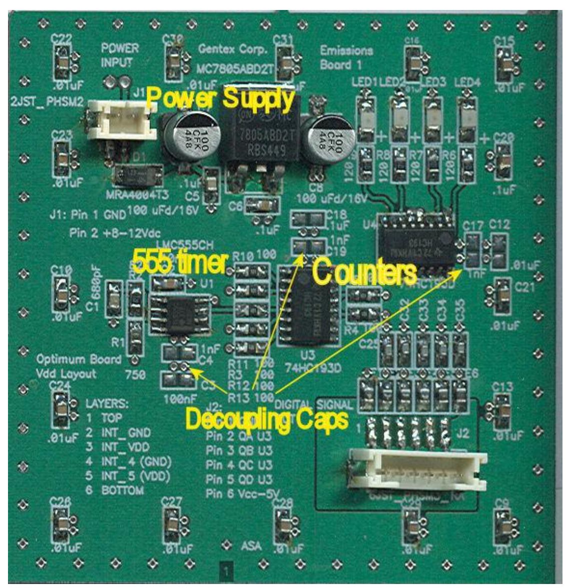

Figure 1.1 Type I board – dedicated power and ground planes

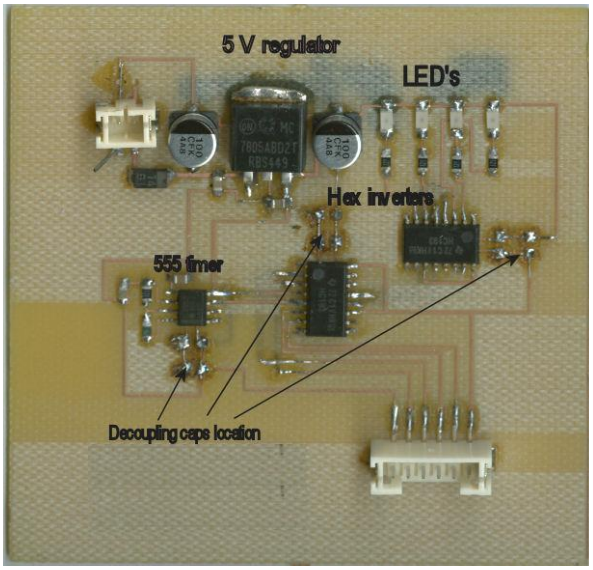

Figure 1.2 Type II board – no dedicated planes

This paper is organized as follows. Section 2 discusses the decoupling phenomenon. PCB circuitry used in this experiment is described in Section 3. In Section 4, the radiated emission test results are presented. Section 5 contains the summary and the conclusions.

2. DECOUPLING PHENOMENON

The following discussion closely follows the material presented in [3,4]. As previously mentioned, when modules switch state, current is drawn through the inductances of the $+5V$ and ground lands from the power supply as illustrated in Fig. 2.1.

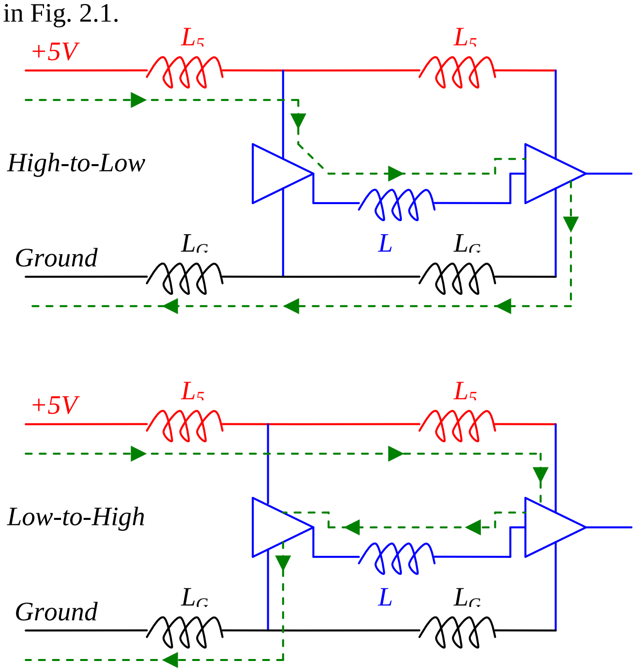

Figure 2.1 Loop areas formed without decoupling capacitors

Note the relatively large current loop area, which gives rise to a higher value of the loop inductance and thus produces higher levels of radiated emissions.

