Radiation Compatible Ports and Loads for the PEEC Method

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***Abstract*—The partial element equivalent circuit method (PEEC) has been popularly used for signal integrity and power integrity. Its port setup usually only includes conductive effects in the format of current sources or voltage sources. However, its radiation effect was neither included nor studied. In this paper, for the first time we provide novel solutions to approximate the radiation contributions from the port and load setups of PEEC. They serve to compensate the accuracy of electromagnetic radiation analysis based on PEEC approach. The proposed radiation compatible ports and loads can be easily applicable to EMI related analysis.**

I. Introduction

Radiation from the source part is of great significance to the total radiation due to the rising speed and the increasing working frequency for IC interconnectors, yet it has seldom been fully investigated before. For simplicity, the source part is modeled as a delta-gap source, which means that it is infinitely small, so the radiation from it is omitted. However, in real cases, the source has a certain length, and the length is big enough to make a difference for the total radiation. So radiation form the source part cannot be neglected any more. Even though for signal integrity (SI) region, it will not affect much. But for radiation, it should be attached importance to. In this paper, a radiation model for the source part is developed based on the PEEC model and its accuracy is demonstrated with a pair of differential line.

Partial element equivalent circuit (PEEC) [1]–[4] model serves as a bridge between the electromagnetic problems and the circuit ones. It is based on the electric field integral equation (EFIE) and transforms the EM structure into a circuit model, which can be solved by SPICE-like solvers. PEEC is a powerful tool in solving electromagnetic problems, including the power radiation and transmitting calculation [5], and new material simulation [6], [7], etc.

Previously, in PEEC model, the source is modeled as a pseudo segment with current flowing through the segment, and nodal voltages on the two ends of it. Yet this segment is not regarded as a real cell in the PEEC model, which means that there is no partial inductance or capacitance for it, no matter how long the source is and how high the frequency is. In consequence, the radiation effect from the source part is not taken into consideration, either. This would cause huge loss for the total radiation calculation since the source radiation can dominate under certain circumstances.

In this paper, a typical structure with a source and load gap is investigated, which is a differential pair. Two approaches are presented in order to compensate the radiation from the gaps. The first one is to use traces to make up the gap, so both the source and the load are added in an infinitely small gap. Hence, the radiation issue can be overcome. However, it complicates the problem by introducing more unknowns into the system which is unnecessary. The other method is to apply the Hertzian dipole model to roughly get the radiation from the source gap and the load gap. In this way, the gaps are modeled as Hertzian dipoles with corresponding currents, with finite length, since 1) the length of the source is typically electrically small and the current can be seen as constant, 2) the source is added in the vertical direction and the coupling with the horizontal parts can be neglected. Therefore, radiation from the gap source can be approximated by the radiation from the Hertzian dipoles.

The rest of the paper is organized as follows: Section II investigates the radiation from both the source gap and load gap of the differential pair, with two approaches, respectively. Conclusions are made at the last part of the paper.

II. Radiation Accuracy Issue of Previous Port and Load Setups

If the source is between the two wires, which is depicted in Fig. 1, the total radiated power (TRP) of the structure is illustrated in Fig. 2. This geometry is excited with a 1 V sinusoidal voltage source. R_1 and R_2 are both 192.5 Ω. The radiated power calculated with PEEC obviously is not accurate, since the port and the load part are not taken into consideration in the PEEC model. In PEEC, the source and load are added in pseudo-segments while PEEC itself does not model these components. The radiated power does not take these components into consideration, either. Therefore, total radiated power (TRP) results are negative for this case, compared with EMC Studio results [8] (Fig. 2). In EMC Studio, the source and load gaps are modeled as wires.

In order to compensate the deficiency in the PEEC model, we have two remedies, which are illustrated in Section II-A and II-B.

Fig. 1. Geometry of the two wires with a voltage source between the two wires.

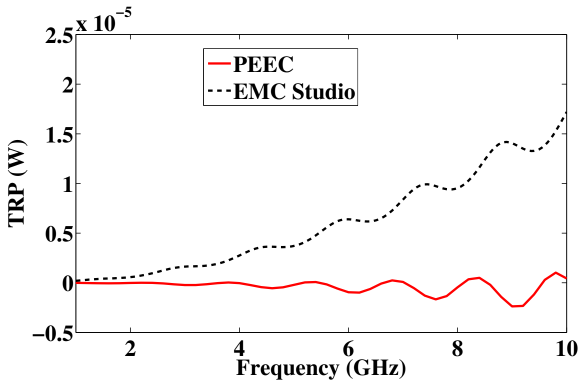


Fig. 2. (a) TRP of the two wires with a voltage source between the two wires calculated with PEEC. (b) TRP calculated with EMC studio [8].

