Prediction of common-mode radiation from cables attached to PCB using imbalance difference and asymmetrical dipole antenna models

A.M. Sayegh* and M.Z.M. Jenu

Cables attached to a PCB can produce a significant amount of unintentional common-mode (CM) radiated emissions (REs). Therefore, it is important to predict these emissions at the design stage before the first prototype is fabricated to ensure time and cost savings. In this Letter, a novel method was proposed to estimate the CM RE from two cables attached to a PCB using the imbalance difference model and asymmetrical dipole antenna model. The proposed method consists of two steps: first, the induced CM voltages on the junctions between the cables and PCB are computed using the imbalance difference model; secondly, the CM REs are then estimated separately for each cable related to half of the ground plane using the asymmetrical dipole antenna model. The overall REs are then computed by superposition of the RE from the two asymmetrical dipoles. The effectiveness of the proposed method has been verified by comparing the predicted results to both 3D high-frequency structure simulator simulation results and measurement results taken in a semi-anechoic chamber. A good agreement with the accuracy of more than 95% is observed for the upper bounds of the measured REs.

Introduction: Cables attached to a PCB are well-known sources of the unintentional common-mode (CM) radiated emissions (REs). Therefore, it is important to predict these emissions at the design stage before the first prototype is fabricated to ensure time and cost savings. In this Letter, a novel method was proposed to estimate the CM RE from two cables attached to a PCB using the imbalance difference model and asymmetrical dipole antenna model. The proposed method consists of two steps: first, the induced CM voltages on the junctions between the cables and PCB are computed using the imbalance difference model; secondly, the CM REs are then estimated separately for each cable related to half of the ground plane using the asymmetrical dipole antenna model. The overall REs are then computed by superposition of the RE from the two asymmetrical dipoles. The effectiveness of the proposed method has been verified by comparing the predicted results to both 3D high-frequency structure simulator simulation results and measurement results taken in a semi-anechoic chamber. A good agreement with the accuracy of more than 95% is observed for the upper bounds of the measured REs.

Estimation of CM voltages: For a simple microstrip structure with two attached cables as shown in Fig. 1a, the CM voltage sources were located at the junctions between the attached cables and the PCB ground plane, where the change in the imbalances occurred as shown in Fig. 1b. The magnitude of the CM voltage at the source point was given by

\[ V_{CM}(s) = (h2 - h3)V_{DM}(s) = h2 V_{DM}(s) \]  

while the CM voltage at the load point was given by

\[ V_{CM}(L) = (h1 - h2)V_{DM}(L) = -h2 V_{DM}(L) \]

where \( h1, h2 \) and \( h3 \) were the imbalance factors for the cable#1 (at the load junction), microstrip PCB and cable#2 (at the source junction), respectively. \( V_{DM}(s) \) and \( V_{DM}(L) \) denoted the CM voltages at the source and load points, respectively. For the microstrip PCB used in this Letter, the imbalance factors \( h1 \) and \( h3 \) were due to the absence of the signal trace, whereas the imbalance factor of microstrip PCB, \( h2 \), was calculated as

\[ h2 = \frac{\epsilon_{trace} + \epsilon_{board}}{\epsilon_{trace} + \epsilon_{board}} \]  

where \( \epsilon_{trace}, \epsilon_{board} \) are the self-capacitance of the signal trace and the PCB board capacitance, respectively. These capacitances were computed in this Letter using Ansys Q3D extractor.

Estimation of maximum CM RE: The CM REs were computed analytically according to the equivalent CM structure illustrated in Fig. 1b. The PCB ground plane was virtually divided into two equal parts as shown in Fig. 1c. This was due to the existence of the CM voltages on the source/load ends of the PCB. The two parts with their attached cables were then analysed as two asymmetrical dipole antennas. The maximum CM RE from each asymmetrical dipole antenna is expressed as

\[ E_{max} = F \times \left( \int_{Z0}^{Z1} I_1(z)e^{-jKP_{max}} \, dz + \int_{Z0}^{Z1} I_2(z)e^{-jKP_{max}} \, dz \right) \]

where

\[ F = 30Kr \sin \theta_{max} \]  

\[ K = 2\pi/\lambda \]

\[ \theta_{max} = \frac{r}{\lambda} \]

\[ P_{max} = \sqrt{(r^2 + z^2 - 2rz \cos \theta_{max})} \]

The currents \( I_1(z), I_2(z) \) on the equivalent asymmetrical dipole branches (board–cable structure) were given in [6, 7]. A MATLAB software was then used to simulate this analytical expression. The analytical results were compared with those results obtained from 3D HFSS simulation and measurements.

Estimated and HFSS simulated results: The effectiveness of the proposed model was verified by comparing the HFSS simulation results with that computed using (4) in the frequency range from 30 MHz to 1 GHz. A 1 V CM voltage was placed at each junction between the PCB and the cables. The estimated result of 20 cm x 4 cm of PCB with two attached cables (0.5 m x 4 mm for each cable) was illustrated in Fig. 2a. Fig. 2b shows the estimated results of a PCB with 10 cm in length and 4 cm in width attached with two 0.5 m cables, whereas
Fig. 2c presents the estimated result of the same PCB geometries in Fig. 2b, except for the lengths of the two cables, which was 0.3 m for each cable. It was clear that the analytical results agreed strongly with the HFSS simulation results. This good agreement showed that the proposed model can estimate the CM RE accurately. It was observed from Figs. 2b and 2c that the length of the cables determined the characteristics of maximum RE. Therefore, the cable length can be employed to locate the positions of the resonance peaks based on the phase constant, $\beta$, and the cables' length ($L_1$, $L_2$).

**Conclusion:** A novel method for estimating the CM RE of the PCB attached with two cables based on the imbalance difference model and the asymmetrical dipole antenna had been presented. The accuracy of the proposed method had been demonstrated by comparing the estimated results to both the HFSS simulation results and the measurement results taken in an SAC. The measured results of REs agreed well with the one obtained using the proposed method for frequencies >200 MHz as shown in Fig. 3b. This was due to the usage of the transmission-line theory in computing differential mode voltage [1] which provided inaccurate results of electrically short traces. Generally, it can be observed from Fig. 3a that the proposed method can predict the CM RE from two cables attached to the PCB with an acceptable accuracy.

**References**


ELECTRONICS LETTERS  14th April 2016  Vol. 52 No. 8 pp. 585–587