A decoupling capacitor placed between the power and ground pins of a module acts as a local reservoir of charge. During the time when the module is changing state, the current is drawn from this local decoupling capacitor and not through the long $+5V$ and ground lands from the power supply as shown in Fig. 2.2. Note the smaller current loop area, which lowers the value of the loop inductance and thus lowers the levels of radiated emissions.

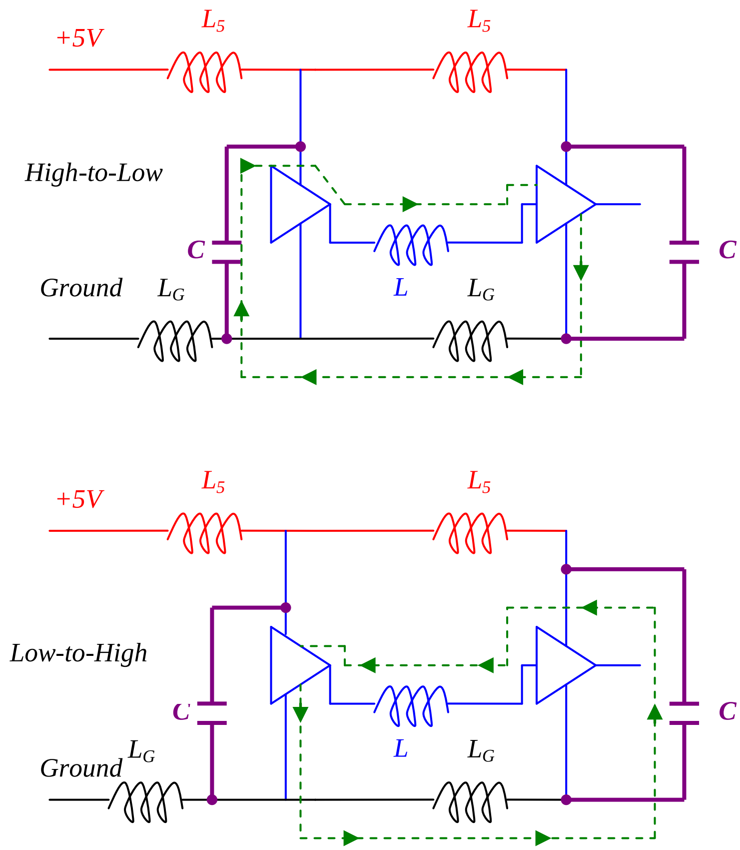

Figure 2.2 Loop areas formed with decoupling capacitors

During the quiescent state when the voltage is not changing level, current is drawn through the long power delivery lands at a much slower rate than during the state transition to replenish the local decoupling capacitor preparing it to serve during the next state change. Hence the effect of the inductances of these long lands is avoided.

3. PCB CIRCUITRY DESCRIPTION

The block diagram of a PCB circuitry is shown in Fig. 3.1. The circuit consist of a fixed 5 volt regulator, 555 Timer, two 74193 4-bit binary counters and 5 light emitting diodes (LED). The 555 timer was configured for an astable mode to operate as a square wave generator with 50% duty cycle. The output frequency was set for ~800 kHz. The DM74LS193 circuit is a synchronous up/down 4-bit binary counter. Synchronous operation is provided by having all flip-flops clocked simultaneously so that the outputs change together. Having two 74193 integrated circuits plus the LED's provide additional current surges for demonstration of power distribution network decoupling.

