Virtual Ground Fence: A Simple Method for Protection against High Frequency Simultaneous Switching Noise

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***Abstract*—When integrating sensitive RF analog devices with complex VLSI digital components, simultaneously switching drivers cause supply voltage fluctuations which can propagate both horizontally and vertically between the power/ground planes. The same voltage source on a printed circuit board can be shared to increase power efficiency and reduce space used. In order to accomplish this, on board filtering is needed to isolate the noise between these two types of devices for proper operation. Hence, accurate estimation and improvement of the performance of power/ground planes is critical in a mixed-signal system. We present a new method to minimize the noise transfer at high frequencies to the power distribution system, called the Virtual Ground Fence. At its basic level, the Virtual Ground Fence consists of quarter-wave transmission-line stubs that act as short circuits between power and ground planes at their design frequency. We will present various configurations of Virtual Ground Fence for different coupling scenarios.**

I. INTRODUCTION

With circuit designs becoming more compact in today's electronic circuitry the necessity for RF/analog devices to perform in close proximity to complex digital components is here. These digital components include VLSI devices such as FPGAs, which are very common in the advancement of electronic devices today. Unfortunately due to the sensitive nature of RF/analog components the switching noise caused by these digital devices can cause degraded performance or in worst case completely subdue the functionality of the RF/analog part all together. The harmful effect caused by these digital devices is the voltage fluctuation that can propagate both horizontally and vertically between the power and ground planes. If these mixed signal devices share a common power plane, this voltage will create noise and disrupt the functionality of the RF/analog device. This is where power filtering is necessary for both RF/analog and digital components so they can coexist and work properly when sharing the same power plane. Typically, decoupling capacitors are placed to protect the RF/analog devices at these low frequencies. These lumped capacitive elements are placed close to the troublesome digital component to short to ground all voltage fluctuations before they can be propagated throughout the board as seen in Figure 1. Since these filtering elements are still only lumped capacitors their parasitic inductance at higher frequencies becomes significant, so protection at RF frequencies become nonexistent. The need for another form of power filtering is needed to protect sensitive RF/analog devices such as low noise amplifiers (LNA). When dealing with higher frequencies the wave length of the propagated wave reduces greatly so high frequency transmission line filtering can be implemented since the physical size of resonators can now fit on printed circuit boards. One method of creating this high frequency filter is known as an Electromagnetic Band-Gap Structure (EGB) [2]. Complex equations are needed to predict the model behavior from such a design and even if the results from the created structure are moderate in performance, the necessary time and resources to fine tune is great. Also the slits needed to create the elegant design come at a price of running into problems for transmission-line return currents to transverse them at high frequencies. In this paper we propose a new design to protect the RF/analog devices at high frequencies. This solution is the Virtual Ground Fence.

This new design was first introduced in [1]. The topic of this paper is the different combinations of the array of such stubs that can be configured for protection against high frequency noise. The Virtual Ground Fence can be as small as an area to fit a single RF device such as a low noise amplifier or as large as the full length dimension of the printed circuit board so any device needing protection is effectively placed inside a Faraday cage, and isolated from the noise in the environment on the printed circuit board. We will present various configurations of Virtual Ground Fence for different coupling scenarios.

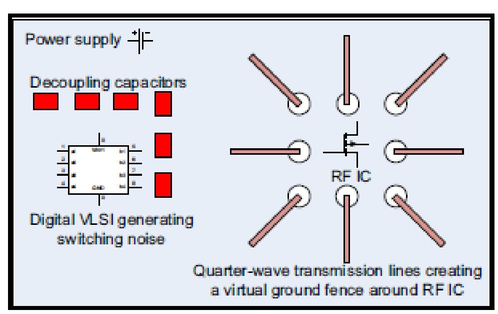


Figure 1: Low and High Power Filtering

II. VIRTUAL GROUND FENCE

The Virtual Ground Fence is composed of many transmission line stubs shorted to the ground plane but routed referenced to the power plane shown in Figure 2. These stubs are left open so at the basic level they look like quarter wave length resonators. Given the proper length they can be designed to resonate at a chosen high frequency so the RF/analog component can be operated without being effected by noise created by the noisy digital devices. This is possible since the resonator will short to ground the voltage noise propagating though the structure at the design frequency. The simplicity of the Virtual Ground Fence comes from using common micro-strip equations when designing for the desired frequency. To prevent any wave energy sneaking past the Virtual Ground Fence we use a 1/10 wavelength (minimum) spacing in between the resonators so all the propagated energy can be caught and shorted to ground.

