Design of Power Plane for Suppressing Spurious Resonances in High Speed PCBs

Seung-Seok Oh · Jung-Min Kim · Jong-Gwan Yook

Abstract

This paper presents a new power plane design method incorporating a single geometry derived from a unit cell of photonic bandgap(PBG) structure. This method yields constantly wide suppression of parallel plate resonances from 0.9 GHz to 4.2 GHz and is very efficient to eliminate PCB resonances in a specified frequency region to provide effective suppression of simultaneous switching noise(SSN). It is shown that with only two cells the propagation of unwanted high frequency signals is effectively suppressed, while it could provide continuous return signal path. The measured results agree very well with theoretically predicted ones, and confirm that proposed method is effective for reducing EMI, with measured near-field distribution. The proposed topology is suitable for design of high speed digital system.

Key words : Simultaneously Switching Noise(SSN), Electromagnetic Interference(EMI), Photonic Bandgap(PBG), Printed Circuit Board(PCB), Parallel-Plate Resonance, Signal Integrity(SI).

I. Introduction

The design of impedance and power/ground distribution networks for high-speed digital and printed circuit boards(PCBs) has become a major challenge to digital engineers due to electromagnetic interference (EMI) problems, mainly simultaneously switching noise (SSN) issues. Combined with higher clock frequencies the increased switching current produces considerable SSN that ultimately degrades the timing margins on critical clock and signal paths, thereby limiting the performance of digital devices. There exist numerous resonances between power and ground planes inside the multi-layer PCB. Since electromagnetic wave generated by the SSN propagates between power and ground planes through the resonances of PCB, SSN affects active devices and signal traces that pass through as well as via holes which exist between power and ground planes. Obviously, the SSN confuses signals flowing on traces to and from chip drivers, and eventually enable signal distortions, uneven power distributions and unnecessary radiated emission, imposing serious EMI issues as well as signal/power integrity problems[1]. As a result, it is impressible to investigate ways to minimize the SSN in high speed digital circuit. There have been numerous studies on analysis methodologies to reduce the SSN by using on-chip and off-chip decoupling capacitors, and by implementing embedded capacitors inside the multi-layer PCB. However, decoupling capacitor has limitation such that it can not provide suppression of SSN up to few hundreds MHz because of inherent parasitic inductances. In case of embedded capacitor, even though it shows improved performance over decoupling capacitor in high frequency region, it can not suppress entire parallel-plate resonances and manufacturing cost is relatively high[2]. Recently, electromagnetic bandgap (EBG) has been studied in order to provide a way to mitigate SSN and several types of EBG geometric have been proposed[3],[4]. Although EBG structures are proved to be quite effective on suppression of SSN, specially designed via holes are needed in multilayer substrate, rendering difficulty in fabrication. Also power plane employing low period PBG structures and constant ground plane has been proposed[5],[6]. Though this structure reveals very wide band suppression of parallel plate resonances, it could cause a signal integrity(SI) problem and spurious radiations from numerous discontinuities. In addition, the characteristics of the PBG-incorporated power plane are dependent on the port location in the PBG cell, that is, if proper port location is not selected in the PBG cell, the desired band stop characteristic is hardly obtained. As a result, this approach is not feasible in realistic situation.

In this paper, another way of designing power plane has been proposed and demonstrated that the parallel plate resonances modes are effectively suppressed in a very wide frequency range. The key feature of this new approach is the application of unit PBG cell, not mul-

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tiple cells, a specific location on a power plane. Of course, when single cell is used, it is not PBG structure anymore. Due to the simplicity of the structure, it is much easier to rout signal lines with minimum discontinuities, rendering minimized spurious radiations as well as cross talk, between adjacent signal lines. Even further, localized geometry helps to decrease SI in high speed digital circuit. For design and optimization of the geometry, 3 dimensional finite element method based fullwave simulation tool has been utilized. The measurement results show good agreement, compared with the predicted performances. Besides, it is proved that proposed structure can be utilized for suppressing SSN through near field measurement.

Ⅱ. Design and Optimization of Power Plane

2-1 Design Ideas

PBG structures are the periodic structures having band gap those forbids propagation of a certain frequency range. Generally, in microwave field, the PBG structure can be realized through periodic etched cells in the ground plane or composing of periodic cells in the power plane. The period which is constant distance between two cells has to be uniformly maintained. For a single period PBG structure, center frequency of the first stopband can be roughly expressed by the period using the formula [7]:

$$f=\frac{c}{\sqrt{\varepsilon_{eff}}}\cdot\frac{1}{\lambda_g} \tag{1}$$

where c is the speed of light in free space, $\lambda_g=2\cdot a$ is the Bragg condition.

To examine the stopband characteristic of PBG structures, the test structure which has power plane composed of two cells cascaded in series was employed. The top view of the test structure is illustrated in Fig. 1, where ports locations are clearly indicated and ground plane is continuous. The geometrical parameters of unit cell are a=30 mm, b=28.5 mm, c=4.5 mm, d=7.5 mm and e=1.5 mm. The dielectric constant of substrate was used 4.4 with a thickness of 0.4 mm (FR4-expoxy). To investigate the periodic characteristic of test structure, the cell with same shape is inserted into between two cells of the test structure, where ports are located in the middle of edge cells. As increasing the number of cell, insertion losses of each case were calculated by FEM (Finite Element Method) based simulator.

