A Study on Power Plane Impedance of PCB and effective utilization for EMC

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1 Introduction

In the fast-evolving landscape of automotive technology, the integration of sophisticated electronic systems has emerged as a pivotal force driving innovation and performance enhancement. Central to this transformative evolution are Printed Circuit Boards (PCBs), which serve as the backbone of electronic systems in vehicles, enabling seamless communication and control. The applications of PCBs in automotive electronics have become integral to the functioning of modern vehicles, contributing to safety, efficiency, and overall performance. These complex electronic systems encompass a diverse range of applications, including engine control units, infotainment systems, advanced driver assistance systems (ADAS), and electric powertrains. The realm of electronics especially for automotive industry see a high demand in high-speed electronics from the past years, and due to these high-speed applications, there is a demand for the Electromagnetic Compatibility (EMC) of the product that performs with especially the high-speed signals. EMC is a critical consideration due to the increasing complexity of electronic systems integrated into vehicles.

These systems include engine control units, communication networks, sensors, infotainment systems, and more. The interactions among these components can lead to electromagnetic interference (EMI), potentially resulting in malfunctions, degraded performance, or safety issues. To address EMC challenges, automotive engineers employ various techniques and technologies. Shielding, grounding, and filtering methods are commonly used to minimize electromagnetic interference. Additionally, strict testing standards and regulations are in place to ensure that vehicles comply with EMC requirements. Compliance with these standards helps prevent electromagnetic disturbances both within the vehicle (intra-vehicle EMC) and between vehicles and external sources (inter-vehicle EMC).

In the recent days due to the advancement of the high frequency systems the PCBs need high voltage/current requirements even at higher frequencies where traditional components like capacitors and inductors do not behave. At these frequencies we can use the capacitance formed by the power planes [1]. This paper studies the effect of adding vias and capacitors to the power plane of the PCB and their effect on the series self-resonance and the parallel self-resonance of the plane which in turn affects the characteristics of the power plane [2].

1.1 Overview

In PCB level, the EMC problems starts to appear significantly due to different reasons, here in this paper we discuss the reasoning and analysis of one of the unintended radiations that may occur at our frequency of interest, i.e., the radiation due to the power plane of the PCB which like other radiations say due to voltage regulators or SoCs are vigorous. The figure 1 shows a basic stack up of a 4-layer PCB.

#	Name	Material	Type	Weight	Thickness	Dk	Copper Ori		Top Ref	Bottom Ref	Width (W1)	Impe...	Devia...	Delay...
	Top Overlay		Overlay											
	Top Solder	Solder Resist	Solder Mask		0.01016mm	3.5								
1	Top Layer		Signal	1oz	0.035mm		Above	✓		2 - Layer 1	0.11652mm	49.99	0.01%	5.9541...
	Dielectric 2	PP-006	Prepreg		0.07112mm	4.1								
2	Layer 1	CF-004	Signal	1oz	0.035mm		Above	✓	1 - Top Layer	3 - Layer 2	0.07141mm	50.01	0.02%	6.8969...
	Dielectric 1	FR-4	Dielectric		0.32004mm	4.3								
3	Layer 2	CF-004	Signal	1oz	0.035mm		Above	✓	2 - Layer 1	4 - Bottom L...	0.07141mm	50.01	0.02%	6.8969...
	Dielectric 3	PP-006	Prepreg		0.07112mm	4.1								
4	Bottom Layer		Signal	1oz	0.035mm		Below	✓	3 - Layer 2		0.11652mm	49.99	0.01%	5.9541...
	Bottom Solder	Solder Resist	Solder Mask		0.01016mm	3.5								
	Bottom Overlay		Overlay											

Figure 1: Stack up of the designed 4-layer board.

The power planes are nothing rather than a microstrip patch and which will act as an antenna at a certain frequency. Thus, a power plane can be a good candidate for acting as a patch radiator. The study radiation can be eliminated from the desired frequency is being studied.
Typically, the above-mentioned phenomenon is observed in 4-layer PCB boards where we have dedicated signal and power planes, where power plane has a contact with a direct ac source say IC excitation signal and the whole power plane can now act as a good radiator which could be seen at the frequency of interest.