III. New Radiation Compatible PEEC Ports and Loads

A. Using Traces Instead of Lines

In order to overcome the inaccuracy problem caused by the source location, we use traces instead of the lines which make the model more physical. This process is illustrated in Fig. 3.

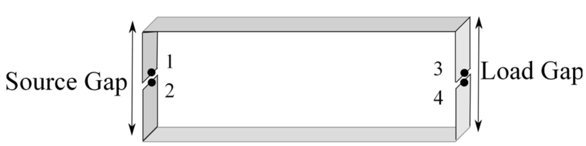


Fig. 3. Geometry of the two wires, with 1 V voltage source and 192.5 Ω internal impedance between node 1 and 2, and a 192.5 Ω load between node 3 and 4.

The total radiated power is shown in Fig. 4.

From Fig. 4 we can see that TRP calculated by PEEC, Green's function and EMC Studio agree favorably, and the power increases with frequency.

However, by doing this, it complicates the PEEC solver by introducing more unknowns into the system, which is

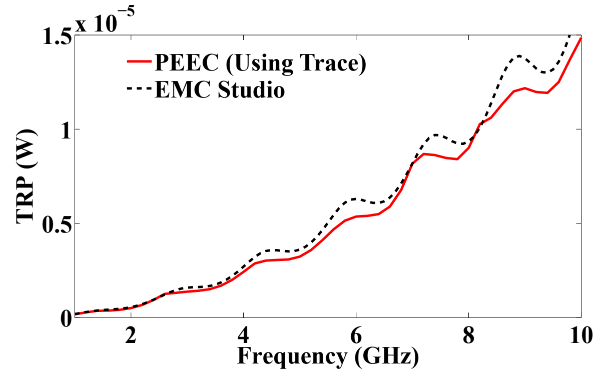


Fig. 4. TRP of the two wires.

unnecessary and avoidable. Hence, a much simpler and easier approach is introduced in Section II-B.

B. Radiation Compensation for the Gaps

In order to compensate radiation from the load gap and the source gap, the simplest way is to approximate the two segments as Hertzian dipoles. Since they are electrically small, the currents can be regarded as constant values. Hence, radiation from the two gaps can be roughly equivalent to the radiation from two Hertzian dipole, respectively. Here, we use two Hertzian dipolos to model the radiation characteristics of the gaps, and is illustrated in Fig. 5.

In the model, the Hertzian dipole 1 is used to model the source gap with the current I_{source}, and the Hertzian dipole 2 is for the load gap with the current I_{load}. For a Hertzian dipole with length l and current I_0, the radiated power can be written as $P^{rad} = \frac{\pi}{12}\sqrt{\frac{\mu_0}{\varepsilon_0}} I_0^2(\frac{l}{\lambda})^2$. Hence, radiation contribution from the two gaps can be approxiamted as

$$\begin{aligned} P_{gap}^{rad} &= P_{Hertz1}^{rad} + P_{Hertz2}^{rad} \\ &= \frac{\pi}{12}\sqrt{\frac{\mu_0}{\varepsilon_0}} I_{source}^2(\frac{l_1}{\lambda})^2 + \frac{\pi}{12}\sqrt{\frac{\mu_0}{\varepsilon_0}} I_{load}^2(\frac{l_2}{\lambda})^2 \end{aligned} \quad (1)$$

where l_1 and l_2 represent the length of the source and load gap, respectively.

Before calculating the radiation from the two Hertzian dipoles, the currents need to be checked carefully, which is illustrated in Fig. 6. The comparison of TRP with EMC studio and PEEC is depicted in Fig. 7. The results calculated by them agree favorably. In Fig. 7, EMC Studio results have ripples since the vertical parts where source and load are added are modeled as cylindrical conductors, and they are not perfectly matched with the 192.5 Ω loads.

C. Radiation from Interconnect Part

By comparing Fig. 2, Fig. 4 and Fig. 7, radiation from the source and load gaps are dominant in this structure.