Fig. 2(a) shows the stopband characteristics of each case concerning the number of cells. It is clearly seen from Fig. 2(a) that stopbands of each structure show good characteristic of suppression in the range from 0.6 GHz to 3.8 GHz. However a slight difference at 3.9 GHz is seen due to the loss in reference to distance. Furthermore, the calculated values comparatively satisfy

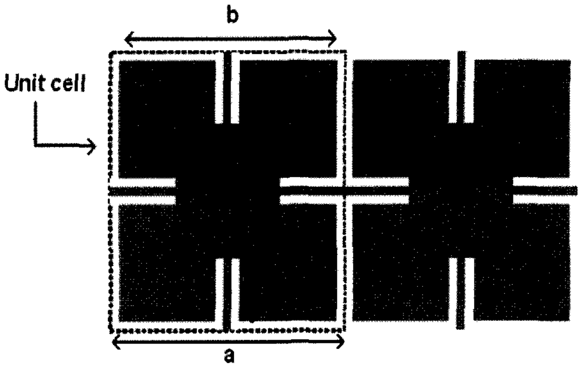
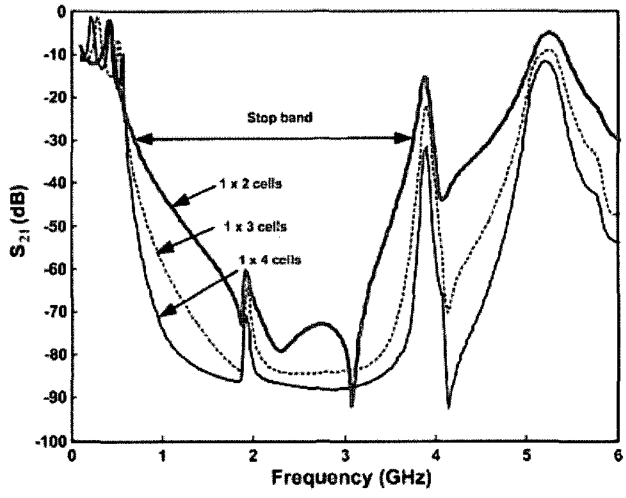
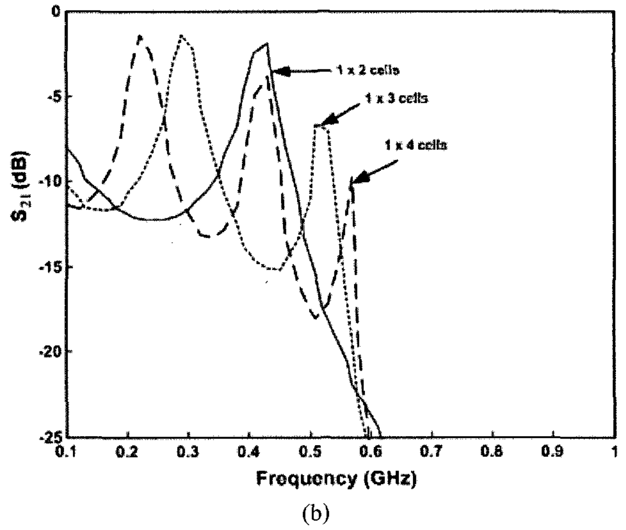


Fig. 1. Test structure.



(a)

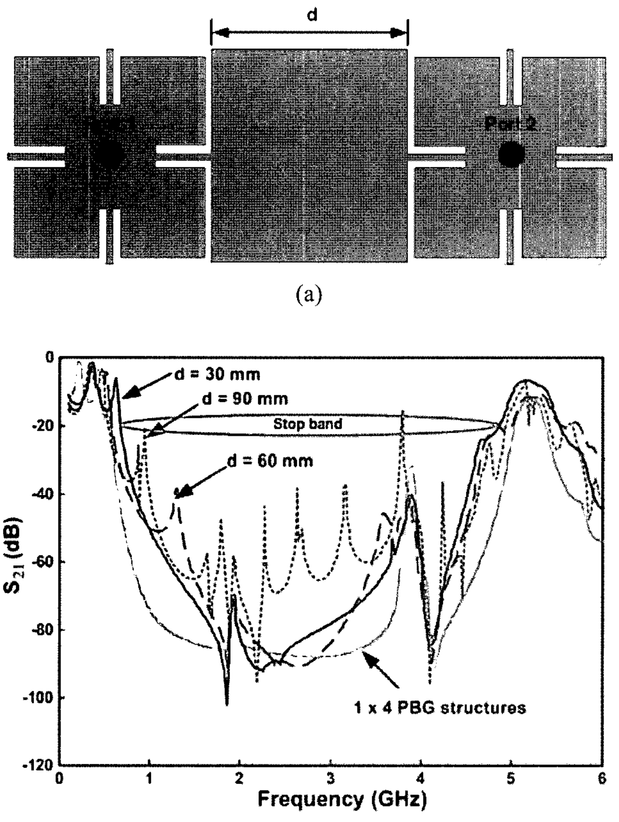


(b)

Fig. 2. Comparison of insertion loss in reference to the number of cells.

the Bragg condition since the center frequency of stopband is about 2.4 GHz. Moreover, based on filter theory, as increasing the number of cells, test structure behaves like a low pass filter using step impedance, and in a Fig. 2(b), a pole is also increased in the low frequency region like a equal ripple response of a low pass filter. It is observed that attenuation over the stopband of the test structures is not associated with the number of cells. In comparison with PBG power plane which has multiple cells, it is observed that the same stopband characteristic can be obtained with only two cells.

