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Near Field Noise Source Reconstruction Using Equivalent Field Box for RF Desensitization Analysis

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***Abstract*— This paper presents a novel method for noise source reconstruction using an equivalent field box based on magnitude-only near-field data. The proposed approach overcomes the limitations of conventional dipole moment-based methods, which struggle to resolve weak noise sources and unclear near-field patterns in practical devices. The noise source is modeled based on the Huygens' box equivalent principle. To facilitate practical implementation, only the tangential field on the upper surface of the equivalent field box is required. Near-field scanning techniques were employed to measure the magnetic field distribution above the noise source, as captured by a spectrum analyzer (SA). By analyzing the near-field pattern and leveraging a physical understanding of the radiation mechanism, the phase information was assigned through the near-field induced by an ideal P_z dipole, which can be analytically calculated. The proposed noise reconstruction method was experimentally validated across five commercial platforms. The method reconstructed the noise source, imported the equivalent field box into Computer Simulation Technology (CST) with a full-wave receiver model, and achieved simulated coupling at the receiver with an error of less than 5 dB compared to measured data.**

***Index Terms*—Near field scanning, equivalent field box, radio-frequency desensitization.**

I. INTRODUCTION

Radio-frequency (RF) desensitization presents a major challenge in modern wireless electronic devices, compromising the reliability and performance of many wireless communication systems. As devices operate at higher speeds, the severity of this issue increases, which leads to a reduction in RF sensitivity [1]-[2]. RF noise source could be different components, such as central processing units (CPUs) [3], memory modules [4], connectors [5] and heatsinks [7]. To address this issue,

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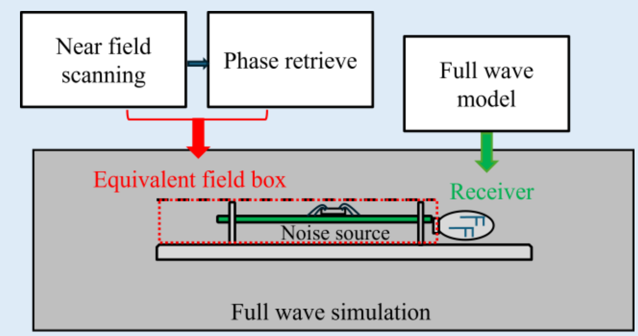


Flowchart of proposed magnitude aware near field source reconstruction

RF engineers could benefit from running simulations to assess new RF product designs through numerical methods before prototyping. To ensure the simulation result is accurate and reliable, one of the challenge lies in accurately characterizing and modeling the noise sources.

There have been a lot of studies on noise source reconstruction. Generally, there are two methods to reconstruct the noise source. The first method is dipole reconstruction, which traditionally relies on the least square method (LSQ). The location and step size of the dipole array are usually pre-defined to solve the magnitude of a set of dipole arrays from the near field distribution. Using Huygens' equivalent field box based on the equivalence principle is another way to reconstruct the noise source [6]. This method requires measuring the tangential field on a closed surface enclosing the noise source. It requires performing near field scanning on both horizontal and vertical planes, which is complex to implement in practical scanning.

However, for both LSQ and equivalent box method, the phase information of the near fields is required. The phase measurement is

Take-Home Messages:

- Equivalent radiation source model is proposed for RF desensitization simulation.
- Huygens' box model with magnitude-only data is applied and the phase is inferred based on the near field pattern of the dominant source.
- The model was validated with data collected from five commercial platforms and two embedded RF antennas.
- The error between simulation and measurement in all cases are less than 5 dB.

usually challenging in practice. One common method for measuring phase is to use an oscilloscope to calculate the phase difference between a primary probe and a reference probe. However, the signals originated from data transmission activities usually do not exhibit measurable, repeated patterns even after sufficient amplification. Hence, it is difficult to set a triggering point for these signals. Also, the oscilloscope's high noise floor typically makes it unsuitable for detecting low-level broadband noise in RF desensitization studies. An alternative approach involves using a second field probe as the reference and measuring the field with a vector network analyzer (VNA) operating in tuned receiving mode [7]. Nevertheless, this method is also limited by the VNA's poor image rejection, which makes accurate measurements difficult when the noise is broadband.

The lack of phase results in solving a set of nonlinear equations, which makes the equation solving more complex [8]. Some optimization methods have been developed to solve these nonlinear equations such as the differential evolution (DE) [9], and genetic algorithm (GA) methods [10]. The equivalent dipoles are optimized to reduce the cost function related to the difference between the measured field and the reconstructed field magnitude. The drawback of these methods is the dramatic increase in computational complexity as the number of dipoles increases, especially for the complex devices under test (DUT) in practice. Furthermore, the methods are limited to converge and produces significant reconstruction errors when dealing with unclear scan patterns.

