A Full-Wave Model Analysis on Noise Reduction and Impedance of Power-Bus Cavity with Differential Signaling

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Abstract

This paper presents a study on the differential signaling for the rectangular power-bus structure. The full-wave modal analysis method analyzes how the differential-signaling can lower the power-bus resonance noise levels. The methodology is validated by the use of the FDTD method and reference measurements.

Key words : Power-Bus, EMC/EMI, Full-Wave Analysis, Noise Reduction, Differential Signals.

Ⅰ. Introduction

Up to date, PCBs have been considered essential to the inside of almost all the electric or electronic systems. Since the components tend to be densely populated in the PCB, it is designed to consist of multiple layers, accommodating signal lines, traces, bias lines, etc(3-dimensional placement). We can see a number of standards and recommendations on the layering in the PCB. According to them, the power- and ground planes are usually placed to face each other and called the power-bus structure[1]~[5].

The power-bus structure as a cavity generates resonance problems and they have been pointed out as the noise in the PCB and part of or entire equipment. Thus, tackling the power-bus resonance needs the accurate analysis methods on it and the ways of damping the resonance. T. Okoshi uses a modal sum expressions to characterize the structure[1]. J. Fan *et al* use the full-wave moment method to accurately predict the power-bus structure's resonance phenomena[2].

The differential signaling is suggested as a countermeasure to the common-mode current occurring due to the PCB power-bus noise like its resonance[3]~[5]. The FDTD technique is employed by C. Wang *et al* to characterize the differential signaling in the power-bus, and it shows the occurrence of the common-mode current and the resonance peaks of the differential-mode current as well[3].

This paper conducts a study on the effect of the differential signaling in the power-bus structure to decrease the impedance level. A number of cases are addressed in providing useful information on the conditions for desirable differential signaling and compared with the measurement and FDTD application to prove the accuracy of the present method.

Ⅱ. Theory

The power-bus structure forms a cavity in that it has the PEC planes(power- and ground plates) of the top and bottom and the PMC planes of the walls. As seen in Fig. 1, two feeding lines for differential signaling ($I_1=+I_0$, $I_2=-I_0$) start from the upper region, and pass the intermediate region through the holes on the planes and end in the lower region.

The size of the rectangular power-bus is $W_x \times W_y \times W_z$. The centers of the feeding holes are denoted as (X_1, Y_1) and (X_2, Y_2), and the field or impedance is observed at (X_{PO}, Y_{PO}). The intermediate region between the metal

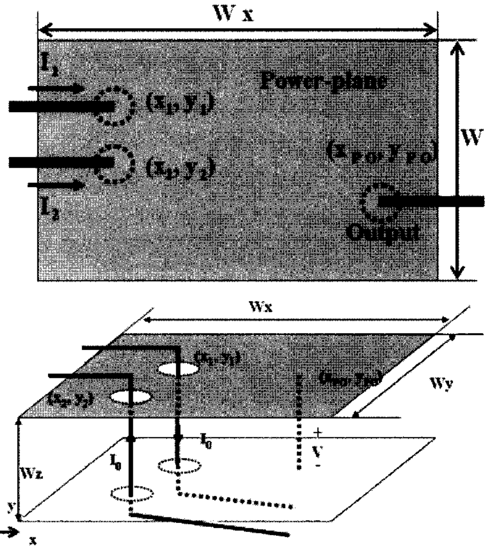

Fig. 1. Top and 3D views of a power-bus cavity with differential signaling.

Manuscript received April 28, 2006 ; revised September 26, 2006. (ID No. 20060428-013J)
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planes corresponds to the PCB's substrate and 4.2 and 0.02 are each chosen as its relative dielectric constant and loss tangent, which is confined within the magnetic-walls.