To verify the previous results, other test structures are simulated, as shown in Fig. 3(a). The middle cell of test structure is substituted to the cell with rectangular shape considered as transmission line having low impedance. As varying the distance between unit cells to 30 mm, 60 mm and 90 mm, scattering parameters of each case are calculated. The simulation condition is similar to previous paragraph. It is observed that stopband characteristic from 0.5 GHz to 4.5 GHz is provided(see Fig. 3(b)). The longer length of d is, the more spurious resonances are generated without remarkably changing stopband characteristic, compared with PBG structures.



(a)

(b)

Fig. 3. Insertion loss of test structure.

Therefore, as previously stated, with only two cells, the similar stopband characteristics can be achieved and applied to various components.

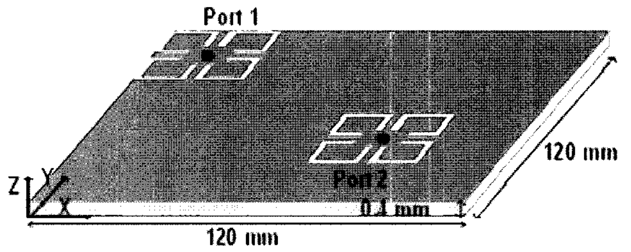
2-2 Proposed Structure Designs

Using above-verified consequence, new power plane design topology is proposed. Fig. 4(a) shows the proposed board using new topology which has finite ground with dimension of 120 mm×120 mm and power plane on which two PBG cells are etched. Also, conventional PBG incorporated board composed of 4×4 cells and its unit cell dimension is 30 mm×30 mm are shown in Fig. 4(b). The input and output ports in either board are located at (x, y)=(15 mm, 105 mm) and (75 mm, 45 mm) for port 1 and port 2, respectively, and those ports are placed in the middle of PBG cells. The port locations are indicated as a dot in the Fig. 4. The geometrical parameters of the unit cell are identical to as shown in Fig. 1. The thickness of the test board is 0.4 mm and relative permittivity of the substrate is 4.4.

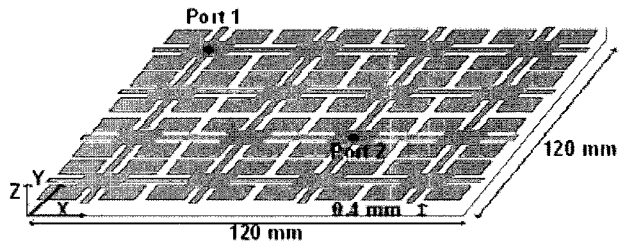
2-3 Suppression of PCB Resonances

Fig. 5(a) shows the scattering parameters of the proposed board and conventional board as well as reference board that is keeping continuous power/ground planes. A simulation is performed with a full wave analysis software based on the FEM. The characteristics of the fabricated PCB are measured with a vector network analyzer.

Note that all of the structure have continuous ground



(a) Proposed board



(b) Conventional PBG board

Fig. 4. Geometry of power/ground planes.

plane. In addition, the frequency response of the conventional PBG board has been also calculated for the comparison. The band stop behavior is observed in terms of insertion loss and the magnitude lower than -30 dB is defined as the bandwidth of the power plane. Compared with reference board, it is shown that the proposed board clearly provides excellent suppression of resonances in a wide frequency range from 0.9 GHz to 4.4 GHz, and the conventional PBG board exhibits very broad elimination of PCB resonances from 0.9 GHz to 4.7 GHz. Although, the conventional PBG board has the a little wider stopband than that of proposed board, unwanted multiple resonances are further observed below 1 GHz regime in conventional PBG board. These unexpected resonances generated below 1 GHz is showed in extended in Fig. 5(b). These unexpected resonances have potential possibility to incur EMI and SI problem in the low frequency region, and as a result the concept is very hard to be realized in practical system. Since it is little difference of bandwidth to suppress resonances and unexpected resonances are markedly less occurred, the proposed board is much more efficient to suppress spurious resonances and easier to realize than the conventional PBG board. Of course, less discontinuous power plane provides continuous and uniform return current paths to signal lines routed in the plane. The simulated results are confirmed with measurement data as in the Fig. 5(c), and reveal excellent correlation between them. Though, there is a little difference over 3.5 GHz between simulated and measured results due to a loss of manufactured PCB, a good agreement can be seen through experiment and simulated results over the entire frequency range.

