Accurate RFI Prediction of 3D Non-planar Connector with Half Magnetic Dipole Pattern

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Abstract— In this paper, a dipole-moment based reciprocity method is applied to a consumer electronic device. The dipole moment is then used to predict radio-frequency interference (RFI) from a high-speed connector to two nearby RF antennas. The connector has a 3D structure with data pins vertically-oriented, for which the near H field pattern around the connector shows a half magnetic dipole pattern. This is different from typical complete dipole patterns over planar printed PCB (printed circuit board) structures. To tackle this problem, a magnetic dipole is placed in full-wave simulation with a similar connector structure. Using the reference near field data from simulation an equivalent magnetic dipole moment for the measured field is obtained. Further reciprocity theorem is applied to predict RFI based on the equivalent dipole magnitude and the antenna reverse H field. The predicted RFI shows a fairly good match with the measured RFI for both victim antennas.

Keywords—radio-frequency interference; dipole moment; half dipole pattern; near-field scanning; high-speed connector; reciprocity

I. INTRODUCTION

In modern wireless consumer electronic devices, there is an increasing need for smaller, compact, and denser design. This often requires wireless components like transceiver, front-end and antenna to be placed very close to noise sources like memory, power supply, and main processor in the device. Electromagnetic noise from noise sources interferes with wireless receiver components causing radio frequency interference (RFI) issues in the device. As a result, wireless performance metrics like range and throughput is degraded, which impacts user experience. Noise sources include ICs [1], memory chips, high-speed signal traces [2] and connectors, flexible cables [3], power regulators [4], heatsinks [5] and etc. With the increase in need for higher wireless throughput and longer range, RFI issues in consumer electronic devices need to be predicted and mitigated early in build cycle to minimize time to market and reduce solution cost.

There has been a lot of research focusing on the reconstruction of RFI noise sources and estimation of RFI noise level. Huygens’ equivalence principle has been used to estimate RFI from a noise IC to a victim antenna [6]. However, the biggest limitation of this method lies in the difficulty of measurement implementation on the side surfaces and the lack of radiation physics inside the Huygens’ box. A dipole-moment based reciprocity method has been widely used to estimate RFI due to its effectiveness and simplicity [7]-[10]. In addition, the method can provide insight into radiation physics of noise source (forward radiation path) and coupling path (reverse radiation path), using which potential mitigation methods can be derived.

Previously shown methods of dipole-moment based source reconstruction dealt primarily with planar noise sources of DUT [8]-[10]. Thus the reconstructed dipole moment can be represented in x-y plane. In this paper, a noisy high-speed connector source with 3D structure is studied. Due to the non-planar structure of the connector the previous planar dipole reconstruction method cannot be directly applied. The measured fields of the connector doesn’t show a typical near-field pattern of a dipole, but it is clipped to that of a half dipole. Therefore, this paper will show the feasibility to reconstruct such a ‘half dipole’ problem, and compare estimated RFI with measured RFI to validate the proposed method.

II. NEAR FIELD SCANNING

A. DUT Description

A simplified version of DUT is depicted in Fig. 1. It is a device with a high-speed connector with width of 15mm and height of 8mm connected to a big PCB with high-speed data and clock traces. These data and clock pins are going through a right-angle transition from the connector to the PCB. An extension from the connector is the main logic board which houses the remaining components of the device including the wireless antennas. Noise from the connector pins and traces couples to antenna and causes RFI to the radio in the device. Note the convention of coordinate system in Fig. 1, which will be used repeatedly in later sections.

Fig. 1. Simplified description of the DUT.
B. Near Field Scanning

Through rough near-field probing measurements, it was found that the data pins are the dominant source causing RFI on the two victim antennas, especially the right-angle transition part. Due to the 3D nature of the connector structure, two scanning planes with different orientations (x-y and y-z) are established to obtain more information about the radiating physics. This is shown in Fig. 2(a) and Fig. 2(b). For x-y scanning, scanning is done at different heights (different z coordinate value) from the PCB. Similarly for y-z scanning plane, distance to the connector (different x coordinate value) is swept.

In dipole-moment based reciprocity method, both forward and reverse field are necessary to predict RFI. Forward field represents the radiated field from active noise source, whereas reverse field means the radiated field from victim antenna at the source location by exciting the antenna. Forward problem quantifies the radiation physics of noise source, whereas reverse problem describes the coupling path and the susceptibility of the victim antenna.

![Fig. 2. (a) x-y scanning plane. (b) y-z scanning plane.](image)

Fig. 2. (a) Measurement setup for near H field of forward problem. (b) Measurement setup for near H field of reverse problem.

![Fig. 3. (a) Measurement setup for near H field of forward problem. (b) Measurement setup for near H field of reverse problem.](image)

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C. Forward H Field Results

As introduced in part B, the forward fields including $H_x$ and $H_y$ were measured in x-y and y-z plane, respectively. The forward H fields are shown in Fig. 4.

![Fig. 4. Measured H field in forward problem. (a) $H_x$ in x-y plane at z=1mm. (b) $H_y$ in x-y plane at z=1mm. (c) $H_x$ in y-z plane at x=4mm. (d) $H_y$ in y-z plane at x=4mm.](image)

Fig. 4. Measured H field in forward problem. (a) $H_x$ in x-y plane at z=1mm. (b) $H_y$ in x-y plane at z=1mm. (c) $H_x$ in y-z plane at x=4mm. (d) $H_y$ in y-z plane at x=4mm.

