AN AVERAGED ESTIMATION OF FIELD STRENGTH INTO AN ENCLOSED LARGE CAVITY WITH PCB BOARD

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ABSTRACT: *In this article, two analysis methods, which are called as one is the combination of coplanar strip line analysis and Baum–Liu–Tesche (BLT) equation and the other combination of PoWer Balance (PWB) method and BLT equation, are used to predict the field strength level from the plane wave outside into an large enclosure with aperture and PCB boards inside. In realistic situations, an electrically large enclosure with an aperture has a drawback in calculating the field distribution inside the cavity precisely because of multiple reflections and resonance phenomena. Commercially available software based on the previously well-established algorithms such as finite difference time domain (FDTD), finite element method (FEM), method of moment (MOM), and so on require much time consumption to carry out the field analysis within a limitation of accuracy, especially in the regime of high frequency. However, to overcome these resource and time-consumption problem, PWB method based on statistical theory and BLT equation applying topological method are introduced and combined to give a reasonably good field estimation result.* Microwave Opt Technol Lett 57:2029–2031, 2015; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.29257

Key words: – *electromagnetic interference (EMI)/electromagnetic compatibility (EMC); power balance method; Baum–Liu–Tesche equation; coplanar strip-line; transmission line theory*

1. INTRODUCTION

As a lot of data are transferred through the wireless communications with the help of the electrical equipment and advanced services, the needs for high power and frequently usage of ultra-wideband electromagnetic field source have been increased gradually. Due to the unexpectedly radiated electromagnetic interference, the nearby electrical equipment and devices may have an electrical damage and operate as malfunction, even shut down with partially burning out. Therefore, to protect the internal system chip and microwave circuits from the unexpected EMI effects, a shielding effect mechanism should be highly considered in many situations where electromagnetic wave penetrations exist. As candidate methods for the estimation of shielding effectiveness (SE), a variety of numerical and analytical methods have been proposed for evaluating the EM coupling level inside rectangular cavities with aperture by many researchers [1,2]. Although the numerical analysis techniques for the various applications have been approved for its validity and usefulness, the required resources and time consumption for the analysis of electrically large structures such as shipboard, aircrafts, aerospace vehicles, as well as car system are too big to be handled because of solving the complete set of Maxwell's equations. In this article, an induced voltage response on the transmission line (TL) of PCB resulted from the plane wave outside through an aperture is investigated with two simplified analysis methods and commercially available software for comparison.

Frist, TL theory and Baum–Liu–Tesche (BLT) equation are combined to predict the relative voltage level on the PCB and electric field distributions inside the rectangular cavity, respectively. As another analysis method, PWB method based on the statistical electric field distributions [3,4] and BLT equation is introduced for the relative error and accuracy estimation.

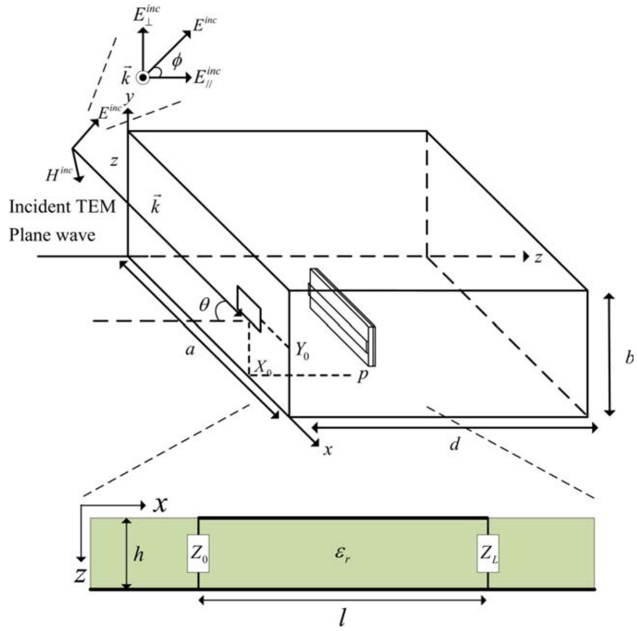

Figure 1 The interior structure of shielding enclosure with an aperture and a TL. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