2-4 Port Location Dependency

As discussed in the previous section, the proposed board shows almost identical stopband characteristic of the conventional one. The key feature of the proposed geometry is that the unit cell can be placed anywhere required to suppress parallel plate modes and similar bandstop characteristic can be obtained. In this section, the port 1 location has been changed to shown in Fig. 6 and its characteristics are examined through simulation as well as measurement. The simulation conditions are identical to the previous case except changing the cell location such that the ports of case 2 are located at (30, 90) and (90, 30), while the ports of case 3 are located at (30, 60) and (90, 60) which are the middle of the board.

In order to validate the effectiveness of the proposed method in power plane, simulated and measurement values of each case are represented in Fig. 7 and a good agreement between them is shown. The bandstop charac-

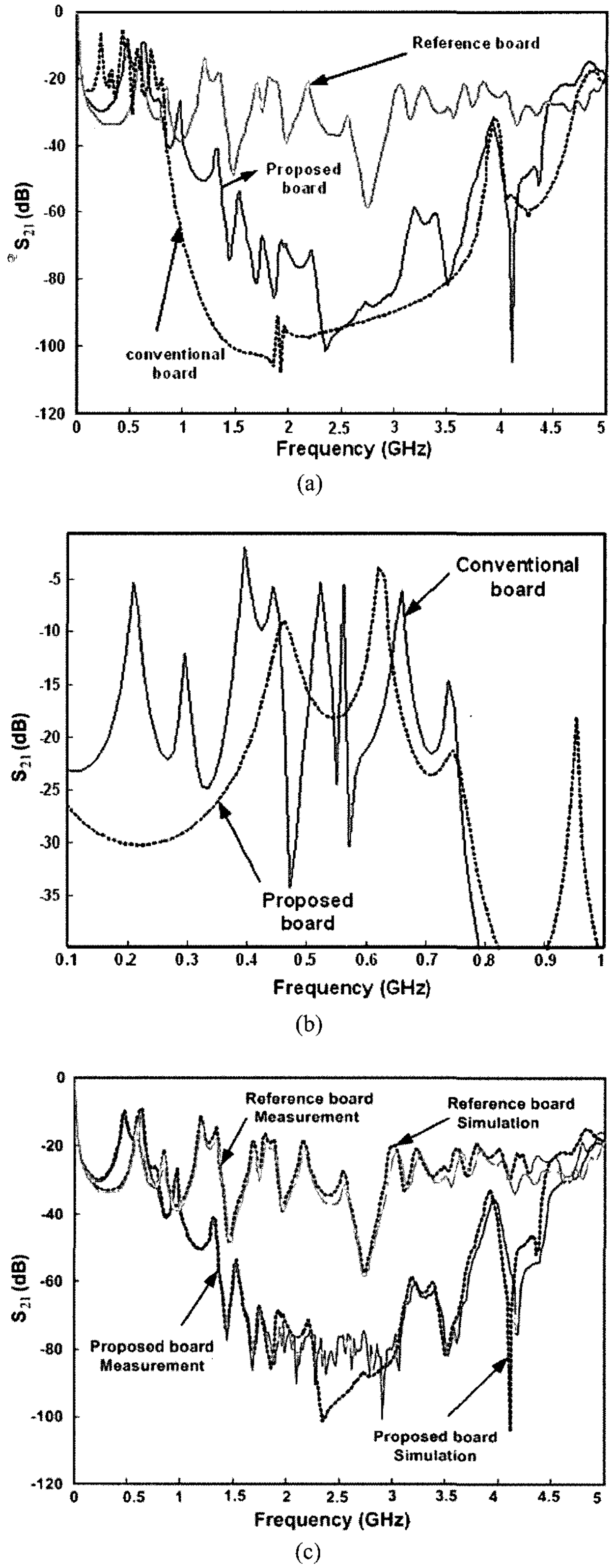
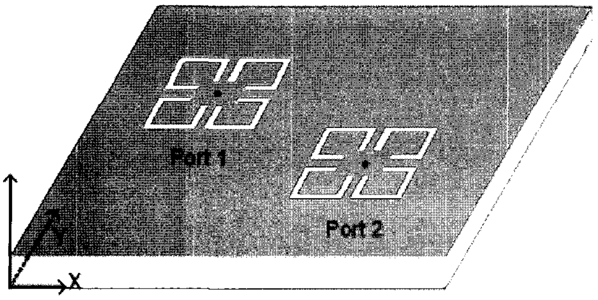
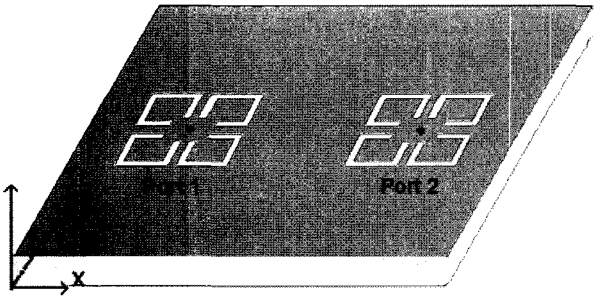


Fig. 5. Comparison of insertion loss between conventional and proposed boards.