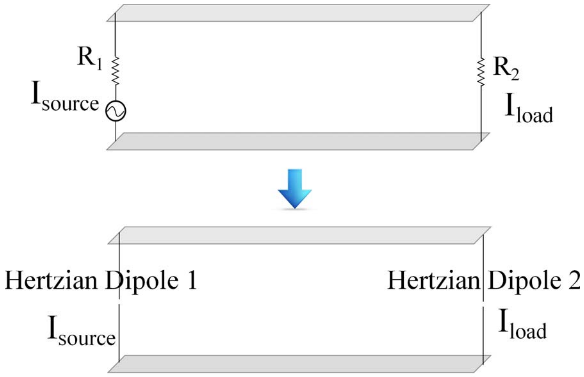
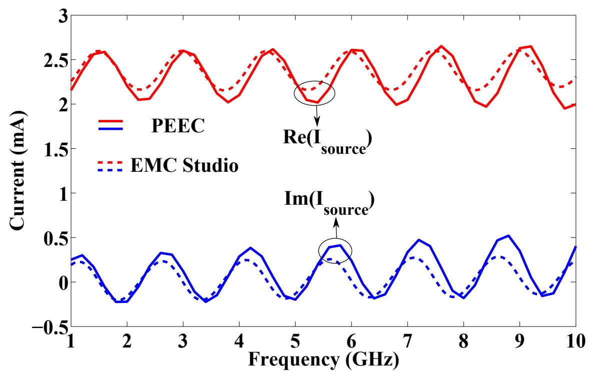
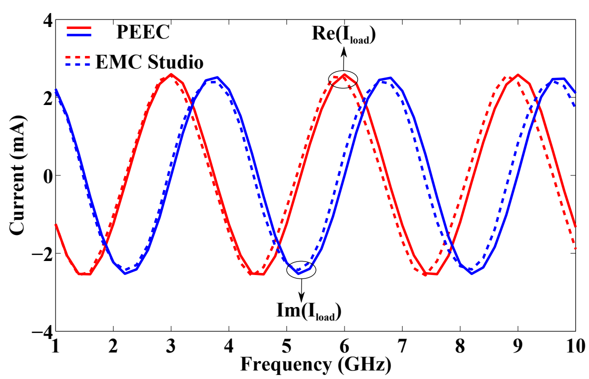


Fig. 5. Geometry of the two wires, and the compensation policy for the structure.



(a)



(b)

Fig. 6. (a) Curernt flows through the source gap. (b) Current flows through the load gap.

IV. Conclusion

In this paper, radiation from the source gap and the load gap of a differential pair is modeled with two approaches, and both of them can work well. Among them, the trace model complicates the problem by introducing more unknowns. The Hertzian dipole model is easier to implement and more user-friendly, since it requires no more pretreatment and can serve as a post-processing procedure. This proposed method provides a remedy for radiation compensation of any radiators with an electrically small length.

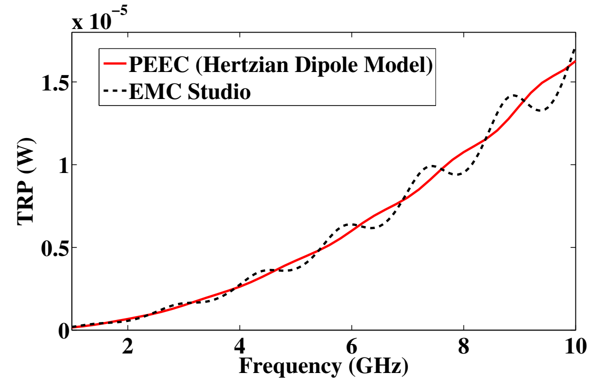


Fig. 7. TRP calculated with EMC studio and with the compensated geometry.

Acknowledgment

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References

[1] A. E. Ruehli, "Equivalent circuit models for three dimensional multi-conductor systems," *IEEE Trans. Microw. Theory Tech.*, vol. MTT-22, no. 3, pp. 216-221, Mar. 1974.

[2] A. E. Ruehli, "Inductance calculations in a complex integrated circuit environment," *IBM J. Res. Develop.*, vol. 16, no. 5, pp. 470-481, Sep. 1972.

[3] A. E. Ruehli and P. A. Brennan, "Efficient capacitance calculations for three-dimensional multiconductor systems," *IEEE Trans. Microw. Theory Tech.*, vol. 21, no. 2, pp. 76-82, Feb. 1973.

[4] G. Wollenberg and S. V. Kochetov, "Fast computation of radiated power distribution in coupled wire systems by the PEEC method," *in 2003 IEEE International Symposium on Electromagnetic Compatibility, 2003. EMC 03.*, 2003, pp. 1152-1155, Vol.2.

[5] Y. S. Cao, L. Jiang and A. E. Ruehli, "Distributive radiation and transfer characterization based on the PEEC method," *IEEE Trans. Electromag. Compat.*, vol. 57, no. 4, pp. 734–742, Aug. 2015.

[6] Y. S. Cao, L. Jiang and A. E. Ruehli, "An equivalent circuit model for graphene-based terahertz antenna using the PEEC method," *IEEE Trans. Antenna Propag.*, vol. 64, no. 4, pp. 1385–1393, Apr. 2016.

[7] Y. S. Cao, L. Jiang and A. E. Ruehli, "The derived equivalent circuit model for magnetized anisotropic graphene," *submitted to IEEE Trans. Antenna Propag.*.

[8] EMC Studio. Available: http://www.emcos.com/