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Power Bus Noise Reduction Using Power Islands in Printed Circuit Board Designs

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Abstract: Power islands are often used to isolate devices that put noise on a power bus from devices that may be susceptible to power bus noise. At high frequencies however, the effectiveness of these islands depends on the implementation. This paper experimentally investigates the effectiveness of different power island structures at frequencies up to 3 GHz.

INTRODUCTION

When digital and analog components are located on the same printed circuit board, their power supplies are often isolated. This is done to prevent noise from the digital components from affecting the operation of the analog components. On printed circuit boards with power and ground planes, isolation is achieved in part by gapping the power plane between the analog and digital components resulting in *power islands*.

Digital devices can draw high levels of current from the power bus when they switch. These spikes of current result in voltage spikes on the power bus. In theory, gaps in the power plane between the digital and the analog sections of a printed circuit board prevent current and voltage spikes on the digital power from coupling to the analog section. In the absence of any direct connection between two power islands, the only mechanism for coupling noise from one island to the other is the electric field coupling across the gap. This coupling capacitance is typically much smaller than the interplane capacitance present in the power bus structure.

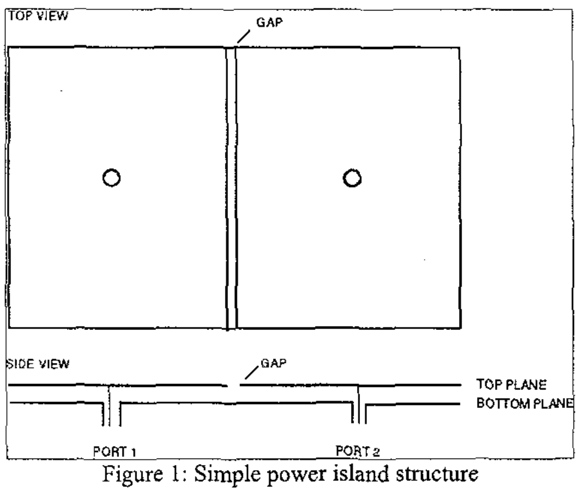

Figure 1: Simple power island structure

TWO-LAYER BOARD MEASUREMENTS

Figure 1 shows a simple two-layer board that was built to illustrate the effectiveness of various power-island isolation strategies. The board is 6 inches long, 4 inches wide and 0.063 inches thick. It consists of two copper planes separated by FR-4. The top plane is gapped, dividing the board into two regions. A short length of semi-rigid coax is attached to the center of each region. Noise is injected into one of these coaxial probes from a network analyzer. The second coaxial probe is used to monitor the voltage induced in the region on the opposite side of the gap. Both the source and receiver impedances are 50 ohms. A schematic representation of the test configuration is shown in Figure 2.

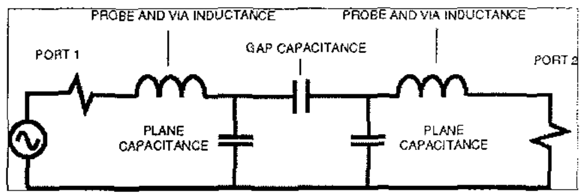

Figure 2: Circuit model of simple power island structure

Modeling the gap impedance as a capacitance suggests that greater isolation should be achieved with wider gaps. Figure 3 shows the measured transfer coefficient, S21, for the board in Figure 1 with various gap widths. The uppermost curve was obtained using a 16-mil gap. Each time the gap width is doubled additional isolation is obtained. This effect is most apparent when the gap width is approximately equal to the plane separation.

Note that even a narrow gap appears to provide very effective isolation between the two planes at all frequencies except approximately 30 MHz. At 30 MHz, a resonance between the probe-via inductance and the plane capacitance creates a peak in the measured response.

