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An efficient characterization approach of radiated electromagnetic field analysis for PCBs

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Abstract

Radiation characterization is composed of radiation mechanism diagnosis and radiated electromagnetic (EM) field estimation. Based on not only the internal relationship between radiated EM field and wave impedance, but also the inner relationship between wave impedance and measurement distance, a new near-field method is proposed for diagnosis of radiation mechanism, including common mode (CM) and differential mode (DM). Furthermore, by employing radio frequency (RF) circuit parameter measurement, a simple approach is presented for estimation of radiated EM field generated by RF current in the cable. The experimental research shows that radiated noises decrease obviously after circuit improvement, meanwhile, the radiation mechanism is achieved by the near-field method; in addition, the results of RF circuit parameter measurement agree well with 3-m chamber measurement results. Therefore, the presented approach is efficient and effective.

Keywords: EMC; radiated EM field; characterization; PCB

1. Introduction

Nowadays, with the development of PCBs, electromagnetic compatibility (EMC) problems are much more serious than before. Therefore, a lot of electrical and electronic devices would be required to test the EMC compliance. The far-field EM field measurement is proposed to investigate radiation characterization for PCBs, which could provide the total noises and contrast with EMC standards directly. In addition, source reconstruction modeling is presented to analyze radiated EMI problems by using HFSS, CST and so on. 3-D radiated EM field can be described well, which is also in favor of radiated EM field analysis.

However, the far-field measurement can not be used for the diagnosis of radiation mechanism, including CM radiated EMI and DM radiated EMI in which different methods should be adopted to suppress noises according to radiation mechanism. Furthermore, facilities for far-field measurement are costly, and OSAT or anechoic chamber is also required, so it is very complicated and time-consuming. Besides that, some boundary conditions must be

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defined in source reconstruction modeling, which is a hard work in practice. The same as far-field measurement, the radiation mechanism can not be determined by source reconstruction modeling.\(^{11}\)

To solve these problems above, in the paper, an efficient characterization approach is proposed to investigate the radiation mechanism and estimation for PCBs. According to not only the internal relationship between the radiated EM field and wave impedance, but also the inner relationship between wave impedance and measurement distance, radiation mechanism diagnosis is achieved by using near-field probes. Moreover, radiated EM field generated by RF current can be estimated by using RF circuit parameter method. The experimental results indicate that the noises decrease obviously after circuit improvement, and of which the radiation mechanism is obtained by the proposed method. In addition, the results from RF parameter method are in good accordance with 3-m chamber measurement results. Therefore, the presented approach is efficient and effective.

### 2. Radiated EM Field characterization

#### 2.1. Principle of radiation mechanism diagnosis

Radiation mechanism is composed of CM radiated EMI and DM radiated EMI. The CM radiated EMI is considered as the electric dipole model, in which it is generated by an interfacing cable without a well defined return path. Oppositely, DM radiated EMI is treated as magnetic dipole model, in which it is produced by a closed circuit loop.

The wave impedance is defined as the ratio of the electric field transverse component to the magnetic field transverse component. In far-field, the wave impedance is about \(273\,\Omega\). However, in near-field, the wave impedance changes with measurement distance and may approach \(273\,\Omega\). Furthermore, according to different models, the inner relationship between wave impedance and measurement distance is entirely distinct. According to the internal relationship between the radiated EM field and measurement distance, in CM model, the wave impedance is expressed as

\[
Z = \frac{E}{H} \frac{1}{r} \quad (1)
\]

And in DM model, the wave impedance is also expressed as

\[
Z = \frac{E}{H} \frac{1}{r} \quad (2)
\]

From equation (1) and equation (2), in CM model, the wave impedance increases with the measurement distance reduction; and in DM model, the wave impedance increases with the measurement distance increase. Therefore, the radiation mechanism can be diagnosed by the near-field measurement method.

It should be mentioned that the min-wavelength should be considered as the measurement distance for avoiding signal coherence. Furthermore, in practice, the cable loss (\(L_{\text{dB}}\)) is neglected for simplicity and efficiency.

#### 2.2. Principle of radiated EM field estimation

**Based on RF Voltage Measurement:**

In electric dipole model (CM model), the radiated CM noises are generated by CM current in the cable. Based on the Thevenin theorem, the circuit generating CM radiated EMI is equivalent to a DC voltage source (\(V_N\)) and impedance (\(Z_{CM}\)), as shown in Fig. 1 (a).

