A FDTD PREDICTION APPROACH TO FAR-FIELD RADIATION FROM PRINTED CIRCUIT BOARDS

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1. Introduction

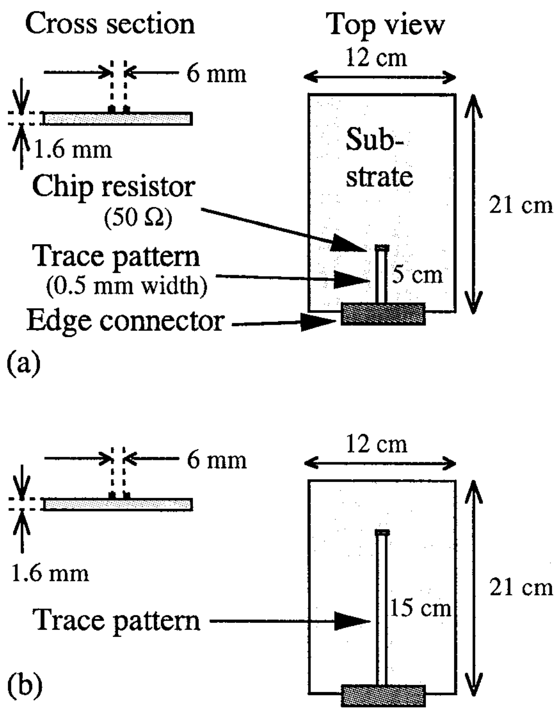
It is widely accepted that printed circuit boards (PCBs) are one of the electromagnetic radiation sources from electronic devices. For such PCB radiated emissions, there are a lot of investigations reported so far, whereas a prediction of the electromagnetic interference (EMI) level is still quite difficult due to lack of knowledge on the noise radiation mechanism. Paul claimed that in comparison with differential-mode (DM) currents on the traces common-mode (CM) currents greatly contributed to the far-field radiation, which was validated in the frequency range up to 200 MHz by the measured CM currents for electrically short traces on the PCBs [1] with narrow-band harmonics of a 10 MHz clock signal as a noise source. Similar conclusions can be seen in some other reports [2-3].

In this paper, a far-field prediction for the PCBs based on the FDTD (Finite-Difference Time-Domain) computation of the CM currents on the traces was investigated, which was validated in the frequency range from 30 MHz to 1 GHz for two sample PCBs with simply parallel traces that were not always electrically short.

2. Measurement

Figure 1 shows the specification of sample PCBs that were prepared. They have simple trace patterns with a width of 0.5 mm, which were fabricated on a glass epoxy substrate (21 cm × 10 cm) with a thickness of 1.6 mm. Two types of balanced parallel traces have 5 cm length (Sample A) and 15 cm length (Sample B). The separation of these parallel traces was 6 mm, and their far ends were terminated in 50 Ω chip registers, which were not matched to the trace impedances. Each PCB was driven from 30 MHz to 1 GHz by a battery powered unbalanced sinusoidal signal generator (SG). Figure 2 shows the PCB being installed in a rectangular metal box (188 × 120 × 64 mm) connected via card edge connectors, BNCs and short coaxial cable.

As shown in Figure 3, the radiated emissions from the sample PCBs were measured at an open area test site with a biconical antenna in the frequency range from 30 MHz to 300 MHz and a log-periodic antenna from 300 MHz to 1 GHz. The sample PCB was placed on the 1 m height table, as the PCB's long side was perpendicular to the direction of the antenna, which was also set constantly at a height of 1 m from the ground plane. The distance between the PCB and the antenna was set just 3 m, and measurement was made with a spectrum analyzer as rms peak voltages in the frequency range from 30 MHz to 1 GHz. Since the field strength of horizontal polarization was higher than the vertical polarization for each sample, decision was made to compare only the horizontal polarization. In this case, the traces on the PCBs might be a simple antenna or radiator not for functional signals, so-called, DM currents but for CM currents [1].



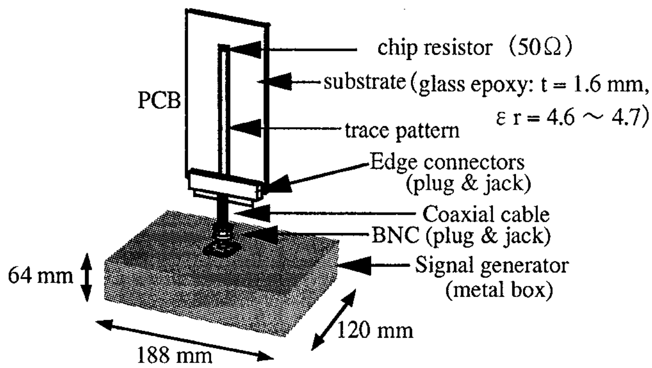


Figure 2 PCB installation in a metal box signal generator.