2. METHODOLOGY

Consider the shielding enclosure with a rectangular aperture and a loaded TL as shown in Figure 1. The final victim is located at the distance P along Z-direction from the rectangular aperture. TEM plane wave is incident on the shielding cavity with an incident angle θ and a polarized angle ϕ. The overall size of the shielding enclosure is 300 × 120 × 300 mm^3 ($a \times b \times d$). In general, the resonant frequencies of resonant cavity can be estimated and expected from the following formula [5]

$$f_{mnl} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{l\pi}{d}\right)^2} \tag{1}$$

The resonant frequencies depend on the cavity size and observation points.

2.1. Using Equivalent TL Model and BLT Equation

In Figure 1, the aperture and electric wall causing a power loss due to a resistivity characteristic are modeled as an equivalent TL.

$$Z_{\mathrm{ap}} = \frac{1}{2} C_{\mathrm{m}} Z_{\mathrm{a}} \frac{Z_{\mathrm{L}} + jZ_{\mathrm{a}} \tan(k_o l/2)}{Z_{\mathrm{a}} + jZ_{\mathrm{L}} \tan(k_o l/2)} \tag{2}$$

In particular, the aperture has been modeled as the characteristic impedance Z_a of the coplanar strip line and the internal electric wall has been replaced with lossy impedance Z_L. The parameter C_m represents the coupling parameter playing as an important role in estimating the characteristic impedance of coplanar strip line [6,7]. With an assumption that the PCB located at the observation point does not affect the field distribution inside shielding enclosure and an equivalent TL modeling, the final circuit model corresponding to the given structure shown in Figure 1 can be drawn as follows in Figure 2. In this model, V_{ap} means the delivered voltage through the aperture from an external radiation source. In addition to that, V_{ap} can be divided into two components, perpendicular $V_{\perp}$ and parallel $V_{\|}$ to any adopted coordinate system.

$$V_{\perp}=\frac{\left(2.Z_{ap}/\sqrt{1-\sin^2\theta(\varepsilon_1/\varepsilon_1)}\right)/\left(Z_{ap}/\sqrt{1-\sin^2\theta(\varepsilon_1/\varepsilon_1)+Z_0/\cos\theta}\right)}{\cos(k_{mg}p)+j(Z_m/Z_{mg})\sin(k_{mg}p)}\cdot E\cdot\sin\varphi \tag{3}$$

$$V_{||}=\frac{\left(2.Z_{ap}/\sqrt{1-\sin^2\theta(\varepsilon_1/\varepsilon_1)}\right)/\left(Z_{ap}/\sqrt{1-\sin^2\theta(\varepsilon_1/\varepsilon_1)+Z_0/\cos\theta}\right)}{\cos(k_{mg}p)+j(Z_{in}/Z_{mg})\sin(k_{mg}p)}\cdot E\cdot\cos\varphi \tag{4}$$

In Eqs. (3) and (4), K_{mg} and Z_{mg} represent the propagation constant and characteristic impedance according to the propagating modes, respectively.

$$V_{total}=\sqrt{(V_{\perp}^{total})^2+(V_{||}^{total})^2} \tag{5}$$

$$V_{\perp}^{total}=\sum V_{\perp}Z_3/(Z_2+Z_3) \tag{6}$$

$$V_{||}^{total}=\sum V_{||}Z_3/(Z_2+Z_3) \tag{7}$$

As a next step, if the induced voltage at the aperture is defined and evaluated, the voltage at the observation point P in Figure 2 can be predicted from the well-known TL theory. As seen in Figure 2, Z_2 and Z_3 mean the impedances looking into left to the aperture and right to the electric wall at the observation point P, respectively; and the total voltage at point P is composed of multimode responses as listed in Eq. (5). The voltage Vtotal is used as an input voltage of BLT equation on the loadedTL. The general BLT equation is usually used in the TL analysis and is simultaneously solved from the propagating Eq. (8) and scattering Eq. (9) resulting in the final Eq. (10). Reference [8] $[\Gamma]$ in Eq. (8) $[S]$ in Eq. (9) include the reflection coefficients with phase information and scattering coefficients with reflection and transmission characteristics.

$$[V^{inc}]=[\Gamma]\cdot[V^{ref}]+[V_s] \tag{8}$$

$$[V^{ref}]=[S]\cdot[V^{inc}] \tag{9}$$

$$([I]-[S][\Gamma])\cdot[V^{ref}]=[S]\cdot[V_s] \tag{10}$$

The final voltage response at the loaded resistor of the given TL in PCB can be obtained from substituting the voltage in Eq. (5) into an induced voltage source V_s in Eq. (10).