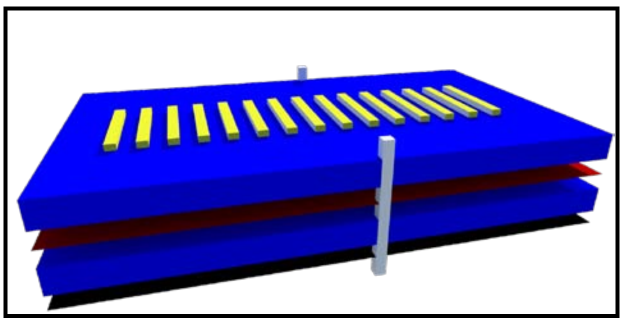


Figure 2: Virtual Ground Fence Model

III. 2.4GHz PASSIVE TEST BOARD

Next we have designed a test board using these quarter wave length resonators using common micro-strips shorted to ground for a frequency of 2.4GHz. The design consists of a 4 layered printed circuit board with 3.8 x 2.5 inch dimensions separated by a dielectric medium of FR4 with constant of 4.6 and a height of .012 inches. The resonators have a length of .630 and sit upon the layer of the FR4 with a width of .020 inches. With an equal spacing of .236 inches in between the resonators, port 2 located inside of the Virtual Ground Fence protected from unwanted noise shown in Figure 3.

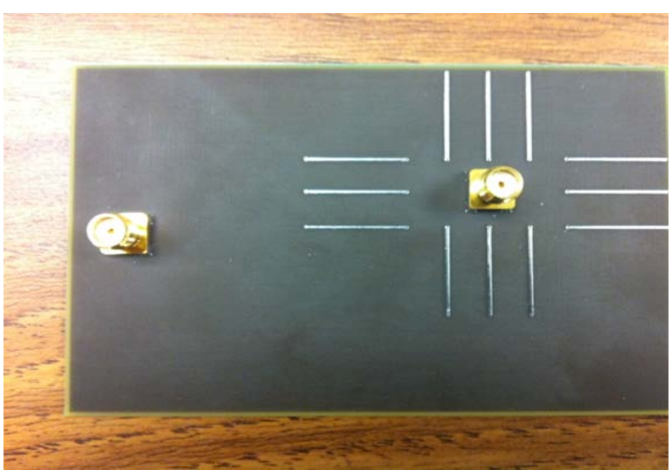


Figure 3: 2.4GHz Passive Test Board Model

The passive test case will be the virtual ground fence designed to protect at 2.4 GHz with a discrete area reserved for integrated circuit chips that are greatly affected by unwanted noise such as a low noise amplifier. These front end RF devices may not need a lot of area on the printed circuit board, so for this test model we have limited the space of protection from the virtual ground fence so the rest of the printed circuit board can be used for other items who are unaffected by undesirable noise such as digital devices. 2.4 GHz is a critical frequency in devices such as those based on Blue-Tooth standard. As the baseline board, we also designed a test board without any virtual ground fence.