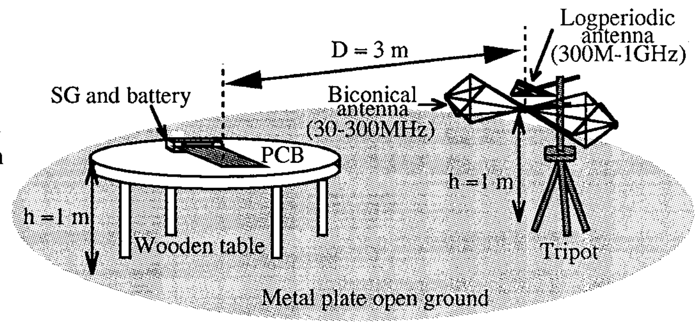


Figure 1 Specification of sample PCBs.

Figure 3 Setup for the radiated emission measurement.

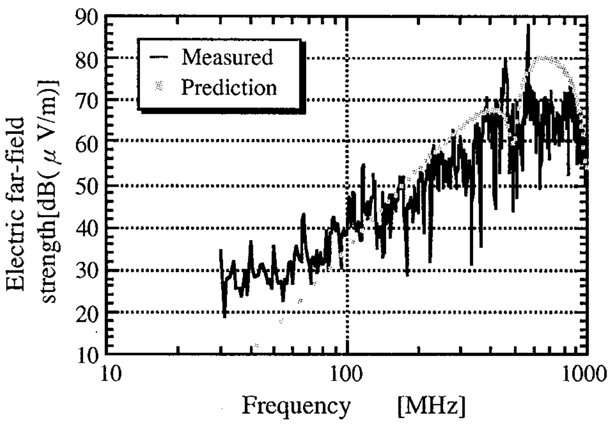


Figure 4 Frequency spectra of the elctric far-field strength for sample A (solid line: measurement and dotted line : prediction).

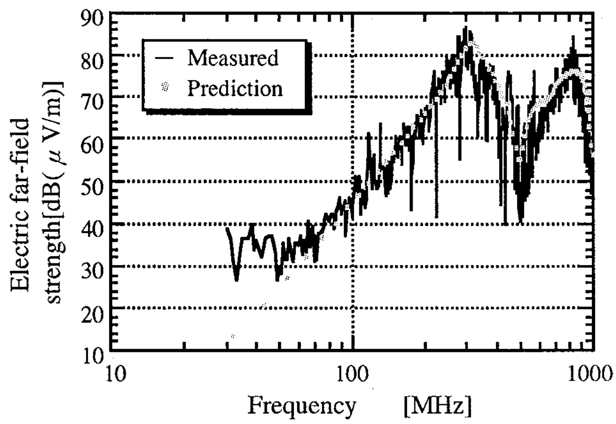


Figure 5 Frequency spectra of the elctric far-field strength for sample B (solid line: measurement and dotted line : prediction).

Figures 4 and 5 show with solid lines the measured frequency spectra of the electric far-fields for the samples A and B, respectively. Also shown are their predictions, which will be described below.

3. FDTD Prediction Approach

By expanding the Paul's prediction theory [1] for electrically short traces, the strength of the electric far-field $E(\omega)$ from the PCB setup for the actual far-field measurement can be derived as

$$E(\omega)=|E_z| = \frac{\omega\mu_0 L}{4\pi D}\cdot\sqrt{\frac{2+(\frac{2h}{D})^2}{1+(\frac{2h}{D})^2}-\frac{1}{\sqrt{1+(\frac{2h}{D})^2}}\cos\frac{\omega D}{c}(\sqrt{1+(\frac{2h}{D})^2}-1)}\cdot \bar{I}_c(\omega) \qquad (1)$$

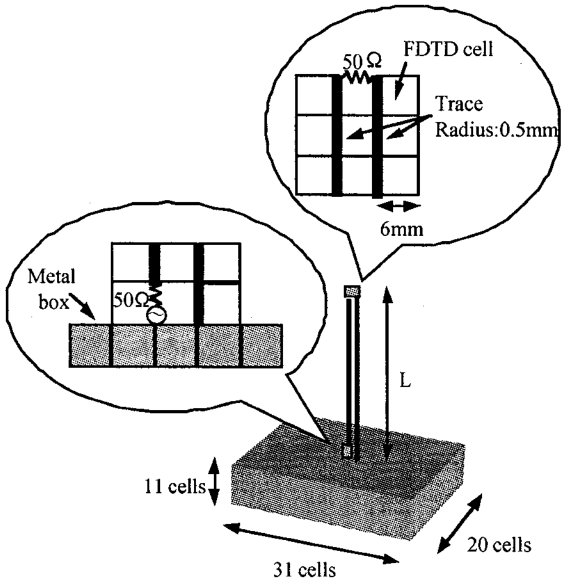


Figure 6 Simplified FDTD model for PCBs.