2 Methodology

The understanding and the study have been observed from a 3D simulation software known as Computer Simulation Technology (CST) Studio Suite. The initial studies such as how a metallic patch can radiate at a specific frequency, how does the resonant frequency change as we change the excitation etc. are performed on CST before concluding. A practical scenario has also been explained for the same to provide a detailed clarity. The approach of power plane resonance can be observed by an individual as two different ways i.e., the resonance or the radiation where the whole patch when connected with a 50-ohm impedance can act as an antenna and the radiation where it is formed due the combined effect of RLC. The 3D simulation model for a simple 4-layer PCB and its associated radiation parameters are given below.

The 3D model for the 4-layer PCB is provided below, the excitation is given as a practical scenario where an IC will provide an AC signal to the power plane.

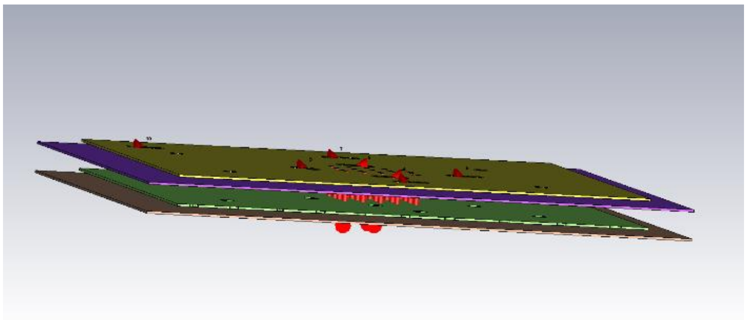

Figure 2: 3D view of the 4-layer board.

2.1 The use of power planes in practical automotive ECUs

The power plane structure exhibits characteristics reminiscent of very low-value capacitors, proving particularly effective in the filtration of undesired high-frequency signals. As we delve into frequencies surpassing 400 MHz, the conventional components like inductors and capacitors face challenges as they are reaching their self-resonating points and complicating the intricacies of filter design for high-frequency applications. A strategic approach involves harnessing the parasitic capacitance inherent in the power plane, providing a practical solution to the hurdles posed by traditional components at extremely high frequencies. The inherent capacitance of the power plane becomes pivotal, allowing for effective filtering without succumbing to the complexities associated with traditional components in this frequency range.

Furthermore, the malleability of the power plane's behavior comes to the forefront. Minor adjustments, such as the strategic addition of vias, can be instrumental in fine-tuning its characteristics. In essence, the interplay of parasitic capacitance and strategic adjustments underscores the power plane's significance in optimizing filter designs for demanding high-frequency applications. Upon closer examination, the power plane structure exhibits similarities to an antenna. The impedance when viewed from different pins of the integrated circuits (ICs) reveals peaks, suggesting points where signals may radiate. This radiation poses a concern for radiated emissions, potentially leading to issues in electronic systems.

The impedance at these points implies a potential for signal radiation, and this phenomenon can have cascading effects. The emitted noise can couple with various other circuitry, potentially impacting the functionality of surrounding circuits. The coupling of this noise introduces a risk of interference, potentially causing disruptions in the normal operation of electronic components and systems. This highlights the importance of carefully managing and optimizing power plane structures to mitigate the risks associated with unintended signal radiation and the subsequent impact on circuit functionality.

3 Analysis

3.1 Study of parallel plate capacitance and plane resonance of a Power Plane

A parallel plate capacitor is a device that uses two metal plates with the same surface area as electrodes. One plate is positive and the other is negative when a power source is applied. The plates are separated by a gap filled with a dielectric material, which doesn't conduct electricity but can hold electrostatic charges without any energy loss. The dielectric material's molecules get an electric dipole moment when placed in an external electric field, which is called electric polarization, or we can say that the effect is formed due to displacement current from one metal plate to another.

The parallel plate capacitance is defined by,

$$C=\frac{\epsilon A}{d}$$

Where ϵ is the relative permeability of the material present, which is free space, A is the area of the metal plate covered and d is the separation between both the plates. The figure 3 shows a representation of the parallel plate capacitor [4].