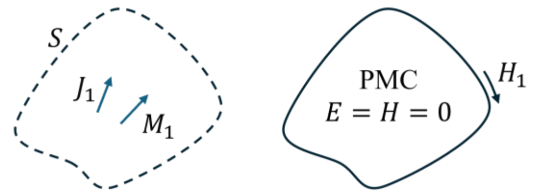
This paper introduces a novel method for reconstructing noise sources using an equivalent field box with the following process. Firstly, to simplify the model, only the top surface of the field box is defined, resulting in a minimal reduction in accuracy. Secondly, near-field scanning is performed to captures the magnitude of the magnetic field, the capability of the scanning is bottlenecked by the physical dimension of the scanner. Thirdly, the phase information is approximated analytically based on an ideal dipole model. Lastly, the measured near field source is imported to full wave simulator, to represent the noise source.

The proposed method was experimentally validated across five scenarios, where simulated coupling at the receiving antenna showed an error of less than 5 dB compared to measured values.

II. Proposed Noise Reconstruction Method

A. Equivalent Box

According to the equivalence principle, the fields outside an imaginary closed surface can be recreated by placing appropriate electric or magnetic current densities on this surface to satisfy boundary conditions. As illustrated in Fig. 1, the noise sources J and M are enclosed by a closed surface S. The original noise sources could be equivalent to the tangential magnetic field H_1 on surface S placed on a perfect magnetic conductor (PMC).



(a) Original problem (b) Schelkunoff equivalent problem with perfect magnetic conductor

Fig. 1. Equivalence Principal models.

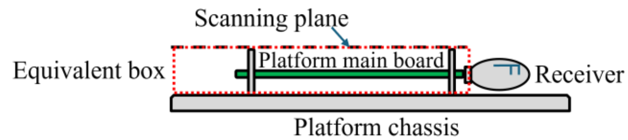


Fig. 2. Diagram of simulation model.

According to the equivalence principle, the noise source can be represented by the tangential magnetic field on an equivalent box that encloses the source. As illustrated in Fig. 2, the goal is to reconstruct the noise source originating from the main board of the digital platform. To accomplish this, the tangential magnetic field on all five surfaces of the equivalent box (indicated by the red dashed line) should be obtained. This includes H_x and H_y components on the large top surface as well as the H_x (or H_y) and H_z on four narrow sides surfaces.

The measurement of tangential field components on side surfaces poses significant challenges, as the probe must be oriented parallel to the surface, risking physical interference with the device under test and compromising mechanical stability. Such orientation makes it difficult to maintain consistent scanning height and reliable measurements. Prior work [12] has demonstrated that a one-surface equivalent box of appropriate dimensions can yield a reasonably accurate evaluation. This approach reconstructs the noise source using only the tangential field on a sufficiently large top surface. It allows for a simplified representation of the noise source while still capturing its essential near-field components.

Under the equivalence principle, the reconstructed equivalent box can predict the fields outside of the box but not within it, requiring that the equivalent field box does not intersect with the victim receiver. To accommodate this requirement, the scanning plane extends from the edge of the platform to the connector of the receiver, as shown by the black dashed line in Fig. 2.

B. Near Field Scanning

The near field scanning setup is depicted in Fig. 3. The magnetic field probe was mounted on the scanner using a plastic probe holder. The scanning area was predefined, and probe movement and data acquisition were controlled via computer automation. A broadband loop probe with a diameter of 10 mm, operating over a frequency range of 1 GHz to 3 GHz, was employed for the measurements. The probe was calibrated using a microstrip-based method, as described in [13], to determine the probe factor.

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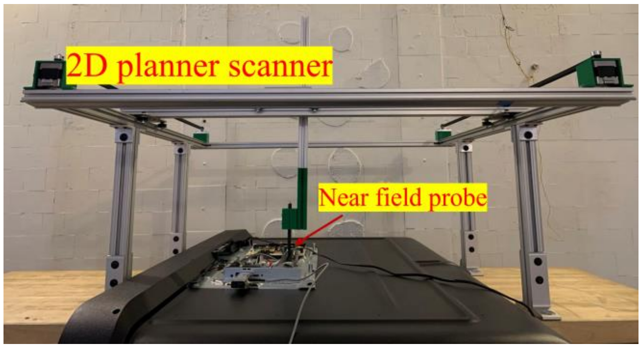

Fig. 3. Near field scanning setup.

Near-field scanning was performed on five different platforms, with the results presented in Fig. 6. Analysis of the scanning results revealed that the hottest spot across all platforms was consistently located above the heatsink, indicating that the dominant noise sources were the CPU and heatsink in each platform examined.

C. Accessorial dipole

To address the lack of phase information, the method is developed that uses unit accessorial dipole at the noise source location in the simulation model and excite it as a current port.