(a) Case 2



(b) Case 3

Fig. 6. Geometry of varied cell location.

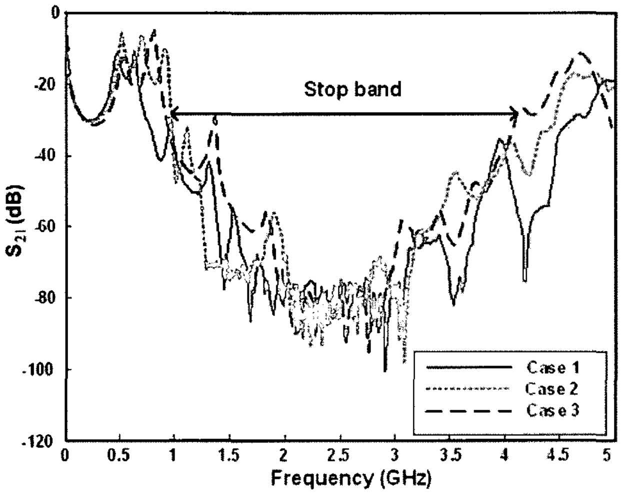
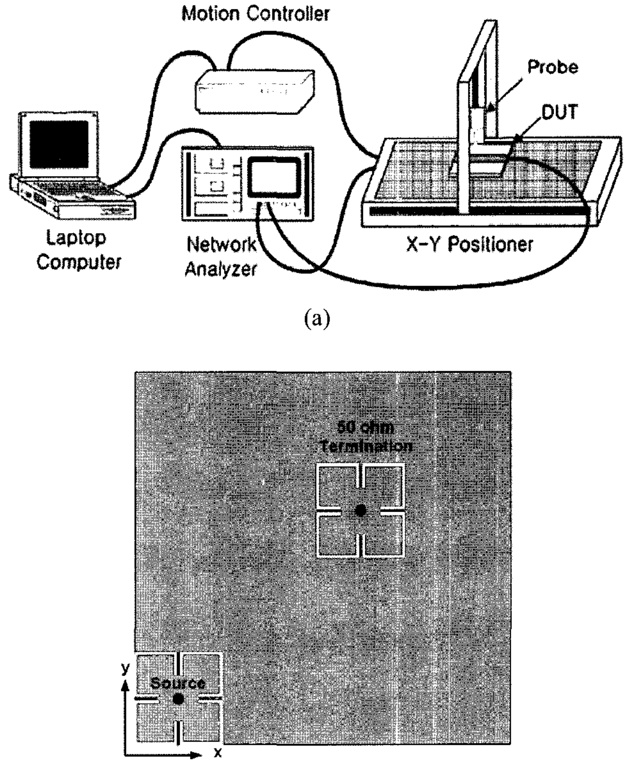


Fig. 7. Comparison of stopband characteristic of each case.

teristics of the proposed geometric in the case 1, 2, and 3 reveal almost identical performances. In the case 1, the stop band ranges from 0.7 GHz to 4.6 GHz, while the case 2 and case 3 are measured from 0.9 GHz to 4.4 GHz and from 0.8 GHz to 4.2 GHz, respectively. Based on the above observation, it is possible to conclude that the proposed power plane design methodology could provide wide band suppression of parallel plate resonances from 0.9 GHz to 4.2 GHz. Furthermore, the presented approach provides almost location independent performance, so that noisy high speed circuits can be isolated from other ports of the board. It is also worthy to note that the new geometry gives rise much less resonances in low frequency region below 1 GHz. As mentioned previously, the simplicity and location independence provide higher degree of freedom in routing signal lines, resulting minimized SI issues as well as EMI. Therefore, the proposed method can be utilized in design of high speed digital circuits.

Ⅲ. Measurement Near Field and Discussion

In order to validate proposed board, near-field distribution is measured and compared with reference board. The electromagnetic field-mapping system used in this study is shown in Fig. 8(a)[8]. It consists of an x-y stage positioner, network analyzer, motion controller, laptop computer, and magnetic and electric field probe. The two port network analyzer is used as a source to the board, as well as receiver. Port 1 of board is connected to network analyzer and another port is terminated 50 ohm, as shown in Fig. 8(b). Since the height of the probe from the board surface is an important parameter in the near-filed measurement system in order to obtain accurate results, for the electromagnetic near-fields scanning, the probe is situated 3 mm above the board.