Figure 4 compares the measured isolation of a gapped plane to the results obtained from a solid plane, a gapped plane with a narrow bridge over the gap and a gapped plane with a ferrite bead connecting the planes. In this figure, the measured frequency range was extended to 3 GHz. Below 1 GHz, the gapped plane and the gapped plane with a ferrite bead provide much more effective isolation than the ungapped plane or the gapped plane with the narrow bridge. Above 1 GHz, the effect of the gap is less noticeable. Peaks in the response appear at 1.5, 2, 2.4, and 2.8 GHz.

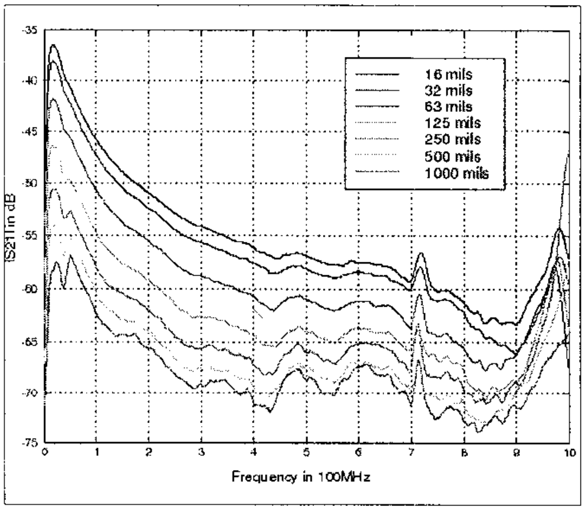

Figure 3: Effect of gap width on coupling

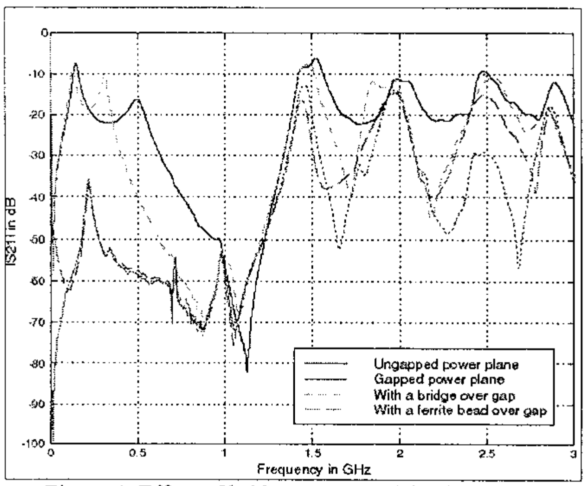

Figure 4: Effect of bridge on power island coupling

The peaks in the response above 1 GHz correspond to resonances in the power-island structure. For example, at 1.5 GHz the width of the test board is approximately one wavelength,

$$\lambda = c\frac{c}{\sqrt{\varepsilon_r}f} = \frac{3x10^8\ m/s}{\sqrt{4}\left(1.5x10^9\ s^{-1}\right)} = 10\ cm = 4\ in.$$

This corresponds to a mode [(2,0) mode of each island] that is driven very effectively by a high-impedance source near the center of the plane. At 2 GHz, each power island is one wavelength long [(0,2) mode]. At 2.5 GHz, the (2,2) mode is excited. When both islands are resonant, even a weak coupling between them will cause the voltage on the isolated island to be comparable to the voltage on the driven island.