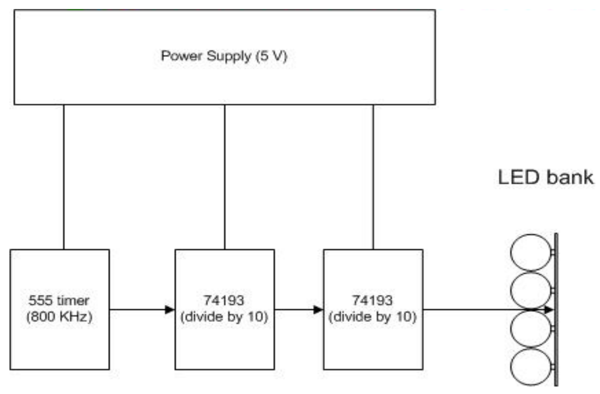

Figure 3.1 Block diagram of the PCB circuitry

4. MEASUREMENT RESULTS

The radiated emission tests were performed in an anechoic chamber over three ranges of frequency with a different antenna in each frequency range:
- Region 1 – 100 kHz – 30 MHz (monopole antenna)
- Region 2 – 30MHz – 200 MHz (biconical antenna)
- Region 3 – 200MHz – 500 MHz (log-periodic antenna)

In each region three different configurations were tested:
- Type I board no caps vs. Type II board no caps
- Type I board, no caps vs. decoupling caps
- Type II board, no caps vs. decoupling caps

The results for each region for all three configurations are discussed next.

4.1 REGION 1: 100 kHz – 30 MHz

Figure 4.1a compares the radiated emissions results for Type I board vs. Type II board (no decoupling capacitors on either board).I.

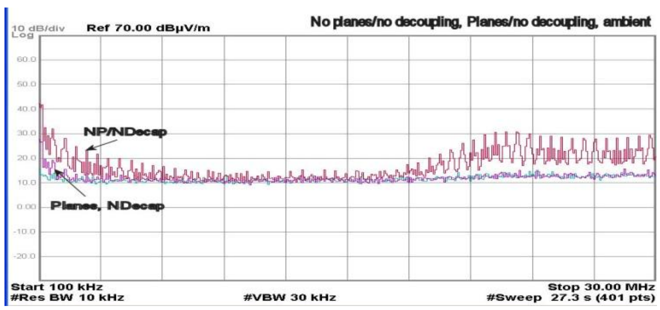

Figure 4.1a – Type I vs. Type II board, No caps

Type I board outperforms (lower radiated emissions) type II board over the entire frequency range 100kHz-30MHz. In the lower frequency region, 100 kHz-9MHz, Type II board exhibits up to 12dB higher emissions, especially at the lower end of the interval. In the higher frequency region, 18MHz-30MHz, Type II board exhibits up to 16 dB higher emissions, especially above 21MHz.

Figure 4.1b compares the radiated emissions results for Type I board with decoupling capacitors vs. Type I board with no decoupling capacitors.

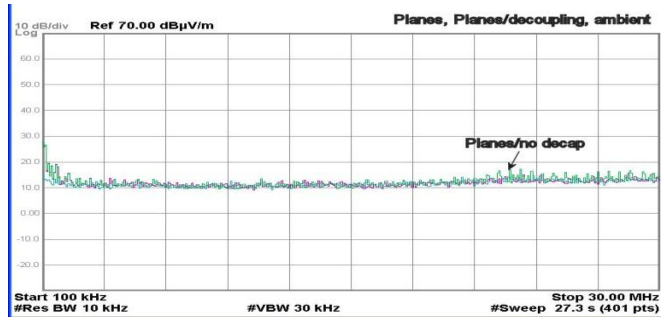

Figure 4.1b – Type I board -decoupling caps vs. no caps

Around 23 MHz the decoupling caps provide up to 6dB improvement over the no-decoupling approach. No visible differences in performance otherwise.

Figure 4.1c compares the radiated emissions results for type II board with decoupling capacitors vs. type II board with no decoupling capacitors.