2.2. Using PWB Method and BLT Equations

As a starting equation of PWB method, the definition of quality factor Q and the relationship between the quality factor and the power dissipated P_d are introduced for the field evaluation based on the statistical electromagnetic phenomena [9].

$$Q=2\pi f\cdot\frac{W}{P_d} \tag{11}$$

where W means the stored total energy in the cavity. The important parameters explaining the lossy mechanism in the cavities are mainly four lossy factor: (a) aperture (Q_{ap}), (b) electric wall (Q_w), (a) absorption (Q_{obj}), and (a) antenna (Q_{ant}).

As the stored energy W in Eq. (11) can be represented by integrating the average energy density S through the volume and dividing it by the speed of light c, we can derive the following equation.

$$P_d=\frac{2\pi V}{\lambda Q}\cdot S \tag{12}$$

where V means the cavity volume. For steady-state condition, by assuming that the transmitted power P_{inc} through the aperture is equal to the dissipated power P_d, the average power density S can be represented as a summation of all the lossy mechanisms including Q factors.

$$S=\frac{\lambda}{2\pi V}\cdot\frac{P_{inc}}{\sum_j(1/Q_j)} \tag{13}$$

where Q_j means the quality factor related with the internal cavity loss. For instance, in the case of Figure 1, Q_j is the quality factor of aperture (Q_{ap}) and the electric wall loss (Q_{wall}) inside cavity, respectively. To obtain the voltage response on the TL of PCB, substitution of Eq. (12) into Eq. (10) replacing by $[V_s]$ has been performed.

3. SIMULATION AND NUMERICAL COMPUTATION

The dimension of shielding cavity is 300 × 120 × 300 mm^3 ($a \times b \times d$) made of copper whose conductivity is 5.8 × 10^7 *S/m*. The center point of the aperture is X = 225 mm and Y = 60 mm and the aperture size is 50 × 5 mm. We assume that the voltage magnitude of the incident plane wave is 1 V/m and the incidence angle and polarization angle are $\theta = 0°$ and $\varphi = 0°$, respectively. The center point of the PCB is x = 225 mm, y = 60 mm, and z = 140 mm. The used substrate has thickness of h = 1.5 mm, and the relative permittivity of ε_r = 4.7. The total length and the width of the given TL are l = 100 mm and w =