![Fig. 5. Complete H field pattern for a $M_y$ dipole. (a) $H_x$ in x-y plane. (b) $H_y$ in x-y plane. (c) $H_x$ in y-z plane. (d) $H_y$ in y-z plane. Dashed part is the half region to be compared with Fig. 4.](image)

Fig. 5. Complete H field pattern for a $M_y$ dipole. (a) $H_x$ in x-y plane. (b) $H_y$ in x-y plane. (c) $H_x$ in y-z plane. (d) $H_y$ in y-z plane. Dashed part is the half region to be compared with Fig. 4.
Note that the measured H field is similar to the near H field pattern of a magnetic dipole loop oriented in y-direction ($M_y$ dipole), but that of half of a complete $M_y$ dipole pattern. The complete field pattern of a $M_y$ dipole is shown in Fig. 5 for reference. Comparing Fig. 4 and Fig. 5 it can be easily found that the patterns in Fig. 4 are actually half of the patterns in Fig. 5. The dashed region in Fig. 5 represents the half part to be compared with Fig. 4. In section III the method to reconstruct the half dipole will be introduced. In another perspective, the measured “half” dipole pattern reveals that the center of equivalent $M_y$ dipole is at the right-angle transition point of the connector pins. In other words, transition part is the main source for RFI.

D. Reverse H Field Results

In order to predict RFI noise using reciprocity theorem, reverse H field is measured using the setup in Fig. 3(b). In reverse field measurement, only the field on x-y plane at $z=1\text{mm}$ is measured as shown in Fig. 2(a). The reverse $H_x$ and $H_y$ are shown in Fig. 6. It is worthwhile noting that $H_y$ is especially strong at the dipole location. Since the identified dipole is in y direction, according to the reciprocity theorem, only reverse $H_y$ will contribute to the coupled RFI.

III. EQUIVALENT DIPOLE RECONSTRUCTION AND RFI PREDICTION

A. Equivalent Dipole Reconstruction

At this point both forward and reverse H field have been obtained, and the equivalent dipole type has been identified. The remaining problem is how to calculate the equivalent dipole strength for the ‘half’ dipole pattern. The solution described in this paper is still based on the least square method [1]:

$$M_y = [T_{r,M}]^T T_{r,H} F_s \quad (1)$$

where $F_s$ is the measured H field data. $T_{r,M}$ is the transfer coefficient of field data $F_s$ due to equivalent magnetic dipole moment $M_y$. However, the transfer coefficient $T_{r,M}$ cannot be derived analytically as in [1][6][9] due to the existence of the non-planar structure. Differently, the transfer coefficient was obtained through numerical simulation with a magnetic dipole moment placed in a similar 3D structure as shown in Fig. 7. A PEC block is used to represent the 3D connector structure, and a square current loop is used as a magnetic dipole. The loop is placed in the right-angle corner of pins transition to mimic the previously identified $M_y$ dipole in the right-angle transition part. Nevertheless, this method will work only when dipole type and location are known. Through the near field results and physics-based knowledge [9], the dipole type and location can be confirmed.

![Fig. 7. $M_y$ dipole in simulation using a square current loop.](image)

![Fig. 8. (a) Simulated $H_x$ on x-y plane at z=1mm. (b) Simulated $H_y$ on x-y plane at z=1mm. (c) Simulated $H_x$ on y-z plane at x=4mm. (d) Simulated $H_y$ on y-z plane at x=4mm.](image)
in this case, according to the reciprocity theorem, the RFI noise can be predicted using [12]:

\[ U_{\text{a}}^{\text{pred}} = \frac{Z_L}{2U_{\text{rev}}} H_y \cdot M_y, \]

(2)

In (2), \( U_{\text{a}}^{\text{pred}} \) is the induced voltage at the RF antenna port due to the noise source. \( Z_L \) is the load impedance which is usually 50Ω. \( U_{\text{rev}} \) is the incident voltage when exciting the victim antenna for reverse field measurement. \( M_y \) is the reconstructed magnetic dipole moment with the unit of \( V \cdot m \), and \( H_y \) is the reverse H field. With the previously calculated \( H_y \) and \( M_y \) and using equation (2), the coupled voltage at victim antennas can be calculated.

To verify the accurateness of the predicted RFI, the actual RFI was measured for comparison. The measurement was performed based on Fig. 1 when the noise signal is active, by simply connecting the victim antenna with a SA through a low-noise amplifier with about 33dB gain and noise figure less than 1dB. Resolution bandwidth of 100 kHz is used in both forward problem and RFI measurement. The final comparison between predicted and measured RFI for both victim antennas are shown in Fig. 9(a), (b) respectively. The two results correlate within error of up to 4dB. This is acceptable at this time as the half dipole reconstruction has been never done before attributing the accuracy in resolving the half dipole magnitude.

To ensure the feasibility of constructing the equivalent dipole and using equation (2), the coupled voltage at victim antennas can be calculated.

Fig. 9. Comparison between predicted RFI and measured RFI on antenna #2.

CONCLUSION

In this paper, dipole-moment based reciprocity method is successfully applied on a complex 3D structure of a high-speed connector. The feasibility of constructing the equivalent dipole strength for a ‘half’ dipole pattern is shown by using the numerical simulation field to calculate the transfer coefficient and afterwards calculating the equivalent dipole moment with the least square method. The predicted RFI using reciprocity theorem matches fairly well with the measured RFI level. Improving the prediction accuracy of reciprocity method, elaborating radiation physics and coupling path of the high-speed connector and providing mitigation methods by either blocking the coupling path or suppressing the noise source are recommended as future work of this paper.

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REFERENCES