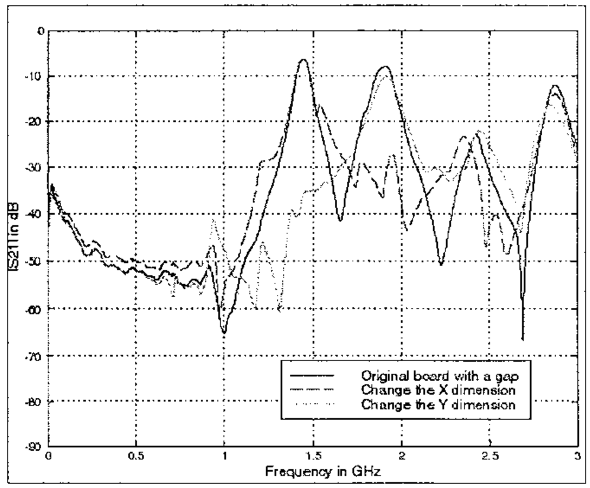

Figure 5: Effect of varying the size of the driven plane

Figure 5 shows the effect of varying the dimensions of the driven island. Decreasing the width of the driven island from 4 inches to 3 inches eliminates the peak in the response at 1.5 GHz. This peak had resulted when both islands were simultaneously resonant. By changing the width of the driven plane, the two islands no longer share a common (2,0)-mode resonant frequency.

Reducing the length of the driven plane from 3 inches to 2 inches eliminates the peak at 2 GHz. This is because the two islands no longer have a common (0,2)-mode resonance.

Measurements were also made of a personal computer motherboard with a power island. The motherboard dimensions and the approximate location of the power island are illustrated in Figure 6. Since the power island structure was on layers 2 and 3 of the motherboard, it was not possible to evaluate the effect of eliminating the power island on the motherboard itself. For this measurement, a two-layer mock-up of the motherboard was built that had similar dimensions. Figure 7 shows the measured transfer coefficient between probe locations 1 and 2 of the mock-up with and without the gap. At most frequencies, the measured transfer coefficient of the gapped structure is well below the transfer coefficient of the solid plane configuration. At these frequencies, the gap between the two islands provides effective isolation. However around 1.7 GHz, there is very little difference between the two configurations.

At 2.7 GHz, the island height and the distance from the top edge of the island to the top edge of the motherboard are approximately one wavelength. Therefore, 2.7 GHz corresponds to a resonant frequency of both the island and the motherboard. The resonance has a current null at the location of the gap and the gap is relatively ineffective.

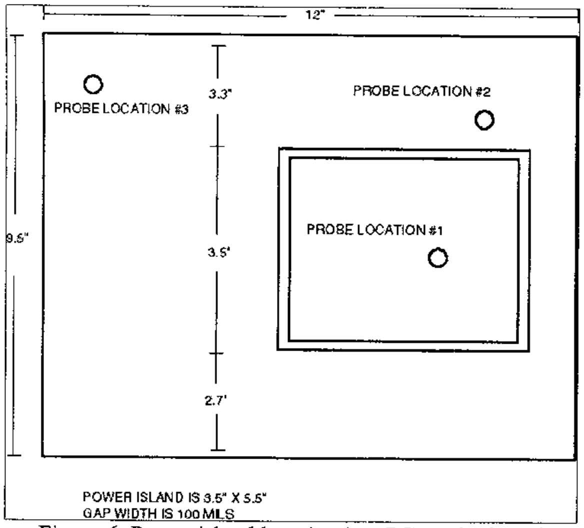

Figure 6: Power island location in a PC motherboard

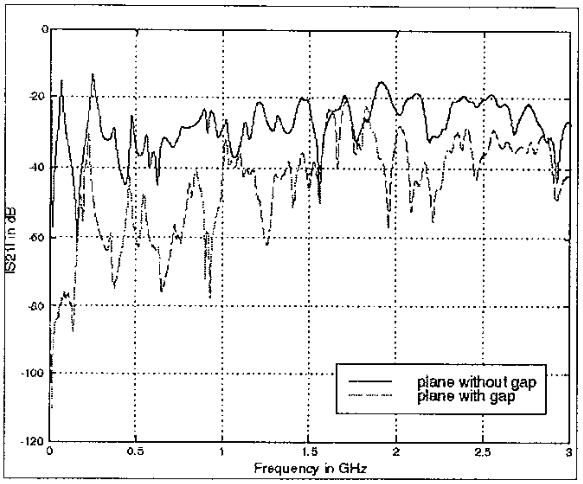

Figure 7: Measured S21 with and without power island

At probe locations that did not excite common resonances of the island and the motherboard, the isolation was good at all measured frequencies. The solid curve in Figure 8 shows the measured transfer coefficient between probe location 1 and 3 on the unpopulated motherboard. The isolation is greater than 40 dB above 300 MHz.