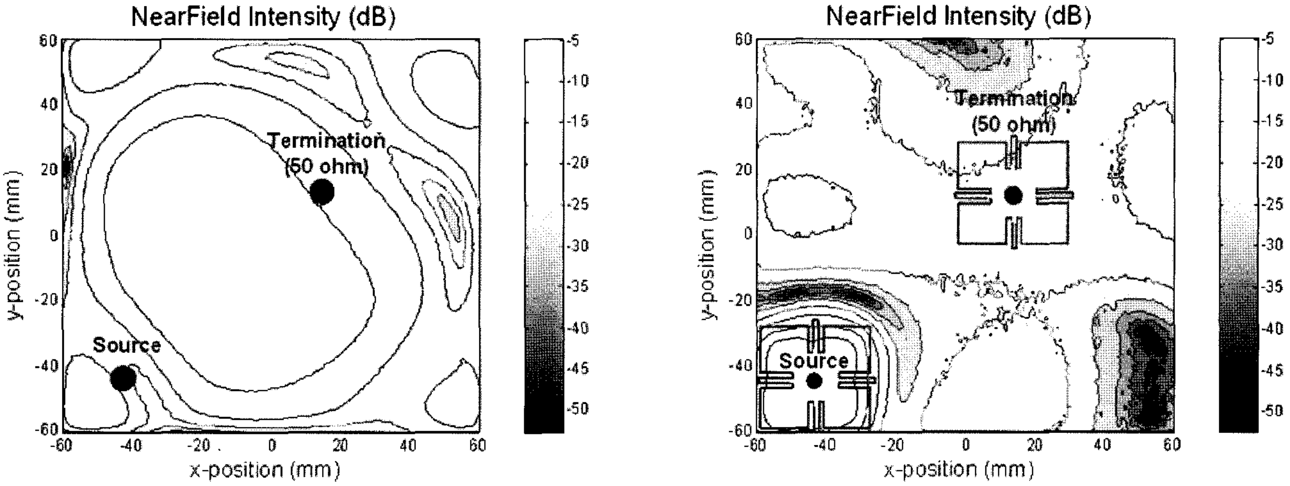


(a)

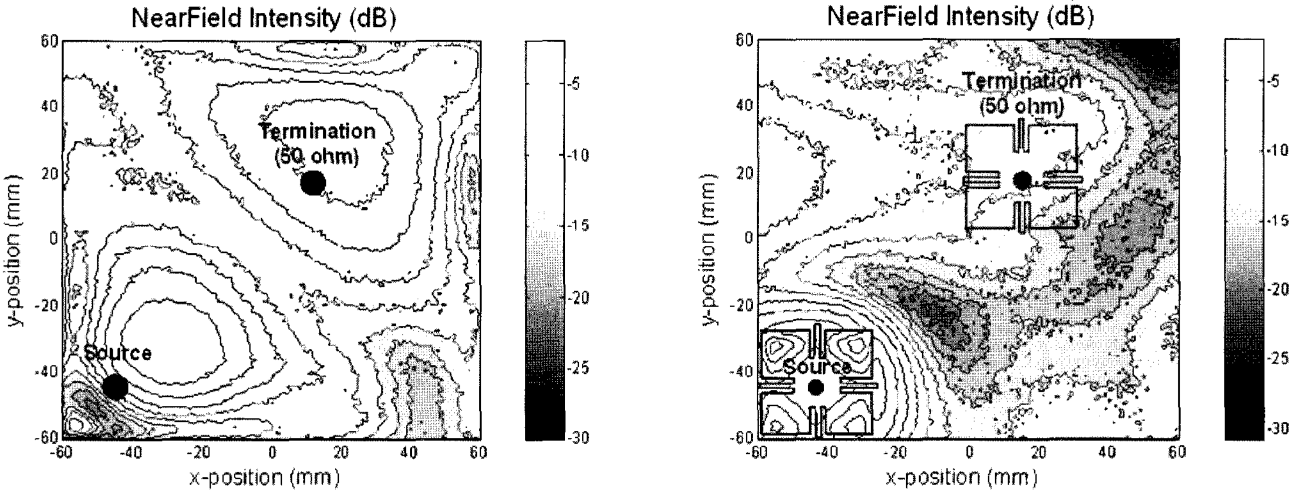
(b)

Fig. 8. Measurement setup.

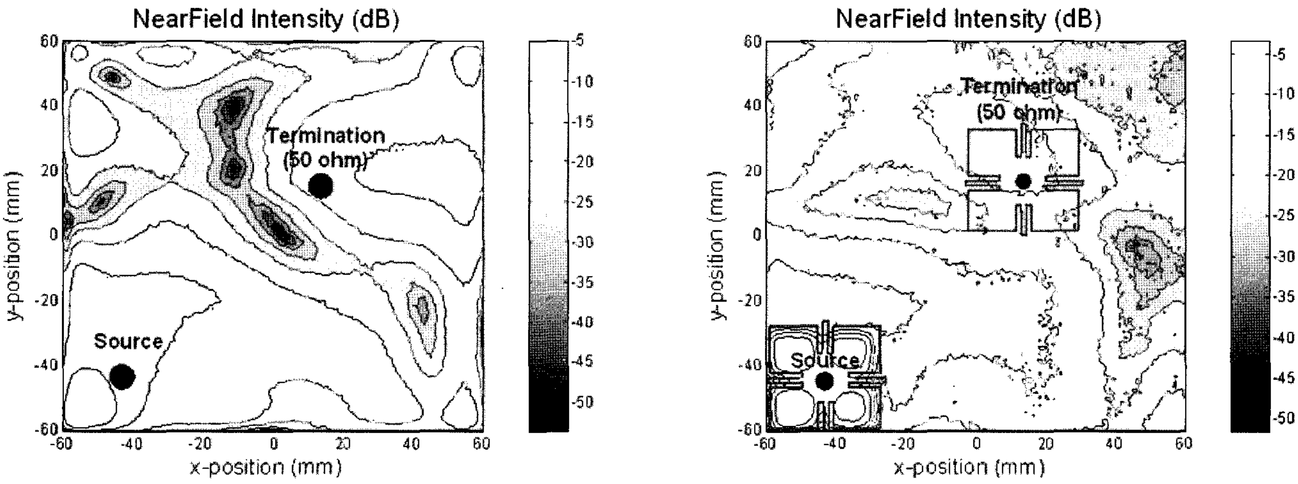
To investigate the electromagnetic near-fields on the board, three different frequencies, all of them lie in the stop band region depicted in Fig. 5(c), which are 1.7 GHz, 2.174 GHz and 3.045 GHz are selected. These



