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A FIELD-PROBING APPROACH AND ITS APPLICATION TO A POWER DISTRIBUTION NETWORK

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Abstract

This study presents a means to probe the electric-field distribution in a microstrip resonator using the existing power/ground pins. The strength of the electric-field could be correlated with the reflection coefficient. Physical mechanism for the position-depended reflection effect is interpreted from the perspective of probe coupling. An application of this method is demonstrated through three phases: determining the maximum field of a microstrip resonator, shaping the geometry at the field bulk, and detuning the resonant frequency of a power distribution network. The results reveal that this approach can be employed to achieve a resonance-free operating environment.

Key words: Resonance, noise, quality factor, high-speed digital system, signal integrity, power integrity.

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I. Introduction

The requests for faster data throughput have led to a demand for increased operating frequency, limiting the maximum noise-induced timing skew. Besides, to reduce the electromagnetic interference and the power consumption, a lower voltage signaling is generally preferable. These requirements motivate this study, with a view to providing a stable voltage supply. However, such a system has rarely been investigated because it normally involves a very complicated network, called a power distribution network (PDN).

Several remedies have been proposed. The most common solution is to add decoupling/bypass capacitors [1-4], which do not change the dc voltage while provide a shorter loop for real-time energy supplement. However, the equivalent series inductance (ESL) of the lumped component limits the application of the decoupling capacitor. Additionally, in some congested substrate layouts, the space is too small to enable these extra capacitors to be allocated.

A multi-layer PDN forms some resonators that could store noise energy. When the operating frequency or its harmonics are close to the resonant frequencies, the supply voltage might fluctuate strongly in time. This effect results in not only power integrity (PI) but also signal integrity (SI) problems. Therefore, the resonant effect must be analyzed in the design phase [5]. Lowering the Q-value can reduce the resonant effect. Two approaches have been proposed. The first is to use lossy dielectric material or using conductor inherent skin loss [6-7]. To meet this requirement, new dielectric material and stackup must be developed. The second method is to add lossy material to the edge of the circuit board edge [3, 8]. This method effectively minimizes the reflection and radiation from the edge discontinuity especially in the high frequency regime, but it fails to provide broadband absorption, because of the absence of appropriate absorbing materials.

Although solutions have been proposed, little work has been conducted to alleviate the resonant effect by detuning the resonant frequency. The objective of this study was to present an approach that staggers the fundamental power/ground plane resonant frequency from the operation frequency and its harmonics. A method for reconstructing the resonant field pattern by external probing was presented and this information further supports the determination of the optimal trimming position.

This paper analyzes the resonant effect of a multi-layer printed circuit broad (PCB) from a frequency-domain viewpoint using an HFSS (High Frequency Structure Simulator, Ansoft [9]) and PowerSI (Sigrity [10]). The field probing technique will be demonstrated by applying it to the circular and rectangular microstrip resonators, providing a fundamental understanding. A Y-shaped layout will then be examined. The field probing result will be compared with the calculated field distribution. Trimming the geometry at the bulk field is shown to be able to detune the resonant frequency.

Table 1. Stack-up of the PCB under study: three layers in unloaded cases and five layers in loaded case. 1 mil = 0.001 in.

Layer	Thickness (mil)	Unloaded case (HFSS)	Loaded case (PowerSI)
L1 (Signal)	1.4		**Metal: copper**
D1 (FR4)	4.0		**dielectric: FR4**
L2 (PWR)	1.4	**metal: copper**	**Metal: copper**
D2 (FR4)	6.0	**dielectric: FR4**	**dielectric: FR4**
L3 (GND)	1.4	**metal: copper**	**Metal: copper**

II. Coupling effect and pattern probing

Table 1 presents the stackup used throughout this paper, regardless of the plane geometry. The relative dielectric constant of FR4 is 4.2 , with a loss tangent of 0.02 at 1 GHz. The thickness of a dielectric layer is typically much smaller than the power/ground plane. Therefore, the electric field is constant and normal to the power/ground plane, but it still exhibits a planar distribution that depends on the boundary condition. This wok will characterize two simple planar microstrip resonators, in terms of their resonant properties using two models: the full wave model (HFSS) and the coupled port model (PowerSI).

The quality factor is a unique property of associated with a resonant system. Measuring quality factor of the system, however, will always perturb the original system. A common approach to measuring the quality factor is to probe it with minimum coupling. However, in a practical measurement setup, the use of a probe connected to the power pin and the nearest ground pin with careful calibration to the probe tip, is more efficient and cost-effective. Accordingly, the probe is strongly coupled with the resonator. The coupling effect will shift the resonant frequency and cause the quality factor to become position-dependent, but it also provides a means of measurement to probe the electric field distribution. The variation in the coupling amount, determined from the simulation results of PowerSI, measures the resonant field strength distribution and support a direct comparison with the measurement.