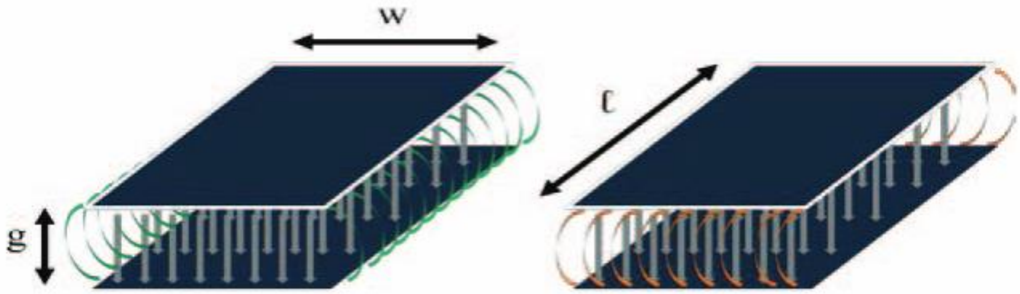

Figure 3: Formation of parallel plate capacitance.

The impedance of the parallel plate capacitor is studied initially for further progress of knowing by how analyzing the impedance profile gives the resonance and further how to mitigate that undesired radiation from the frequency of interest.
A simulation of a parallel plate capacitor with FR-4 dielectric with a relative dielectric of 4.3 is shown in figure 4.

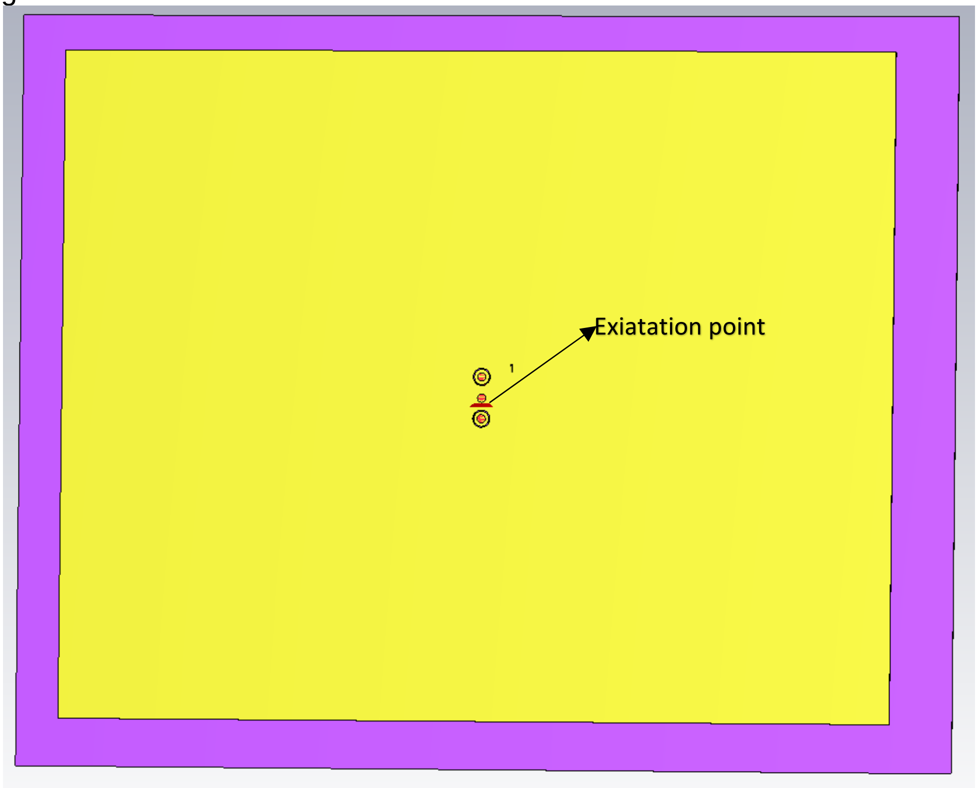

Figure 4: 3D structure of a parallel plate capacitor with FR-4 as dielectric.

For the same the impedance analysis was performed, and the below figure 5 shows the same.