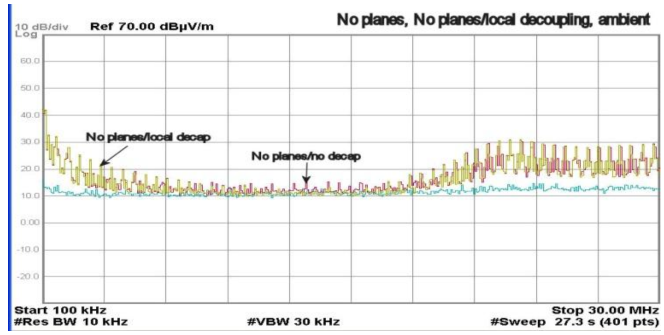

Figure 4.1c – Type II board, decoupling caps vs. no caps

4.2 REGION 2: 30 MHz – 200 MHz

Figure 4.2a compares the radiated emissions results for Type I board vs. Type II board (no decoupling capacitors on either board).

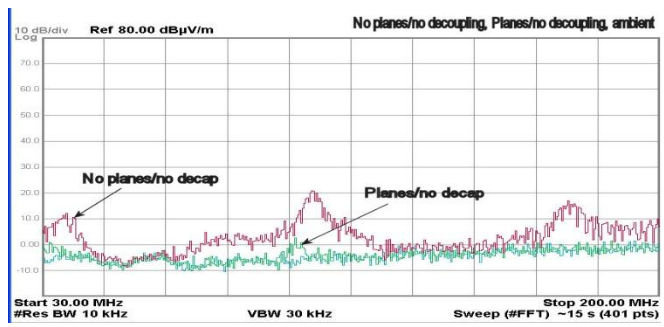

Figure 4.2a – Type I vs. Type II board, No caps

Type I board outperforms (lower radiated emissions) type II board over the entire frequency range 100 kHz-30MHz. Type II board exhibits up to 20 dB higher emissions over several frequency regions.

Figure 4.2b compares the radiated emissions results for Type I board with decoupling capacitors vs. Type I board with no decoupling capacitors.

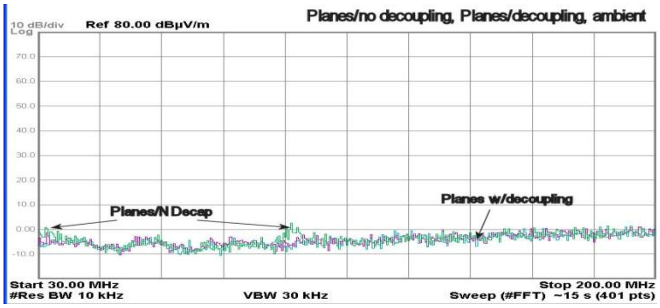

Figure 4.2b – Type I board -decoupling caps vs. no caps

Around 105 MHz the decoupling caps provide up to 6dB improvement over the no decoupling approach. There is no visible difference in performance otherwise.

Figure 4.2c compares the radiated emissions results for type II board with decoupling capacitors vs. type II board with no decoupling capacitors.

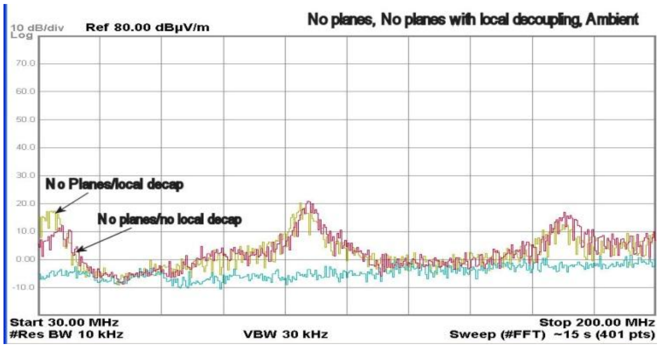

Figure 4.2c – Type II board, decoupling caps vs. no caps

There is no visible difference between the two scenarios.

4.3 REGION 3: 200 MHz – 500 MHz

Figure 4.3a compares the radiated emissions results for type I board vs. type II board (no decoupling capacitors on either board).