(a) Reference board at 1.7 GHz (b) Proposed board at 1.7 GHz



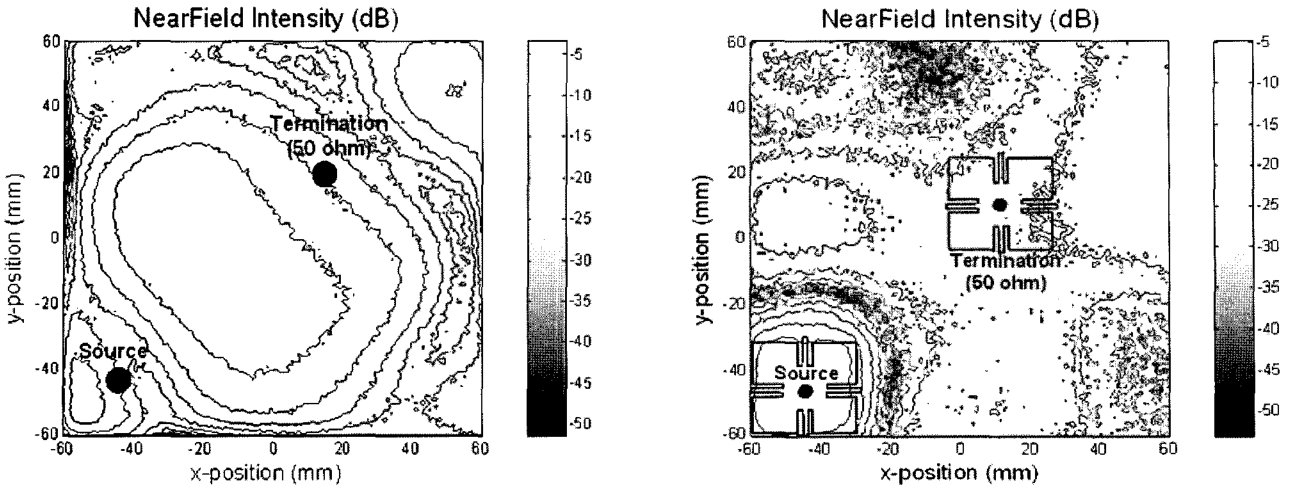
(c) Reference board at 2.174 GHz (d) Proposed board at 2.174 GHz



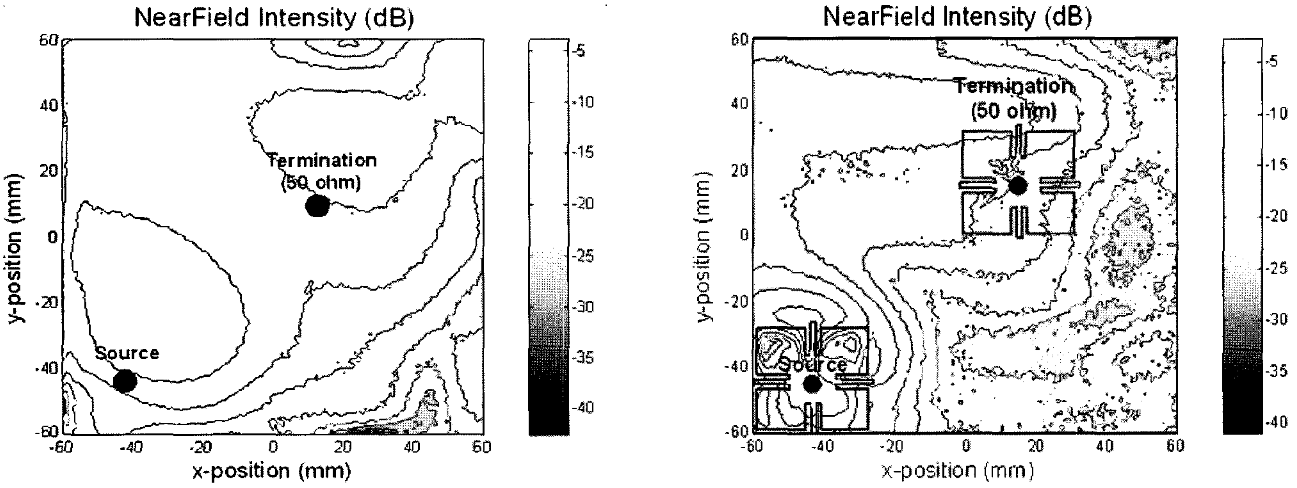
(e) Reference board at 3.045 GHz (f) Proposed board at 3.045 GHz

Fig. 9. Measured E_z field distribution(1.7 GHz, 2.174 GHz, 3.045 GHz).