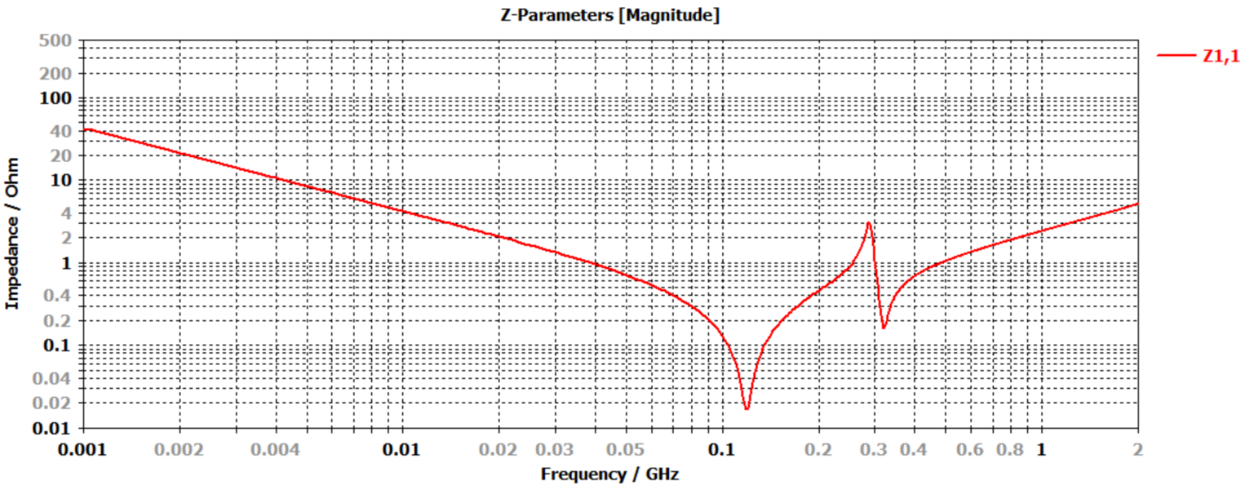

Figure 5: Impedance profile for a parallel plate plane.

The key takeaway from the study was that the patch or the parallel plate capacitor so created is produce a capacitance with self-resonating frequency at 400 MHz and the plane can radiate which is based on its cavity dimension at 1.13, 1.48 and 1.89 GHz. However, for the study we have considered an actual scenario where we have an IC as the excitation source since in PCBs IC plays an important role of providing and receiving necessary signals to other components or peripheries so the same IC can generate an unintentional signal if which approaches other components or peripheries the overall performance can be compromised.

3.2 Study of capacitor variation on power plane

Generally, it is a practice to keep decoupling capacitors near to the IC which can pave low impedance path to the high frequency currents, it is said that one should keep the decoupling capacitors as much as near as possible. since there is a probability of unwanted signals or noise being generated. The presence of decoupling capacitors closer fitters the noise immediately which ensures lesser coupling / radiations. Figure 6 shows how a series of capacitor is mounted on a power plane.

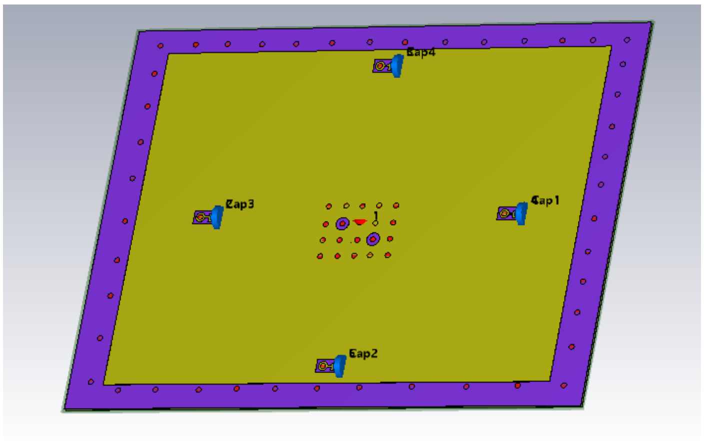

Figure 6: Capacitor positions on the power planes.

Different iterations of simulations are done for different positions where the capacitors are kept i.e., the positions of the capacitors are moved from the near vicinity of the IC to the very far end of the plane. The figure 7 below shows the impedance analysis of the effect of adding capacitors on the plane.