Prior to considering the differential signals with the two feeding lines, the structure with one feeding line should be solved. The field and impedance on the structure can be accurately calculated by the full-wave modal analysis, instead of the moment method or FDTD method that requires more time. So the following expression is employed[1].

$$Z_{Ld}(f, X_f, Y_f) = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \frac{\gamma_{mn} \cdot c_{mn}(X_s, Y_s) \cdot c_{mn}(X_f, Y_f) \cdot W_z/(W_x W_y)}{\varepsilon\omega/Q + j\left(\varepsilon\omega - \dfrac{k_{xm}^2 + k_{yn}^2}{\omega\mu}\right)} \qquad (1)$$

where

$$c_{mn}(X, Y) = \cos(k_{xm}X) \cdot \cos(k_{yn}Y) \cdot \sin c(k_{xBm}P_{xi}/2) \cdot \sin c(k_{yBn}P_{yi}/2)$$

$$k_{xm} = m\pi/W_x, \quad k_{yn} = n\pi/W_y, \quad \omega = 2\pi f$$

$$Q = [\tan\delta + \{2/(\omega\mu_0 k W_z^2)\}^{0.5}]^{-1}$$

$$\omega_{mn} = \{(k_{xm}^2 + k_{yn}^2)/(\varepsilon\mu)\}^{0.5}$$

$$G_{mn} = C_0 \cdot \omega_{mn}/Q$$

γ_{mn} is 1 and 4 for (m=0, n=0) and ($m \neq 0$, $n \neq 0$) each. With ($m \neq 0$, n=0) or (m=0, $n \neq 0$), γ_{mn} is 2. P_u, $\tan\delta$, ε, μ, f and j denote u-direction width of a port, loss-tangent, permittivity, permeability, frequency and $\sqrt{-1}$, respectively. Based upon the one-feeding line case, the differential signaling can be characterized with no difficulty, since the superposition principle also works in this structure. Therefore, the common-mode impedance and the differential-mode impedance are calculated as in [3].

Ⅲ. Experimental Results

Before analyzing the power-bus cavity with differential signals, the resonance behavior of the original structure needs addressing in terms of impedance. The power-bus structure's size equals (54×35×1.5 mm) and the intermediate region between the parallel plates has 0.02 and 4.2 as $\tan\delta$ and ε_r, respectively.

The corner at (0,0) is excited by one feed to investigate all the resonance peaks up to 5 GHz, with regard to input impedance. The impedance is calculated using Eq. (1) and agrees well with the experimental result. The peaks from mode (1,0) through higher modes such as (3,1) account for the rise in the average impedance level. This is ascribed to electromagnetic noise and should be mitigated by a number of approaches like decoupling capacitors, separation of the palanar area, etc. In particular, the differential signaling is chosen and examined about the way it works.

Firstly, the impedance is evaluated on the differential signals at (X_1=27.4 mm, Y_1=17.2 mm), (X_2=0.0 mm, Y_2= 0.0 mm) and (X_{PO}=41.8 mm, Y_{PO}=27.4 mm).

The differential mode seems worse than the common-mode in that the former has greater impedance level than the latter, even with the same number of resonance peaks. The lower frequency regime including DC exposes the lower impedance of the differential mode, since the physical distance between the two feeds is extremely shorter than the electrical distance. Instead, the resonance modes survive the change, since (X_2, Y_2) remains the same as Fig. 2 that excites all the modes possible.

Secondly, the change in (X_2, Y_2) to (X_2=27.4 mm, Y_2

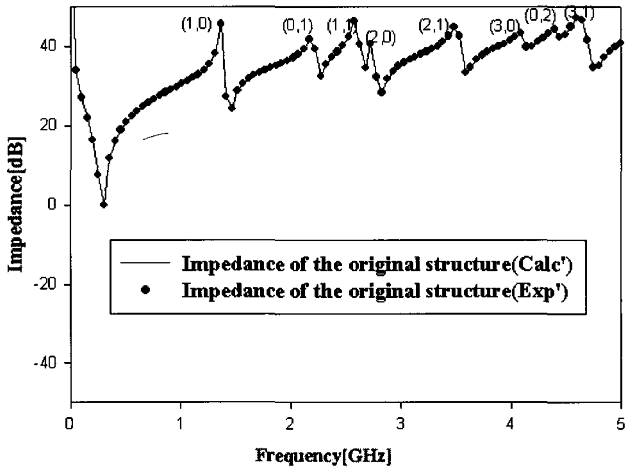


Fig. 2. Examination of resonance behavior of the original power-bus cavity structure.