According to Fig.1 (a), the internal relationship between radiated EM field and RF voltage in cable is obtained as

\[
E = I_{CM} Z_{CM} \quad (3)
\]

From equation (3), it is found that the radiated EM field can be determined by employing RF voltage measurement, and the equivalent voltage (\(V_N\)) can be measured by using RF voltage probe.

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Fig. 1. (a)Equivalent circuit of common Mode radiated EMI; (b) Scheme of radiated EMI field estimation by using RF current probe (I1, I2…IN
Based on RF Current Measurement:
In free space, the relationship between the radiated EM field and the radio frequency (RF) current is as follows:
\[ E_\theta \approx j L Z_0 I \beta \sin \theta e^{-j \beta r/4\pi r} \]  
(4)

Where, \( Z_0 \) is the wave impedance in free space; \( L \) is the cable length; \( I \) is RF current in the cable; \( r \) is the measurement distance; and \( \lambda \) is the wave length of coefficient signals.

The cable can be divided into \( N \) segments. Current in every segment is determined by using RF current probe. \( I_1, I_2, \ldots I_N \) are defined as the currents in \( N \) segments correspondingly, as shown in Fig.1(b).

According to equation (4), radiated EM field is obtained by measuring the total current in the cable.

\[ \tilde{E}_C \approx 2\pi f \cdot 10^{-7} \cdot (I_1 + I_2 + \ldots + I_N) \cdot L \cdot r^2 + (H - 0.8)^2 f^{0.5}/3 \]  
(5)

Where \( E_C \) is the resultant radiated EM field, \( L \) is the length of each segment, \( f \) is the frequency and \( r \) is the measurement distance at the OATS, and \( H \) is the measuring antenna height in m. \( F \) is the correction factor to account for reflection from the OATS’s ground plane.

3. Experiment results and analysis

3.1. Experiment scheme

Radiation Mechanism Diagnosis
Based on the principle of radiation mechanism diagnosis, the experimental set-up is designed as shown in Fig.2.

Fig. 2. (a) Experiment scheme of radiation mechanism diagnosis for PCB; (b) Experiment setup 1; (c) Experiment setup 2

The experimental instruments include 1) GWINSTEK GSP-827 spectrum analyzer (10KHz-2.7GHz); 2) ROHDE&SCHWARZ HZ-11 near-field probes (10KHz-2GHz) including a magnetic probe Loop 3cm and a electric probe Stab 6mm; 3) Wooden work bench (150cm in length, 70cm in width and 50cm in height) with probe support of 100cm in length( the probes can move freely in a space of 120×50×100cm³).

In the test, three circuits are designed, with the same schematics. The first one is circuit S1 (ranging in 60cm²); the second one is circuit S2(ranging in 24cm²); and the third one is circuit S3 (ranging in 24cm² with a 40cm long cable).

Radiated EM Field Estimation
According to the principle of radiated EM field estimation, the experimental set-up is shown in Fig.3 (a)-(c).

The experimental instruments include 1) GWINSTEK GSP-827 spectrum analyzer (10 KHz-2.7 GHz); 2) Agilent 85024A high frequency voltage probe (300 KHz-3 GHz); 3) Compliance Direction BCP-512 high frequency current probe (1 MHz to 1GHz); 4) Com-Power PA-103 pre-amplifier (32dB input gain). And in the test, one circuit is designed to verify the proposed method, and its schematic is from references [12].

Fig. 3. (a) Experiment scheme of radiated EM field estimation for PCB; (b) Experiment setup 1; (c) Experiment setup 2; (d) ETS-Lingdren 3-m
3-m Anechoic Chamber

In the paper, 3-m anechoic chamber measurement is used to verify the proposed methods. The apparatus include 1) ETS-Lingdren 3-m standard anechoic chamber (14 KHz-18 GHz); 2) ROUDE&SCHWARZ ESU26 EMI receiver (9 KHz-26.5 GHz), as shown in Fig.3 (d).