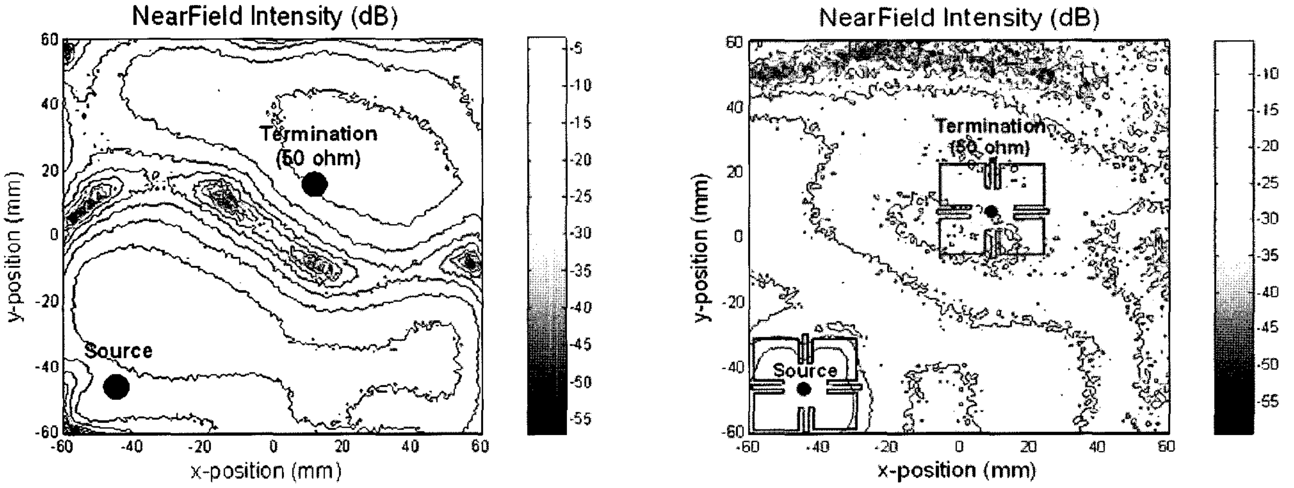
frequencies are parallel plate resonances of reference board. The tangential electric field component E_z is measured in the scanning range of 120 mm in the x-direction and 120 mm in the y-direction at each



(a) Reference board at 1.7 GHz (b) Proposed board at 1.7 GHz



(c) Reference board at 2.174 GHz (d) Proposed board at 2.174 GHz



(e) Reference board at 3.045 GHz (f) Proposed board at 3.045 GHz

Fig. 10. Measured H_x field distribution(1.7 GHz, 2.174 GHz, 3.045 GHz).

frequency point. Fig. 9 and Fig. 10 illustrate the measured E_z and H_x near-field distribution on the proposed board and reference board in each selected frequency. It is clear that the proposed board effectively suppresses the resonance behavior so that the level of near-field distribution from port 1 to 2 dramatically changes in the range from -10 to -30 dB over the whole frequency range. Particularly, the field distributions above surface of the power plane are entirely suppressed. In other words, at the specified resonance frequencies in the proposed board, electromagnetic field does not reach from port 1 to 2. As the measuring frequency goes higher, spurious resonances occur in the reference board. But in the proposed board, these severe resonances are remarkably suppressed. Since the measured field level is entirely lowered on the surface of the proposed power plane, EMI problem such as unnecessary spurious radiation, crosstalk, SSN, uneven power distribution is minimized, so the PCB using proposed method can be very effectively utilized in high speed digital system.

Ⅳ. Conclusion

A novel power plane design method is proposed in this paper, revealing wideband suppression of PCB resonances from 0.9 GHz to 4.2 GHz. Compared with conventional PBG board, the power plane utilizing the proposed method have various advantages. First, the proposed method could reliably secure equivalent suppression performances that of conventional board composed of PBG cells. Secondly, much less numbers of unwanted resonances are observed below 1 GHz in proposed method. Thirdly, discontinuous edges are dramatically reduced so that the SI is certainly guaranteed. Lastly, the proposed design method can be applied to any desired position where there are noisy circuits need to be isolated or where noiseless condition is necessary. Of course, minimum number of required geometry and its simplicity provide rooms to route critical nets. The proposed method is validated with both simulated and measured data. And measured near field distribution shows good efficiency for reducing EMI. Therefore proposed method is expected to be utilized for high speed digital system.

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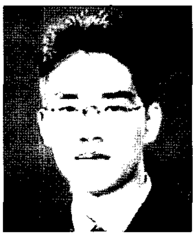

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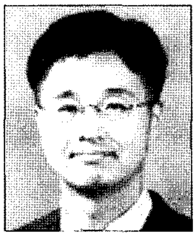

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