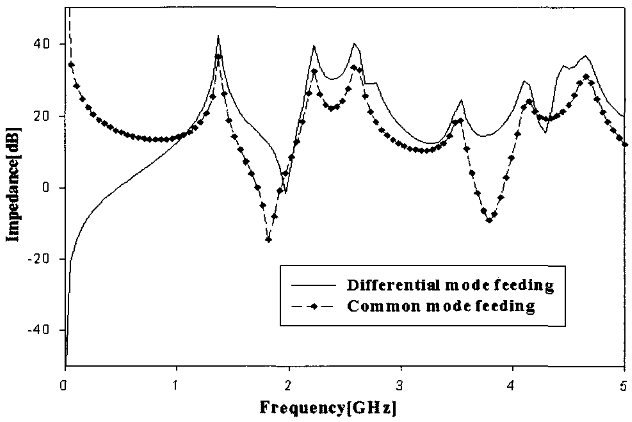


Fig. 3. Case 1: (X_1=27.4 mm, Y_1=17.2 mm), (X_2=0.0 mm, Y_2=0.0 mm) and (X_{PO}=41.8 mm, Y_{PO}=27.4 mm).

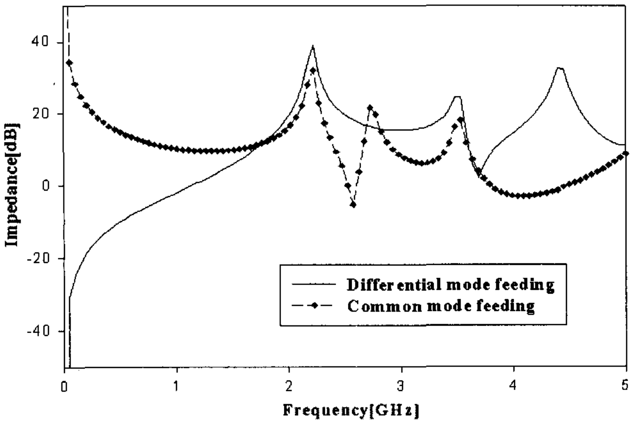


Fig. 4. Case 2: (X_1=27.4 mm, Y_1=17.2 mm), (X_2=27.4 mm, Y_2=0.0 mm) and (X_{PO}=41.8 mm, Y_{PO}=27.4 mm).

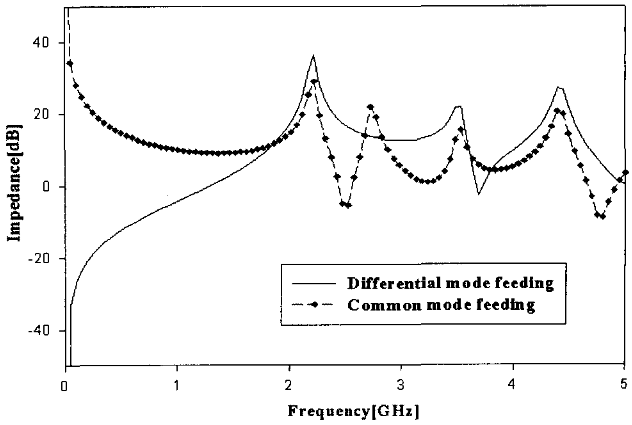


Fig. 5. Case 3: (X_1=27.4 mm, Y_1=17.2 mm), (X_2=27.4 mm, Y_2=8.2 mm) and (X_{PO}=41.8 mm, Y_{PO}=27.4 mm).

=0.0 mm) is taken into account.

Both the feeding modes end up with fewer resonance points compared to case 1 owing to the shorter distance between the two ports. However, from 1.8 GHz, the differential mode is seen to have higher impedance value than the common-mode, except for 2.6 GHz-resonance peak. What stands out now is the (1,0)-mode has disappeared. This will be explained later with the following.

Thirdly, (X_2, Y_2) is moved to (X_2=27.4 mm, Y_2=8.2 mm) to see what happens when the path between (X_1, Y_1) and (X_2, Y_2) becomes shortened.

The differential mode has got the same number of resonance points, but its impedance level between 2 GHz and 3.5 GHz has been decreased. On the contrary, the number of resonance peaks of the common-mode has increased, because the differential signals are not sufficient to cancel the magnetic fields bouncing inside the structure. As for the differential mode, despite the shortened path, not much change is seen. Additionally, the m=1-type of modes are not seen any more here with Fig. 5. It is inferred that the coincident x-position of two feeds is not an integer of the half wavelength and it prevents the modes from occurring.