A measurement of the populated board shows significantly better isolation between the islands at nearly all frequencies below 2.5 GHz. From 0 to 800 MHz, the bulk and local decoupling capacitors on the board are still effective. Above 2.5 GHz, the board resonances are damped by the components on the board.

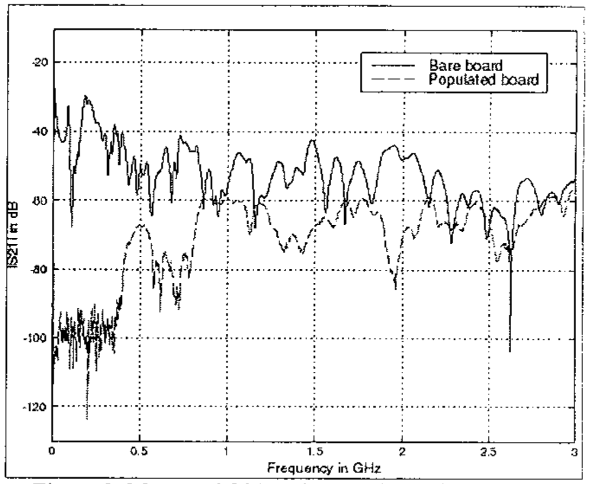

Figure 8: Measured S21 on bare and populated boards

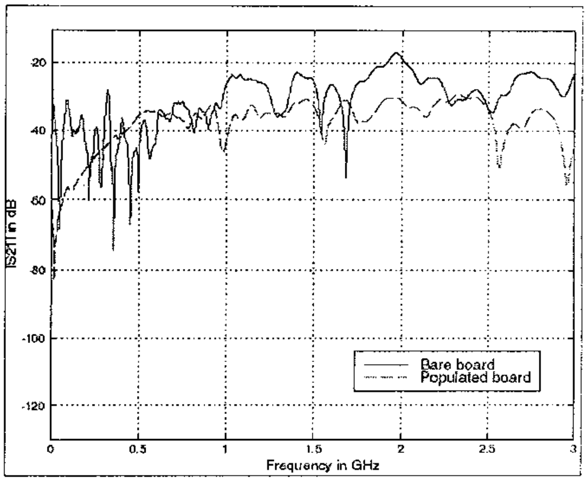

Figure 9: Measured S21 between probes in close proximity

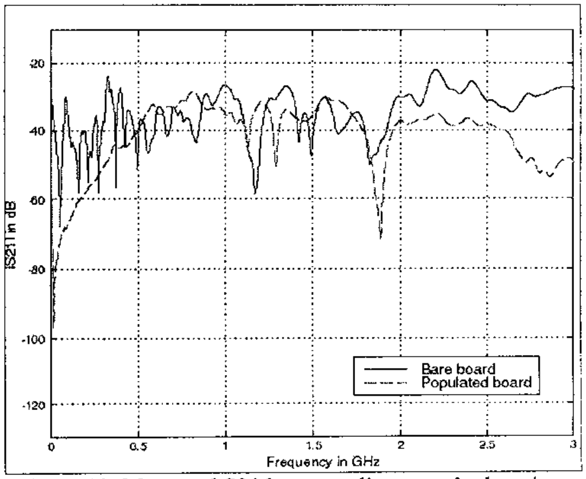

Figure 10: Measured S21 between distant probe locations

Figures 9 and 10 show similar measurements with different probe locations. The probes in the first measurement are located in close proximity on opposite side of the gap. The probes in the second measurement are located at distant points on the motherboard. In both cases, the effect of the bulk and local decoupling capacitors can be observed at low frequencies and there is some dampening of resonances at higher frequencies.