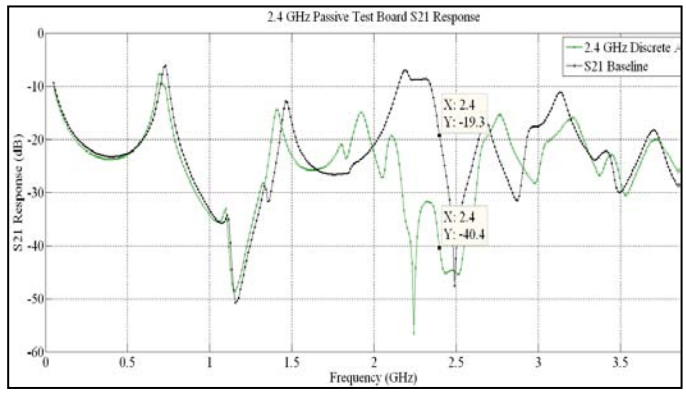


Figure 4: 2.4 GHz Passive Test Board Results

Looking at the S21 simulation in Figure 4, the passive test model results show us a rejection of 20dB at the design frequency of 2.4 GHz inside the virtual ground fence. This 20dB of rejection will help in protecting any unwanted noise inside the area of the virtual ground fence. When a low noise amplifier is placed within this enclosed section of the printed circuit board, we will see the virtual ground fence ability to reject any unwanted noise at 2.4 GHz and short it to the ground plane.

IV. 2.4 GHz HALF BOARD PASSIVE TEST

In order to find the extent on how much area the virtual ground fence can protect from undesirable noise, the area in which will be protected will increase to half the circuit board. Hear the same length micro-strip will be used to keep the same design frequency of 2.4 GHz. Using this virtual ground fence configuration, complete front RF components or other sensitive analog devices can now be populated without restriction on half of the printed circuit board as shown in figure 5.

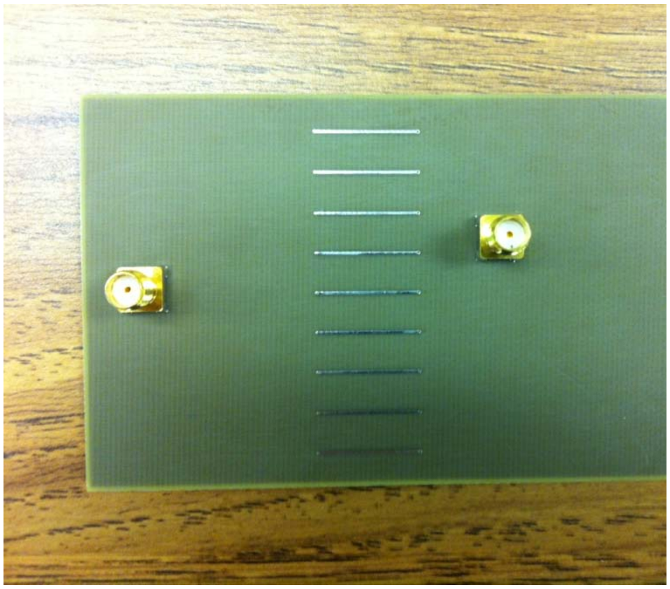


Figure 5: 2.4GHz Half Board Passive Test Model

The S21 results from the half board passive test model can be in figure 6.

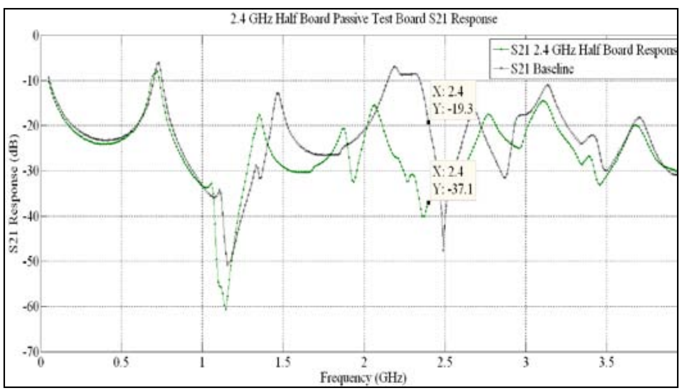


Figure 6: 2.4GHz Half Board S21 Frequency Response

Comparing the S21 data taken from the 2.4 GHz half board passive test board and comparing it to the baseline line data we can still see 18 dB of rejection at the design frequency of 2.4 GHz. These results show the virtual ground fence will still behave correctly when its protection stretches half of the printed circuit board. The only physical restriction the virtual ground fence has is the micro-strips must still maintain a 1/10 wave length between each other in order to fully protect the integrated circuits contained inside the virtual ground fence against undesirable noise at the design frequency.