Next, (X_2, Y_2) is placed at (X_2=27.4 mm, Y_2=16.3 mm), the closest to (X_1, Y_1) throughout the paper.

This case can help us check the accuracy of the present with the result of the FDTD application and measured data for the same environment[3],[5]. Besides, its one-feeding line case is evaluated to see what kinds of resonance properties change before and after the differential signaling with the two feeding lines. Fig. 6 shows good agreement between the present method and the measurement and FDTD in [3], [5]. Seeing the compared curves of the differential signals and one-feeding line structure, it is pointed out that the differential mode can improve the original resonance problem and has lower impedance than the common-mode. It can be stated that the spacing between the two feeds must be determined in order to cancel the magnetic fields radiated out of the two feeds and to hinder the internal magnetic fields from bouncing at the resonance frequencies of the original structure.

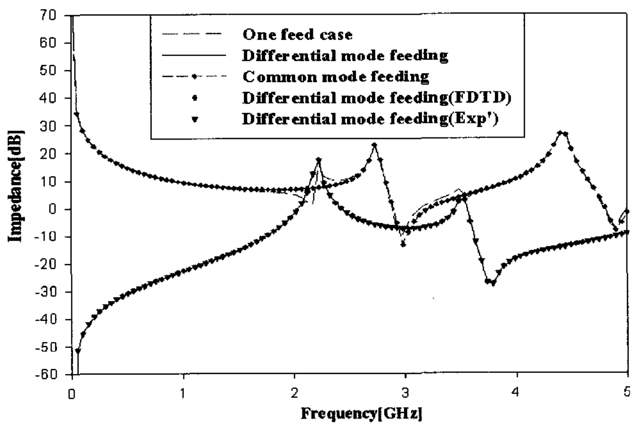
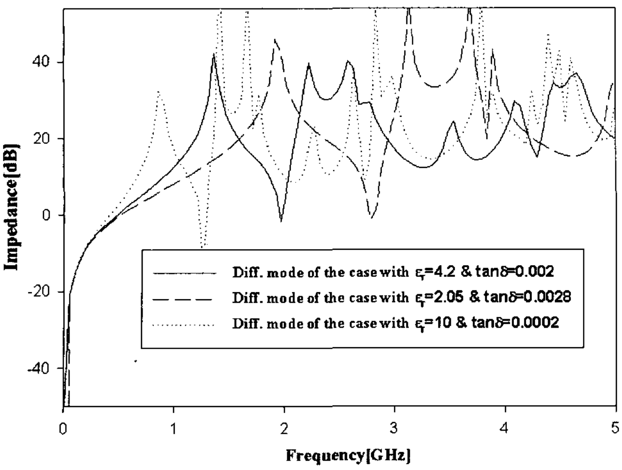


Fig. 6. Case 4: (X_1=27.4 mm, Y_1=17.2 mm), (X_2=27.4 mm, Y_2=16.3 mm) and (X_{PO}=41.8 mm, Y_{PO}=27.4 mm).

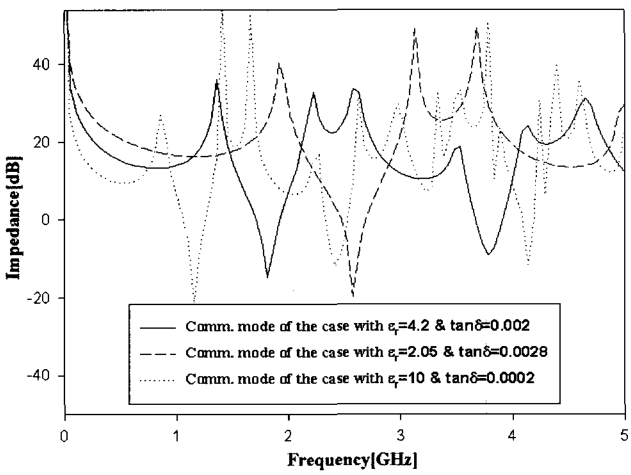
Fifthly, we examine the influence of the different dielectric constants and loss tangent values on the power-bus cavity with the feeds and output port the same as case 1.

Three commercially available materials are considered, Alumina and Silicon including Teflon. With a larger dielectric constant, the resonance frequencies are shifted lower as is expected. Especially, the Silicon causes the increase in the lower region's impedance and Alumina is responsible for the increased level of higher resonance frequencies. And the larger loss tangent tends to make the average impedance drop.