LOCAL DECOUPLING CAPACITORS

In a previous paper, the authors showed that boards with closely spaced power and ground plane pairs generally do not benefit from added decoupling capacitors at frequencies above about 100 MHz [1]. Four-layer boards however, and boards with approximately 40 mils or more of spacing between the power and ground planes benefit from local decoupling caps at frequencies well beyond 100 MHz. This is partly due to the decreased effectiveness of the interplane capacitance and partly due to the mutual inductance between the source and decoupling capacitor vias [2].

Figure 11 shows the results of an S21 measurement on an unpopulated board with and without decoupling capacitors mounted near the probe locations. The probes are both located on the power island. Note that the decoupling capacitors effectively increase the isolation between the two probes at nearly all frequencies up to 3 GHz.

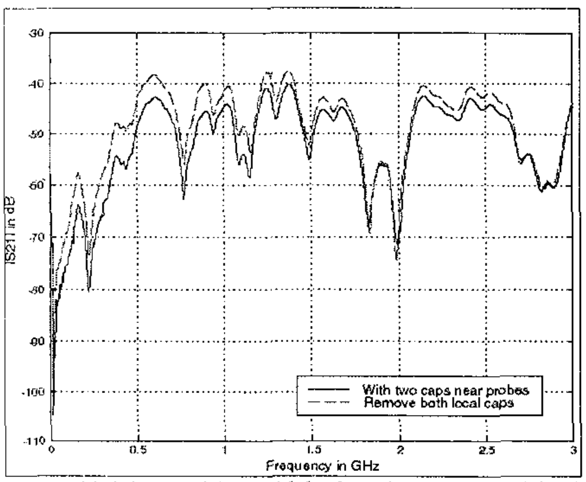

Figure 11: Measured S21 with both probes on power island

When the probe locations are on opposite sides of the gap however, the effect of the decoupling capacitors is less significant at frequencies above 1 GHz as indicated in Figure 12. Below 1 GHz, the decoupling capacitors lower the voltage on the planes and the coupling across the gap is proportional to the voltage on the planes. Above 1 GHz, the situation is more complex and a better model is required to predict how the decoupling capacitors and the gap work together to provide isolation between any two probe locations.

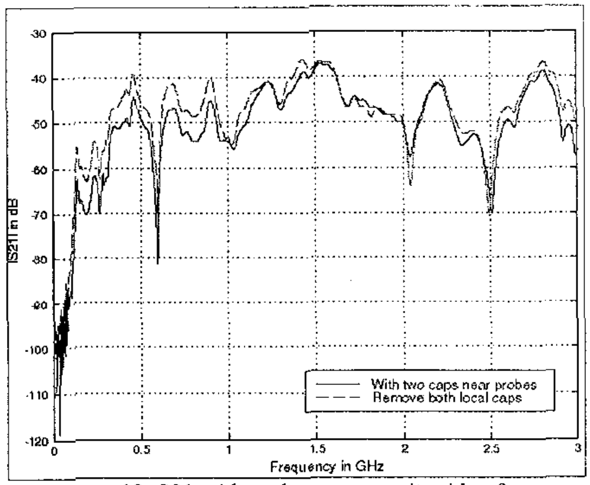

Figure 12: S21 with probes on opposite side of gap

SUMMARY

This paper has presented several measured results illustrating the effectiveness of power island structures for isolating power bus noise. Bridges between islands and power bus resonances can cause power islands to be completely ineffective at some frequencies. However, well-designed power islands can provide an inexpensive and effective means for reducing power bus noise.

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[2] T. H. Hubing, T. P. Van Doren, F. Sha, J. L. Drewniak, and M. Wilhelm, "An Experimental Investigation of 4-Layer Printed Circuit Board Decoupling," *Proceedings of the 1995 IEEE International Symposium on Electromagnetic Compatibility*, Atlanta, GA, August 1995, pp. 308-312.