3.2. Experiment #1

Three circuits are designed for experiment #1, whose schematics are the same. The first one is circuit S1 (ranging in 60cm$^2$ without any cable); the second one is circuit S2 (ranging in 24cm$^2$ without any cable); and the third one is circuit S3 (ranging in 24cm$^2$ with a 40cm long cable); and the three circuits form a PCB. According to electric dipole model (CM model), DM radiated noises generated by circuit S1 are much higher than that generated by circuit S2. In addition, based on magnetic dipole model (DM model), CM radiated noises generated by circuit S3 is much higher than that generated by circuit S2. Rough near-field measurement is adopted to determine the exact radiation bandwidth for the PCB. After that, adjusting the radiation bandwidth as above, the radiated electric field is obtained by ROUDE&SCHWARZ HZ-11 electric probe Stab 6mm, and the radiated magnetic field is achieved by ROUDE&SCHWARZ HZ-11 magnetic probe Loop 3cm. Therefore, the wave impedance can be calculated. Changing the measurement distance and repeating the above experiment process, the relationship between wave impedance and measurement distance can be achieved.

The 2D electric field distribution for the PCB is shown in Fig.4 (a) and the 2D magnetic field distribution for the PCB is shown in Fig.4 (b). In the two figures, S1 stands for the circuit S1 (ranging in 60cm$^2$ without any cable); S2 represents the circuit S2 (ranging in 24cm$^2$ without any cable); S3 symbolizes the circuit S3 (ranging in 24cm$^2$ with a 40cm length of cable); r is the measurement distance between probe and observation points; and f is the relative frequency. It is found that when measurement distance is 0.1cm and frequency is 279MHz, the radiated electric intensity generated by circuit S3 can reach 3 V/m; the radiated electric intensity generated by circuit S2 is only 1.6 V/m, reducing to 50% of the original value. Furthermore, when measurement distance is 2cm and frequency is also 279MHz, the radiated magnetic intensity generated by circuit S1 reaches 12.3A/m; and the radiated magnetic intensity generated by circuit S2 attains 8 A/m, reducing to 65% of the original value. In other hand, Fig.4 (c) and Fig.4 (d) show that the wave impedance of circuit S1 increases as measurement distance increases, and it can reach 200% of the original value; oppositely, wave impedance of circuit S3 increases while measurement distance decreases, and it can reduce to 40% of the original value . Therefore, DM radiated EMI dominates circuit S1 and CM radiated EMI dominates circuit S3 whose noises could be suppressed by improved grounding.

Fig.4. (a) The 2D E field distribution for PCB (measurement distance=0.1cm, f=279MHz); (b) The 2D H field distribution for PCB (measurement distance=2cm, f=279MHz); (c) The Relationship between wave impedance and measurement distance in circuit S1 (DM radiated EMI, f=250MHz); (d) The Relationship between wave impedance and measurement distance in circuit S1 (CM radiated EMI, f=250MHz);

Fig.5 (a) shows that the radiated EMI generated by circuit S3 can reach 33dBV/m; and the radiated EMI generated by circuit S2 is only 16 dBV/m, reduced to 50% of the original. So the proposed method is valid and efficient.

3.3. Experiment #2

One circuit is designed to validate the proposed method, where the schematics agree with reference [7]. Based on the principle of radiated EM field estimation, the attaching wire is divided into 10 segments and the length of every
segment is 01m. After that, RF current probe is used to measure the current in every segment. It should be mentioned that the RF current probe is fixed at the center of each segment. Moreover, the radiated EM field is obtained by the presented approach, as shown in Fig.5 (b). Fig.5 (c) is the test result by using 3-m standard anechoic chamber. Test results by using radiated EM field estimation method are in good accordance with the results in reference [7] and that of 3-m standard anechoic chamber measurement. It shows that the proposed method is convenient and effective.

![Comparison between results by using radiated EM field estimation method and results in reference [7]; (c) Results by using 3-m standard anechoic chamber](image)

Fig. 5. (a) The contrast between suppressed circuit and origin circuit (the original circuit’s range is 24cm² with a 40cm long cable and the suppressed circuit’s range is 24cm² without any cable.); (b) Comparison between results by using radiated EM field estimation method and results in reference [7]; (c) Results by using 3-m standard anechoic chamber

4. Conclusion

The radiation mechanism diagnosis and radiated EM field estimation comprise the radiated characterization. In the paper, an efficient characterization approach is proposed to analyze radiated electromagnetic field for PCBs. According to not only the relationship between the radiated EM field and wave impedance, but also the relationship between wave impedance and measurement distance, radiation mechanism can be diagnosed. Furthermore, radiated EM field generated by RF current is estimated by using RF voltage probe or RF current probe. The results show that noises decrease obviously after improving due to mechanism diagnosis, and the results by radiated EM field estimation method agree well with the results in reference [12], and that of 3-m standard anechoic chamber measurement. Therefore the proposed approach is valid and efficient.

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