Sixthly, the substrate thickness' influence on the impedance of the case 1 is examined.

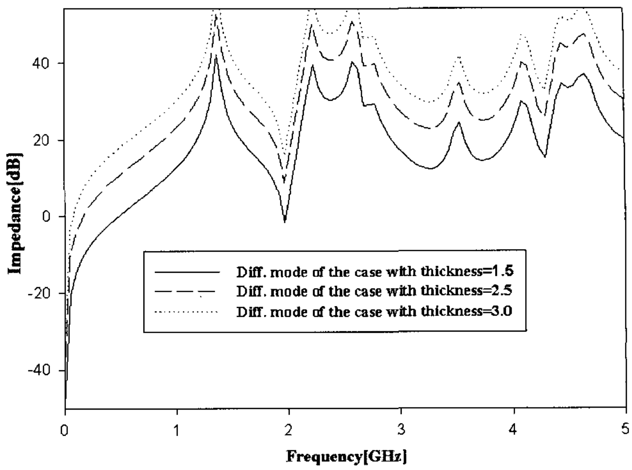


(a) Differential signals

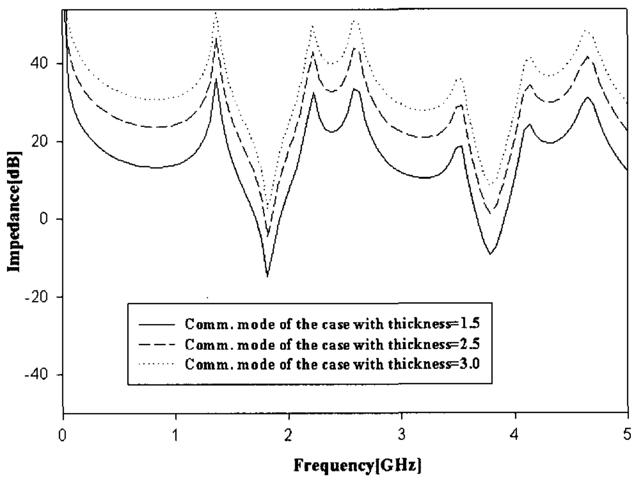


(b) Common-mode signals

Fig. 7. Effects of the different dielectric constants and loss tangent values on case 1.



(a) Differential signals



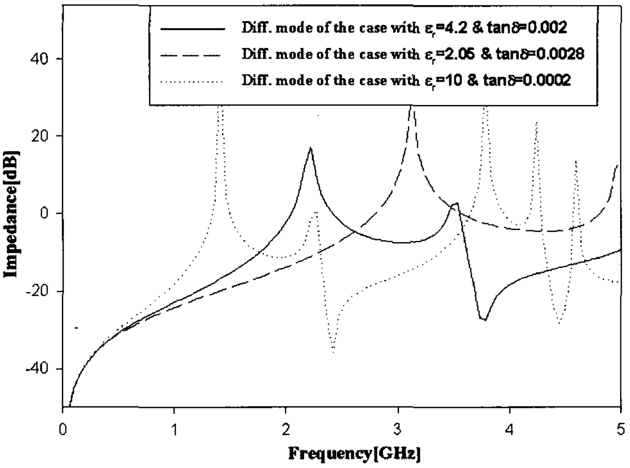
(b) Common-mode signals

Fig. 8. Effects of the different thickness values of the Teflon substrate on case 1.

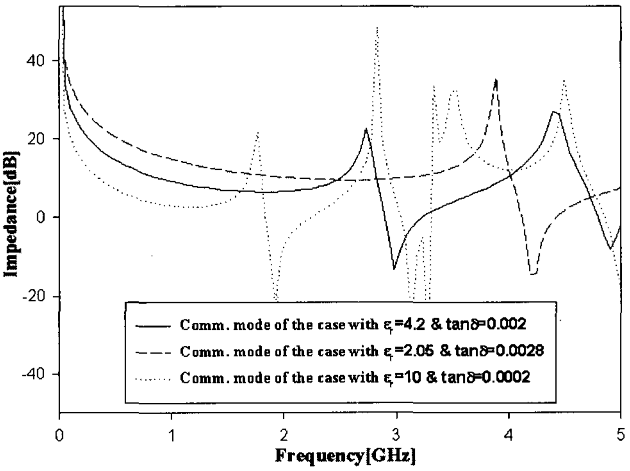
As the case 1 has shown all the excited resonance modes earlier, the evaluation results in the highly noisy behavior with the dominant mode through the highest one. What is found out here is that the thicker substrate has tendency to increase the impedance profiles in both common mode and differential mode as well. The spacing between the two plates lowers the capacitance and lifts the inductance of the structure due to extended current paths on the metal planes rather than inter-plate paths.