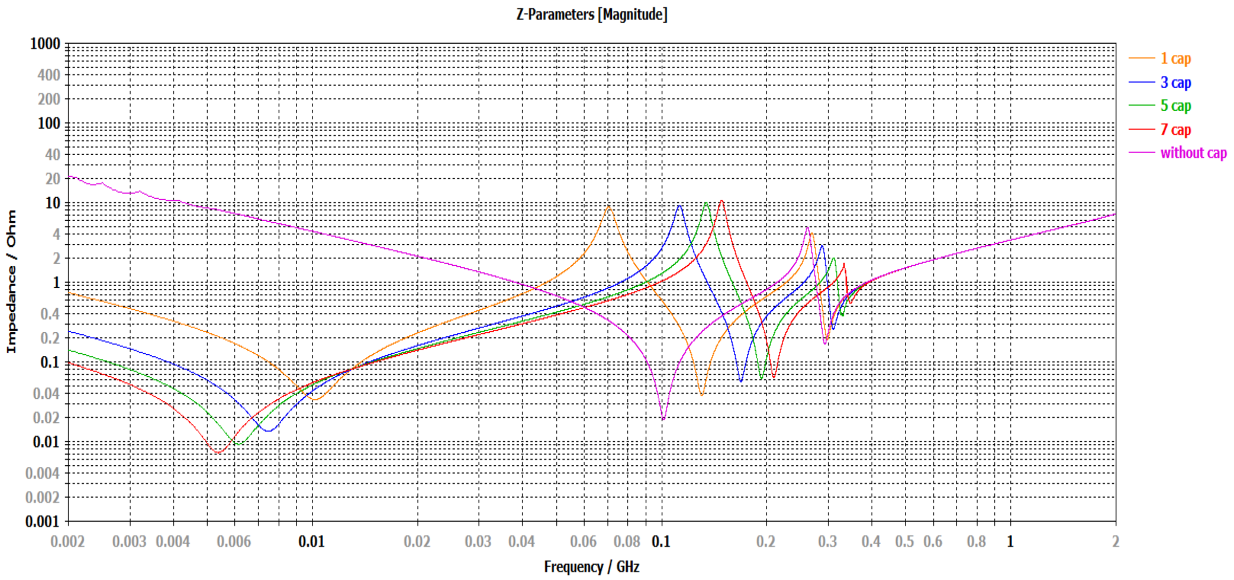

Figure 7: Impedance profile for different numbers of capacitors on the power plane.

The planes will have a parasitic capacitance and here multiple iterations are performed to justify the results. Capacitors when kept on the power plane gives generally the self-resonant frequency

of that chosen capacitor which can be seen at the first series dip forming at frequencies 4 MHz, on adding more capacitors it has been shifted to 7 MHz and 12 MHz respectively.
This has made way to form a new resonance due to the overall parasitic capacitance and the parasitic inductance of the leads of capacitors which can be observed at 70 MHz, 150 MHz, and 180 MHz for single capacitor, four capacitors and seven capacitors respectively. By adding a capacitor, the signal sees an overall impedance rather than just the parasitic capacitance of the planes, one can observe that there is significant variation in the overall capacitance when comparing plane with single capacitor, with four capacitors and finally seven capacitors and the self-resonant frequency of the capacitance due to the plates can be observed at 140 MHz, 180 MHz and 220 MHz for single capacitor, four capacitors and seven capacitors respectively. Adding the capacitors to the power planes does not have an effect to the resonance formed by the parallel plates.