V. 2.4 GHz ACTIVE TEST BOARD

In order to verify the virtual ground fence abilities to protect against high frequency power plane noise, we have made a test model printed circuit board to prove it can reject against undesirables at the known design frequency of 2.4 GHz. Using a LNA (Low Noise Amplifier) as our test component device, it will be placed inside the virtual ground fence. The LNA is a sensitive analog amplifier whose performance is greatly affected by power plane noise. We used an LNA from Hittite Microwave, whose operating range is between 2.3 and 2.5 GHz and a noise figure of 1.7 dB. The LNA will need a +3V dc voltage to operate, so a separate SMA connector will be used to connect this biasing voltage to both the ground and power planes. The LNA we used is a single IC device that encloses all necessary associated components, so no external lumped elements are needed for the device to operate properly. Shown in Figure 5 is the LNA inside the Virtual Ground Fence.

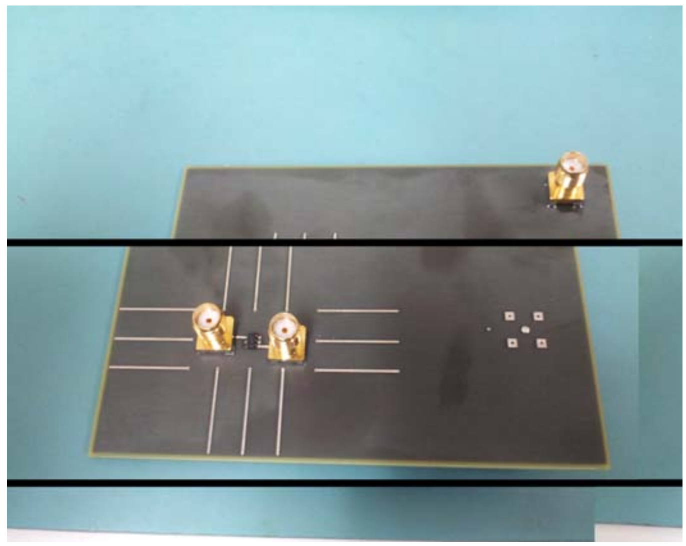


Figure 4: 2.4GHz Active Test Board Model

Once the LNA is operating correctly, there must be some type of digital noise injected into the power plane to verify the virtual ground fence is filtering at the design frequency. Power plane noise is created by a digital signal by Synthessys Reach bit analyser in order to reproduce a digital component in operation. The bit analyser will generate a PRBS bit sequence to simulate the digital noise to affect the LNA's performance at the design frequency. Figure 5 shows the frequency response of the PRBS bit sequence that is introduced to the active circuit board.

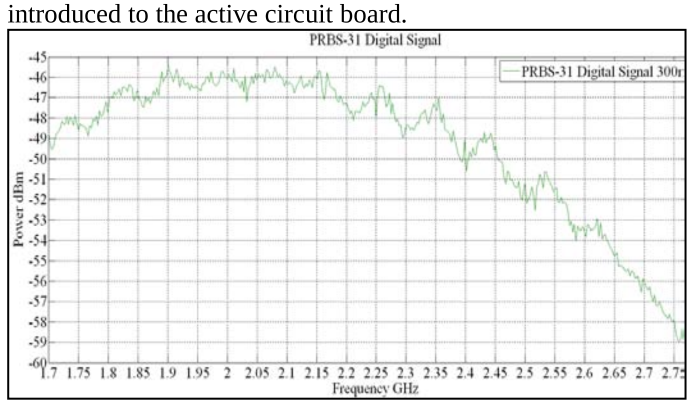
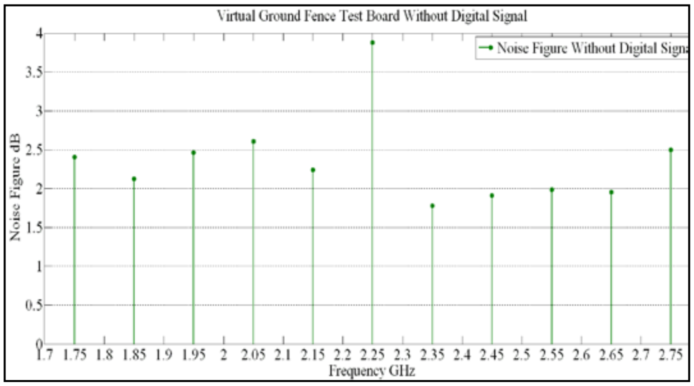