Seventhly, as was done to case 1, case 4's performance is checked about the influence of the different dielectric constants and loss tangent values in order to see what happens to the improved case from the highly oscillatory impedance profiles according to the material change. The values of Teflon, Alumina and Silicon are input for the evaluation. As the dielectric constant grows, the resonance frequencies move down like the findings on Fig. 7. With respect to Teflon case, the differential mode of the lower dielectric constant gets to have better impedance performance in the lower frequency regime. Simultaneously, the larger dielectric constant of the substrate has lower impedance from 2.25 GHz to 3.5 GHz than the case with Teflon in the differential mode. The differential mode is still superior to the common mode signaling.

Lastly, we will see the way thickness of the substrate decides the impedance of the case 4. As is shown in Fig. 8, the thicker substrate causes the impedance profiles to increase in both common mode as well as differential mode. As is addressed before, the varied spacing between the two plates fixes the resonance modes with lowered capacitance and increased inductance of the structure, but extends current paths on the metal

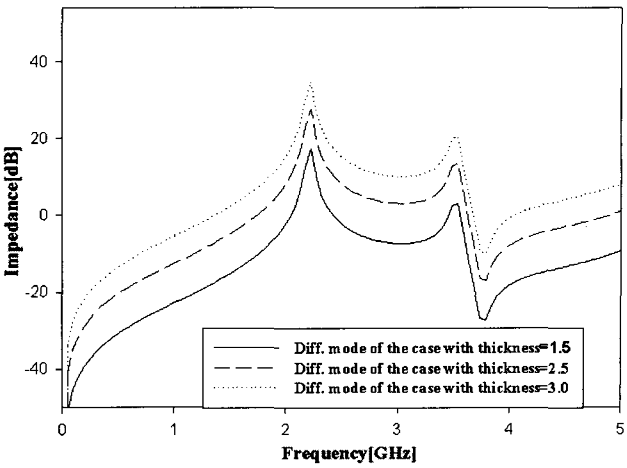


(a) Differential signals

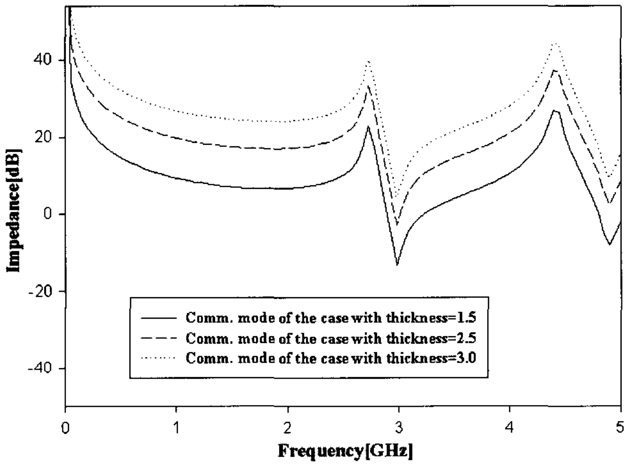


(b) Common-mode signals

Fig. 9. Effects of the different dielectric constants and loss tangent values on case 4.



(a) Differential signals



(b) Common-mode signals

Fig. 10. Effects of the different thickness values of the Teflon substrate on case 4.

planes.

Ⅳ. Conclusion

In this paper, a study has been conducted on the differential signaling for the rectangular power-bus structure. The full-wave modal analysis scheme is used to accurately evaluate the power-bus structure's resonance properties and it can present the way the properly chosen conditions for the differential-signaling can iron out resonance matters very effectively. The present method and idea have been validated by the comparison with the measurement and FDTD method.

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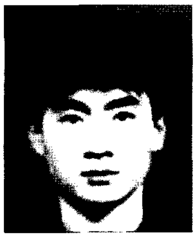

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