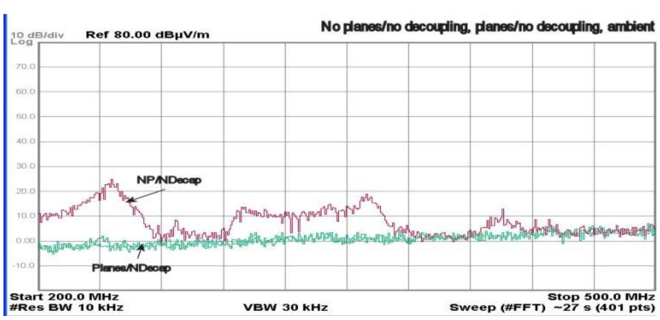

Figure 4.3a – Type I vs. Type II board, No caps

Type I board outperforms (lower radiated emissions) type II board over the entire frequency range 200 kHz-500MHz. Type II board exhibits up to 25 dB higher emissions over several frequency regions.

Figure 4.3b compares the radiated emissions results for Type I board with decoupling capacitors vs. Type I board with no decoupling capacitors.

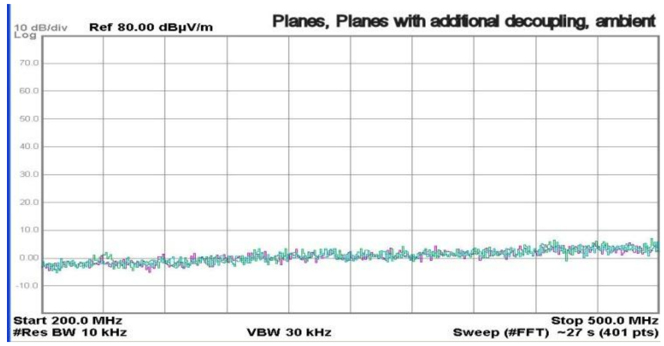

Figure 4.3b – Type I board - Decoupling caps vs. No caps

Decoupling caps show no visible improvement.

Figure 4.3c compares the radiated emissions results for type II board with decoupling capacitors vs. type II board with no decoupling capacitors.

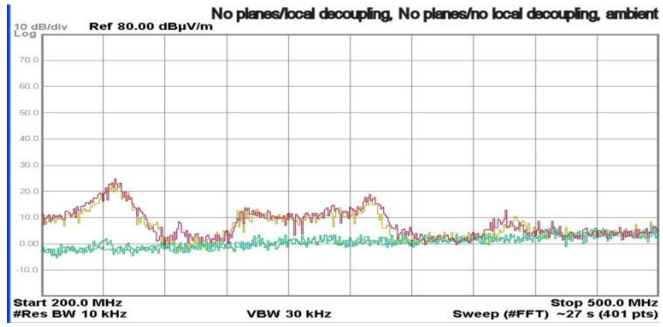

Figure 4.3c – Type II board - Decoupling caps vs. No caps

Decoupling caps show no visible improvement

5. SUMMARY AND CONCLUSIONS

This paper focused on the impact of the power-supply decoupling capacitors on the radiated emissions from a PCB in the 100 kHz – 500 MHz frequency region. Two different board geometries were used, each with and without the decoupling capacitors. It was shown that in all frequency regions, the PCB with the dedicated power and ground planes exhibits lower radiated emissions and is superior to the board with no planes. Except for small frequency regions, PCB with the dedicated power and ground planes does not seem to benefit from the use of the decoupling capacitors. PCB without dedicated power and ground planes does not benefit from the use of the decoupling capacitors. In the frequency range 200 MHz-500MHz, the decoupling capacitors showed on effect on the radiated emissions.

REFERENCES

[1] Bruce R. Archambeault, *PCB Design for Real-World EMI Control*, Kluver Academic Publisher, 2002
[2] Henry W. Ott, *Electromagnetic Compatibility Engineering*, Wiley, 2009
[3] Clayton R. Paul, *Introduction to Electromagnetic Compatibility*, 2nd Ed., Wiley Interscience, 2006
[4] B. Adamczyk, J. Teune, *Decoupling Capacitors* – presentation at Gentex Corp., Zeeland, MI, July, 2009