Figure 5: Digital Broad-Band Noise

Hewlett Packard's broad band noise source will be used to inject a known noise level into the LNA. This noise source is connect to Agilent Technologies spectrum analyser with a noise figure meter add on card to calculate the noise figure of the LNA. Figure 6 shows the noise figure of the LNA with no digital noise introduced on to the test model board.



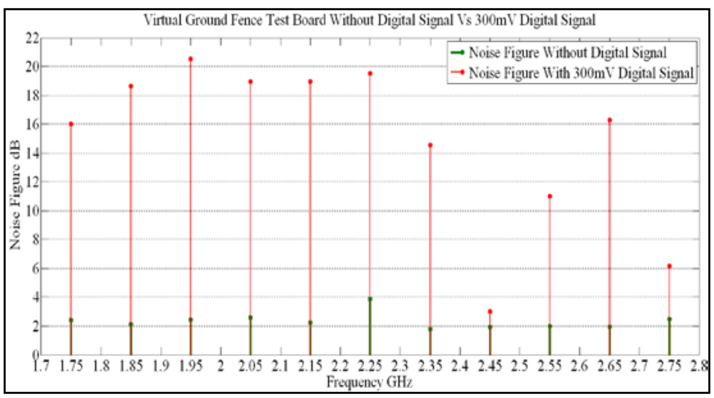


Figure 6: Noise Figure without Digital Noise

When we apply the 300mV digital signal we get the results from Figure 7.

Figure 7: Noise Figure with Digital Noise

The results show at our design frequency of 2.4 GHz we have an increase of noise figure of only 1 dB going from 2 dB to 3 dB. Outside of 2.4 GHz you can see the effects of the digital noise increasing the noise figure of the LNA. This shows the Virtual Ground Fence ability to reject unwanted digital noise.

Using the same digital signal noise source from the previous measurement, we reduce the voltage output to 200mV swing and get the following noise figure measurements seen in figure 8.

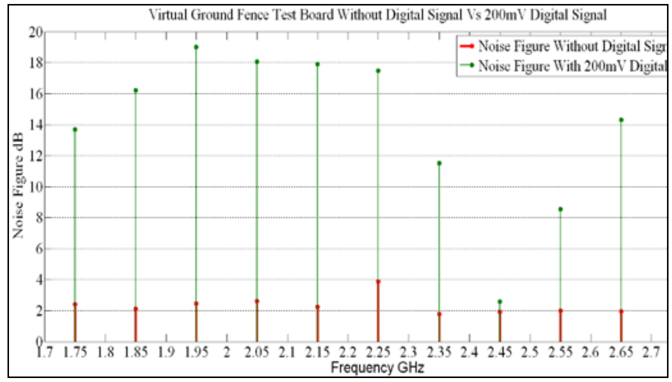


Figure 8: Noise Figure with Digital Noise 200mV

Once again we see great noise reduction around the design frequency of 2.4 GHz. Here the noise figure has only increased 1/2 dB, while the noise found outside the virtual ground fence has raised 17dB. This once again shows the protection at high frequency the Virtual Ground Fence gives.

V. CONCLUSION

The results found when using the Virtual Ground Fence shows high frequency filtering can be accomplished with using common transmission line equations. The design is based on simple quarter wave length micro-strip resonators. Combined with coupling capacitors these filtering methods will protect sensitive RF/analog devices from the voltage fluctuations caused by digital components so common power planes can be shared by both devices.

REFERENCES

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[2] Tzong-Lin Wu, Chien-Chung Wang, Yen-Hui Lin, Ting-Kuang Wang, and George Chang, "A Novel Power Plane With Super-Wideband Elimination of Ground Bounce Noise on High Speed Circuits," *Microwave and Wireless Components Letters, IEEE*, vol. 15, no. 3, pp. 173-176, March 2005.