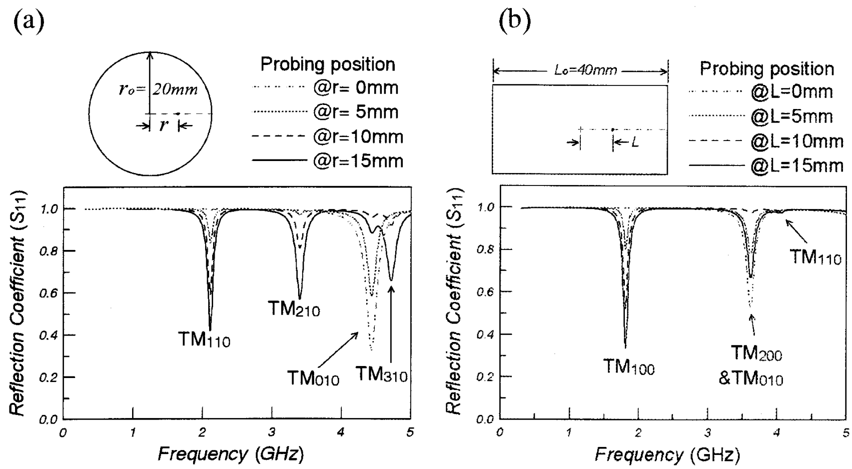

Fig. 1 Frequency response of the reflection coefficient (S_{11}) detected at various: (a) circular disk resonator; (b) rectangular disk resonator.

Figure 1 shows the reflection coefficient (S_{11}) versus the sweeping frequency at various positions for circular Fig. 1(a) and rectangular Fig. 1(b) microstrip resonators, determined using PowerSI. As stated, the response of the curve depends on the position. Higher coupling corresponds to the injection of more energy into the resonator, so the reflection becomes very small. Therefore, if the resonator is probed at its field maximum, then the minimum reflection is obtained. If the resonator is probed at the field minimum, then the signal cannot be coupled into this resonator, causing high reflection or even total reflection. From above understanding, we postulate the relative electric field is related to the reflection coefficient through the following equation,

$$E_R(x,y) = \sqrt{1 - S_{11}^2(x,y)}, \qquad (1)$$

where E_R is the relative electric field strength and S_{11} is the reflection coefficient [11,12]. Both depend on position. Equation (1) yields the relative field distribution. Figure 2 shows the relative field strength of the fundamental mode of the circular (Fig. 2 (a)) and rectangular (Fig. 2(b)) microstrip resonator. The solid lines represent the simulation results of the unloaded field strength (HFSS); the solid dots refer to the case of probing at various positions (PowerSI). Generally speaking, the loaded results agree with the unloaded r esults.

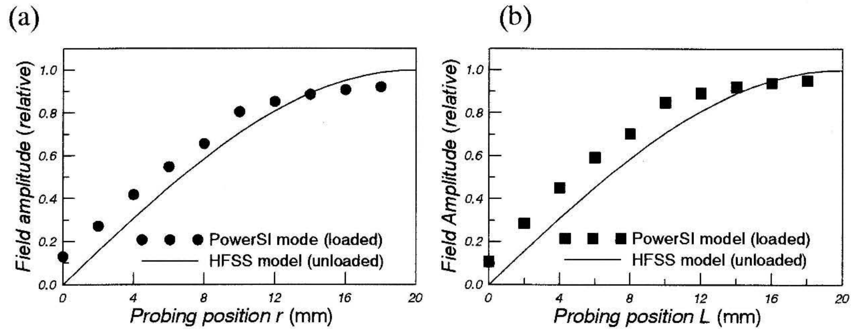

Fig.2 Relative electric field strength obtained for unloaded (lines, HFSS model) and loaded cases (dots, PowerSI) in two resonators (a) circular, along the horizontal axis; (b) rectangular, along the central axis.

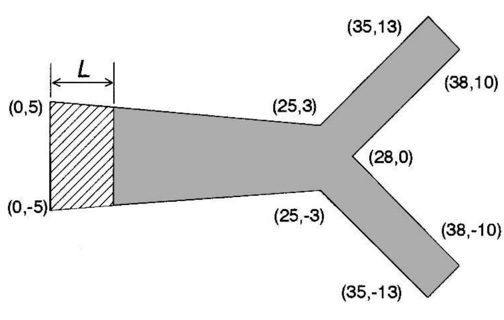

Fig. 3 Planar geometry in the units of mm.