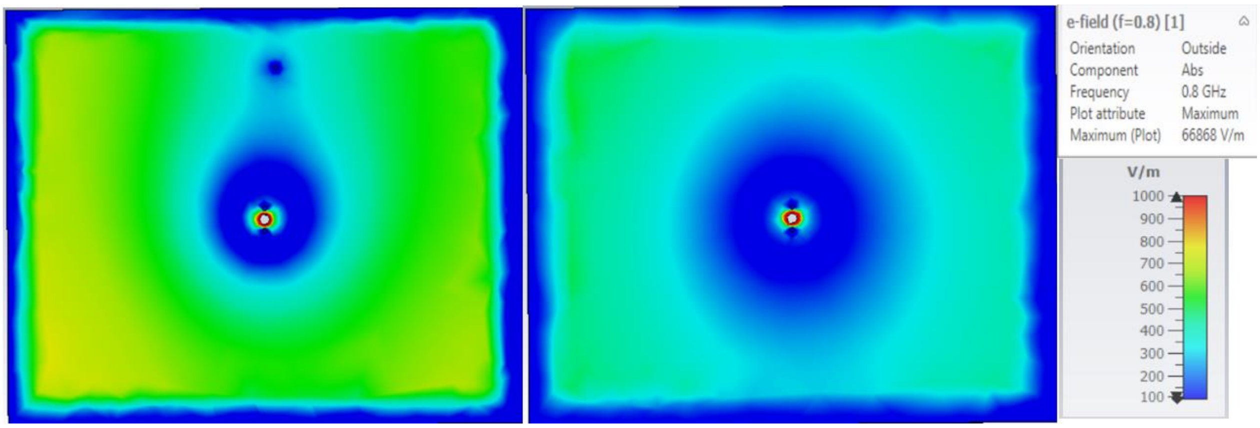

Figure 8: Phenomenon of ac short at 800MHz

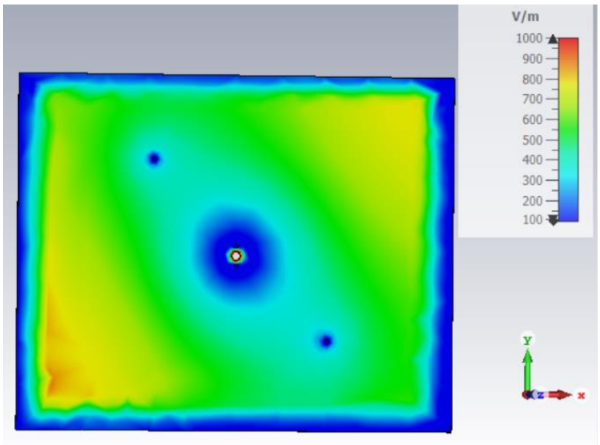

Figure 9: Phenomenon of ac short with 2 capacitors at 800MHz for two capacitors

The shift of the series parallel plate resonance is formed due the dominance of inductive parasitic at high frequencies which means that the capacitor will act as an AC short for the incoming signal. From the above figure 9 when ac signal is provided each side of the plates accumulate positive and negative charges which fluctuates back and forth, and a wave is formed between the two edges. But when a capacitor is added at higher frequency, since the inductive effect dominates the positive and negative charges accumulate between one side and the edge where the capacitor is added, so the signal wave is formed between those points.

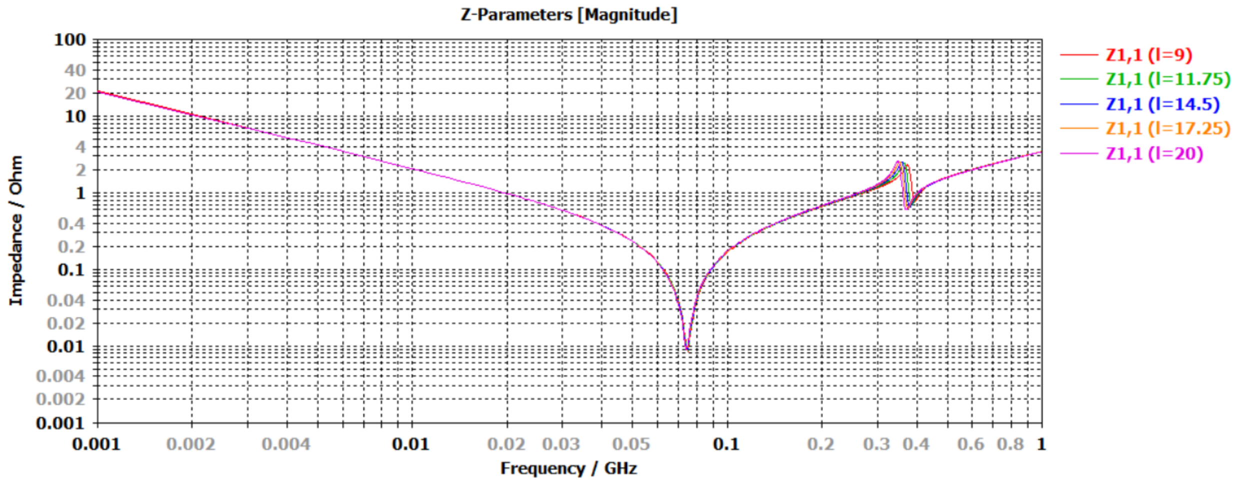

Figure 10: Impedance profile for different positions of capacitor.

The above figure 10 shows the impedance profile of power plane due to change in positions of the 4 capacitors and we can observe that due to the capacitor act as ac short at higher frequencies it acts as a visa and the there is a shift in parallel self-resonance.

3.3 Study of shorting vias on power plane

The study of vias was done to estimate the EMC level remediation, here the initial assumption was weather the same power planes should be shorted together. Forefront to this vias were stitched at four sides of the plane and was varied along the x-y axis. The figure 11 shows how the vias are stitched.
The impedance analysis was done for planes with power with and without shorted and it was observed that by adding a shorting via the resonance caused by the parallel plates was shifted to a higher frequency as shown in figure 11 [3]. Initially the resonance was observed at around 500 MHz, after adding shorting vias the resonance was observed at 900 MHz.