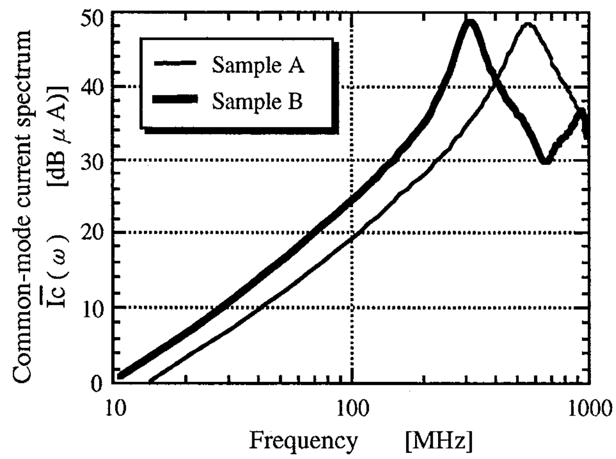


Figure 7 Frequency spectra of the calculated common-mode current by FDTD model for samples A and B.

where D is the distance from the center line between the traces to the measurement point, h is the height of the PCB from the ground and L is the length of the trace pattern. Here, $\bar{I}_c(\omega)$ is given by

$$\bar{I}_c(\omega) \;=\; \frac{1}{L} \cdot \left| \int_L I_c(\omega, z)\, dz \right|, \tag{2}$$

where I_c is the CM current flowing on the traces at a distance of z from the source. This current can be referred to as an effective CM current on the traces, whereas it is not predicted by lumped circuits or the conventional transmission-line theory. In this paper, the FDTD method was used to determine the above effective CM current on the traces for the far-field prediction. Figure 6 shows a simplified FDTD model for the sample PCBs, which was constructed by 6 mm cubic cells. The substrate was removed due to its low permittivity. The two parallel traces were modeled as two circular lines with a radius 0.5 mm, and were extended to the battery-powered SG with the same length as those of the coaxial cable and connectors. For considering the effect of the traces with a radius smaller than the conventional FDTD cell-size, the thin-wire approximation [4] was employed. The SG was modeled as a metal box. The excitation was conducted on the top of the box with a Gaussian voltage source having an internal resistance of 50 Ω. The parameters of the Gaussian pulse were chosen to have a smooth spectrum, i.e., varying within 3 dB below 1 GHz. The FDTD time-step was set to 11.55 ps to ensure the numerical stability, and time-steping was repeated 8192 times. For absorbing outgoing scattered waves, 12 perfectly-matched-layers (PML) were arranged approximately 30 cell apart from the PCB model. The CM currents in the frequency domain were calculated by the Fast Fourier Transformation from the CM currents in the time domain, whose component at each element (6 mm long) was obtained by integrating the magnetic fields along a small curve around the two parallel traces according to the Ampere's law, and then were normalized to the same exciting voltage for all considered frequencies. Figure 7 shows the frequency spectra of the CM currents $\bar{I}_c(\omega)$ for the samples A and B. Substituting the computed $\bar{I}_c(\omega)$ into (1) gives the predictions for the electric far-field strength, which are shown in Figures 4 and 5 with dotted lines. It was found that although there are some discrepancies between the prediction for the sample A and the measurement, the predicted frequency spectra were similar to the measurement. On the other hand, a good correlation was achieved between the prediction and the measurement for the sample B. It is interesting to note that the CM currents flowing only along the traces on the sample PCB yield a good prediction for the far-field strength. This means that the far-field strength from the PCB with the parallel traces is not almost affected by the current which may flow on the SG metal box.

4. Conclusion

The FDTD computations of the CM currents were carried out in order to predict the far-field strength from the sample PCBs with the parallel traces. Good agreement was obtained between the prediction and the measurement.

A far-field / near-field prediction method taking into account of the DM current distribution along the traces and the current flowing on the metal box would be the future work to be investigated.

References

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