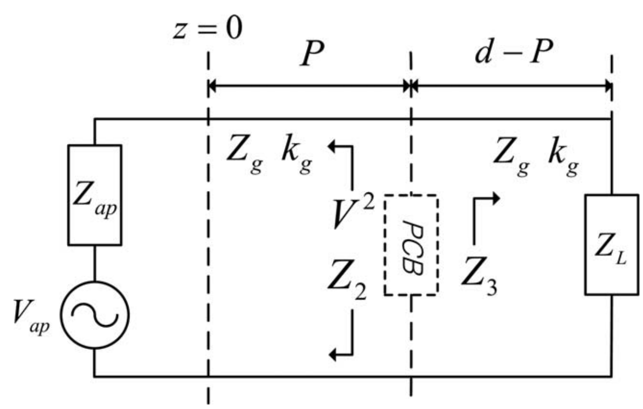

Figure 2 The equivalent TL modeling of Figure 1

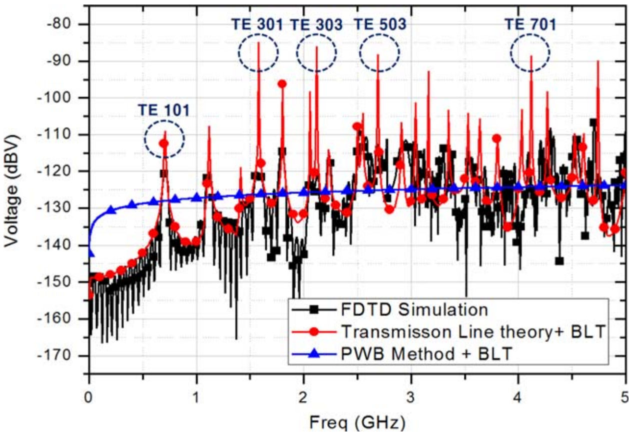

Figure 3 Voltage responses on the loaded TL of PCB according to the analysis methods. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

1 mm, respectively, with the loaded resistors of $Z_0 = Z_L = 82.75\ \Omega$.

Figure 3 delineates the voltage response on the loaded resistor of PCB. The analyzed result using the combination of equivalent TL theory and BLT equation is nearly the same as that obtained from the commercially available software. In addition, it can be expected that the result obtained from the analysis using the combination of PWB method and BLT equation is approximately approaching the average values of the other data. Especially in high frequency region of Figure 3, it is seen that the accuracy of PWB method and BLT equation becomes higher. By comparing the resonant frequencies of Figures 3 and 4 it is guaranteed that the PCB structure given in this article does not affect the original resonant frequency when the interior of shielding enclosure is empty. Hence, the two methods mentioned in Sections 2.1 and 2.2 lead to the reliability of the SE analysis inside shielding cavities.

In addition, we have saved a required time consumption and computer resources caused using a complete mathematical equations as shown in Table 1. For this work, we adopted Intel core I7-3770 working at 3.4 GHz and 12 GB RAM as a processor.

Moreover, using the proposed method in the case of electrically large-scaled structure and high frequency response, the SE

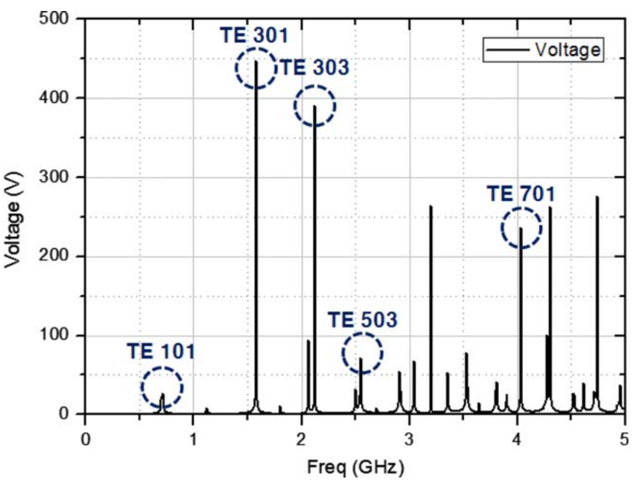

Figure 4 The resonant frequencies of single shielding cavity with an empty space. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

TABLE 1 Comparison of Time Consumption, Computational Resource, and Accuracy

Analysis Type	Time (s)	Memory (kB)	Accuracy
PWB method + BLT Eq (P&B)	0.76	47	Low
TL theory + BLT Eq (T&B)	110	104	High
Full-wave simulation (FDTD)	413	8,486,040	Ref.

estimation can be easily and fast performed and very helpful for fast prediction of SE level.

4. CONCLUSION

This letter presented a simple estimation method to predict the induced voltages on both sides of single TL inside shielding cavity. This simple estimation method, which is combining the statistically-based approaches and BLT equations, was proposed by considering the dependence of incidence and polarization angles. By performing the comparison of the data obtained from the equivalent TL model and commercially available software based on FDTD, a reasonably good agreement has been obtained in the view point of an averaged value. Moreover, using the proposed method in the case of electrically large-scaled structure and high frequency response, the SE estimation can be easily performed and very helpful for fast prediction of SE level.

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HIGH EFFICIENCY POWER AMPLIFIER WITH FREQUENCY BAND SELECTIVE MATCHING NETWORKS

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ABSTRACT: *In this article, a high efficiency power amplifier (PA) with frequency selective matching networks (MNs) that can provide*