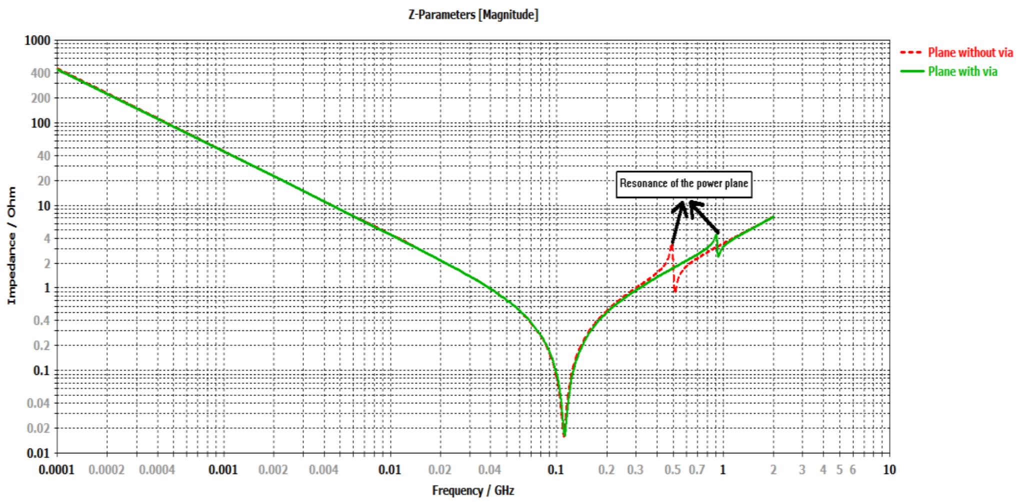

Figure 11: Impedance profile for with and without through hole via on power plane.

3.4 Case study: failure analysis

The below graph depicts the change in the impedance of a power plane where blue represents the impedance of the power plane without any capacitors and the green represents the impedance of the power plane with capacitors placed which shows that the placing the capacitors do not decrease the impedance but also effect the frequency at which the power plane behaves as an antenna.

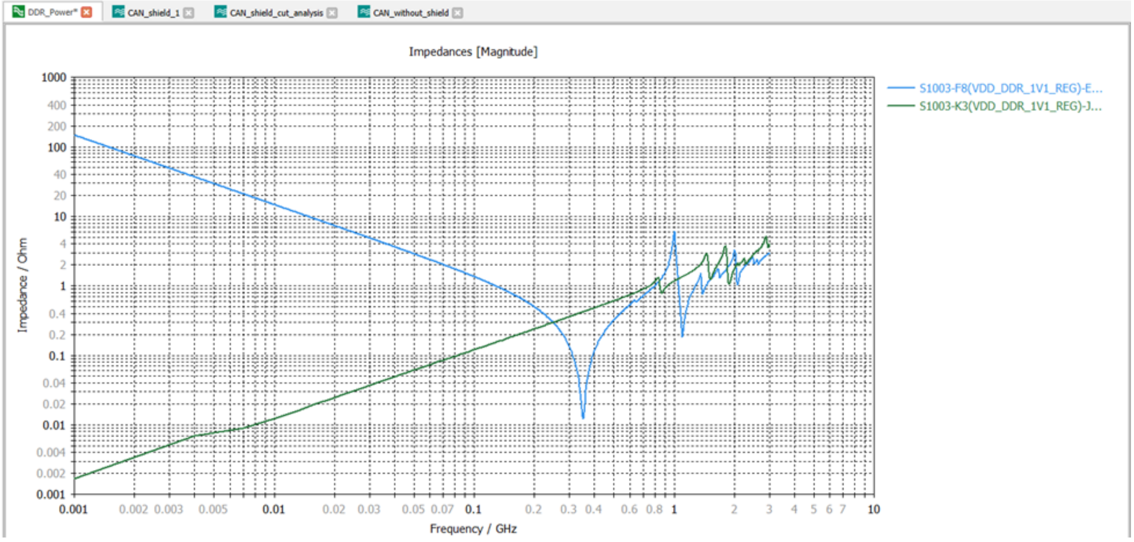

Figure 12: Effect of adding capacitors on power plane.

In future scope can be extended to study of the scalability of this phenomenon on the multi layered board and the measurement study of the radiations can be done.

Literature

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