III. Detuning the resonant frequencies

Shapes of power/ground planes are versatile, but the proposed concept can still be applied to detune the resonant frequency. This work will demonstrate the complete trimming processes for a two-layer resonant system, shown in Fig. 3. The dimensions of this layout are illustrated in 2D coordinates in units of mm. The stackup of this layout is the same as in the previous setup.

(a) (b)

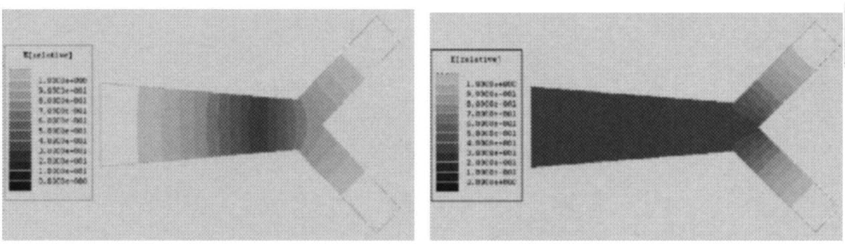

Fig. 4 Electric field pattern of the first two modes : (a) fundamental mode; (b) first high order mode.

Figure 4 plots the field patterns of the first two resonant modes, using HFSS. The fundamental mode (Fig. 4(a), with the lowest resonant frequency of 1.632 GHz) has a field maximum at the central stem and the field variations at the two wings are in phase. However, for the first high order mode (Fig. 4(b), with a resonant frequency of 2.347 GHz), the field variations at the two wings are completely out of phase, resulting in field cancellation at the central stem.

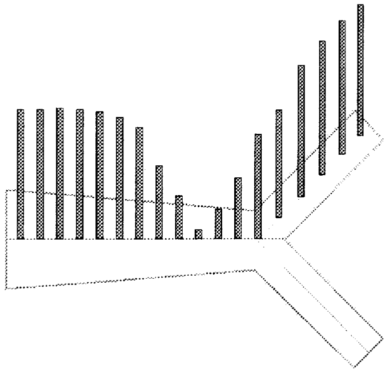

Fig.5 Relative electric field (bar chart), obtained using Eq.(1) at the position where it is probed, is re-constructed using PowerSI.

Figure 5 shows the reconstructed field strength of the fundamental mode by probing at various positions along the central line using PowerSI. Comparing this figure with the corresponding field pattern in Fig. 4(a), reveals good agreement. The field variations at both wings are identical in the fundamental mode, thus only one wing's field strength is shown here. Due to the interference of the probe, the loaded field pattern (Fig. 5) differs slightly from the unloaded one (Fig. 4(a)). Despite this shortcoming, the accuracy suffices to determine the field maximum and be compared directly to the measurement.

Figure 6 shows the variation of the resonant frequency against the trimming length L (defined in Fig. 3). As Fig. 5 reveals, the optimal trimming position is the tip of the central stem, which is in the maximum field region. The resonant frequency in the fundamental mode is raised from 1.632 GHz to 1.826 GHz, if 4 mm length is trimmed from the original length. That the resonant frequency of the first high-order mode is independent of such a trimming position is also verified, based on the argument of minimal coupling.

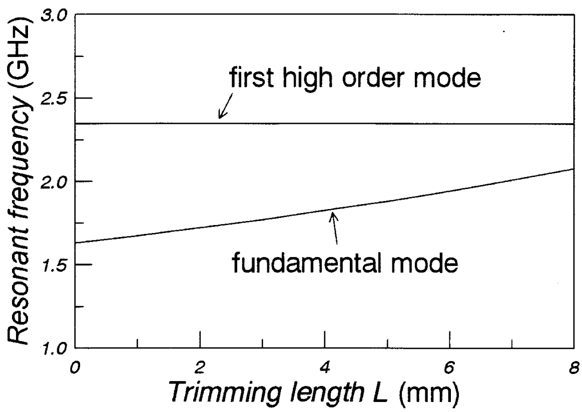

Fig. 6 First two resonant frequencies versus the trimming length L, obtained using HFSS.

IV. Conclusion

This study has presented an effective means of reconstructing the field distribution pattern and an application to detune the resonant frequency accordingly. The proposed method is helpful in reducing the power/ground noise of a PDN and should be considered in the design. Although this work demonstrated only three geometries, the technique is general and can be applied to a much more complicated power/ground layout.

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