The near-field patterns showed a P_z dipole-like distribution based on the magnitude-only measurements, aligning with the radiation mechanism of the heatsink, which can be approximated as a monopole antenna, as illustrated in Fig. 4. With this physical understanding of the noise source, the phase information could be estimated through analytical calculations. As shown in Fig. 5, after pinpointing the noise source position at the center of the hotspot, we computed the magnetic field phase on the scanning plane by assuming a virtual P_z dipole located at the same position. The magnitude of the virtual P_z is arbitrary, as it does not influence the phase distribution. This inferred phase information is then combined with the magnitude-only measured field data.

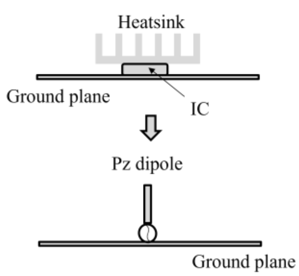

Fig. 4. Heatsink modeled as a monopole antenna.

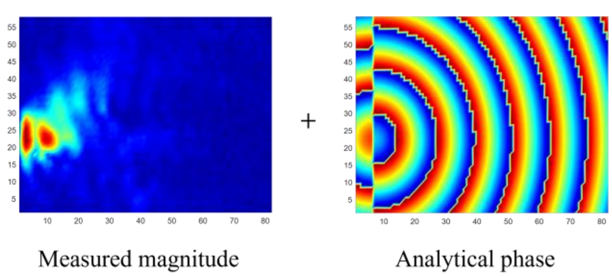

Fig. 5. Example of magnitude and phase of the near field source.

III. Measurement Validation

To validate the proposed equivalent field box, the model was implemented in electromagnetic simulation software, CST. The simulation setup is shown in Fig. 7, where the magnetic near-field source is positioned atop a PMC box. Since CST does not provide a direct PMC material option, the PMC was simulated by defining a material with high magnetic conductivity. The full-wave model of the receiving antennas was placed at the same location as in the physical setup. Two discrete ports were assigned to the receiving antennas, each terminated with a 50-ohm load. The receiving antennas are designed for communication and suffered from the noise generated by the platform. The coupled voltage on the receiving antennas was compared between simulation and measurement.

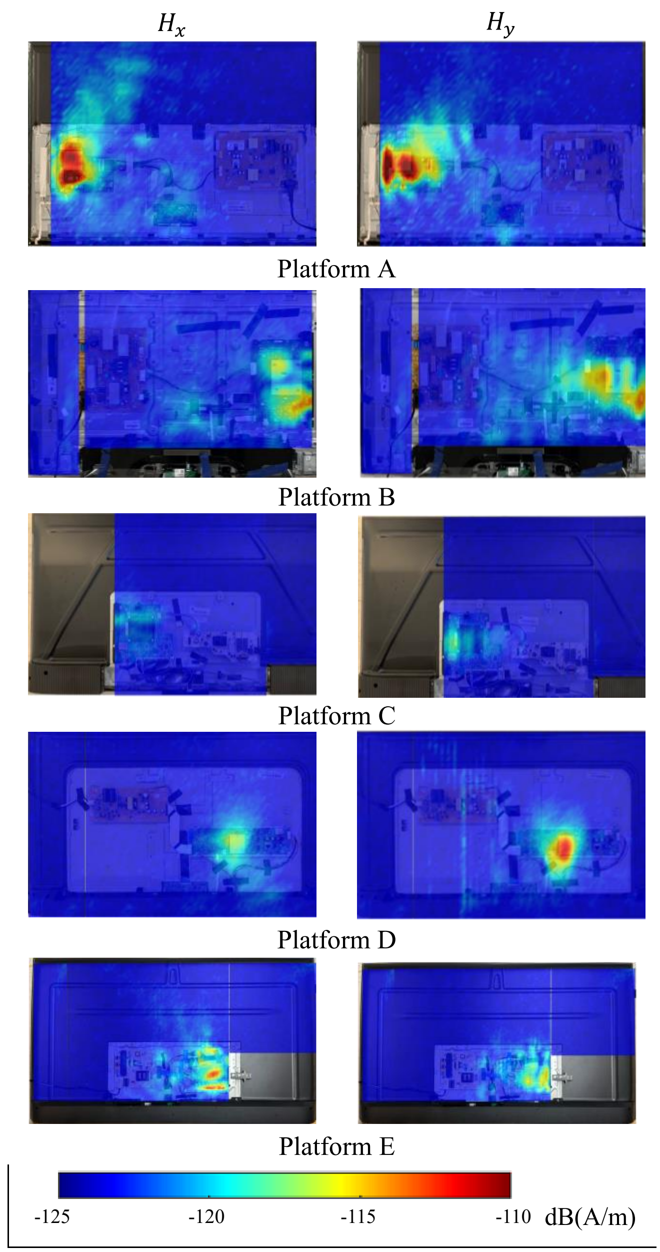

Fig. 6. Near field scanning results of four platforms.

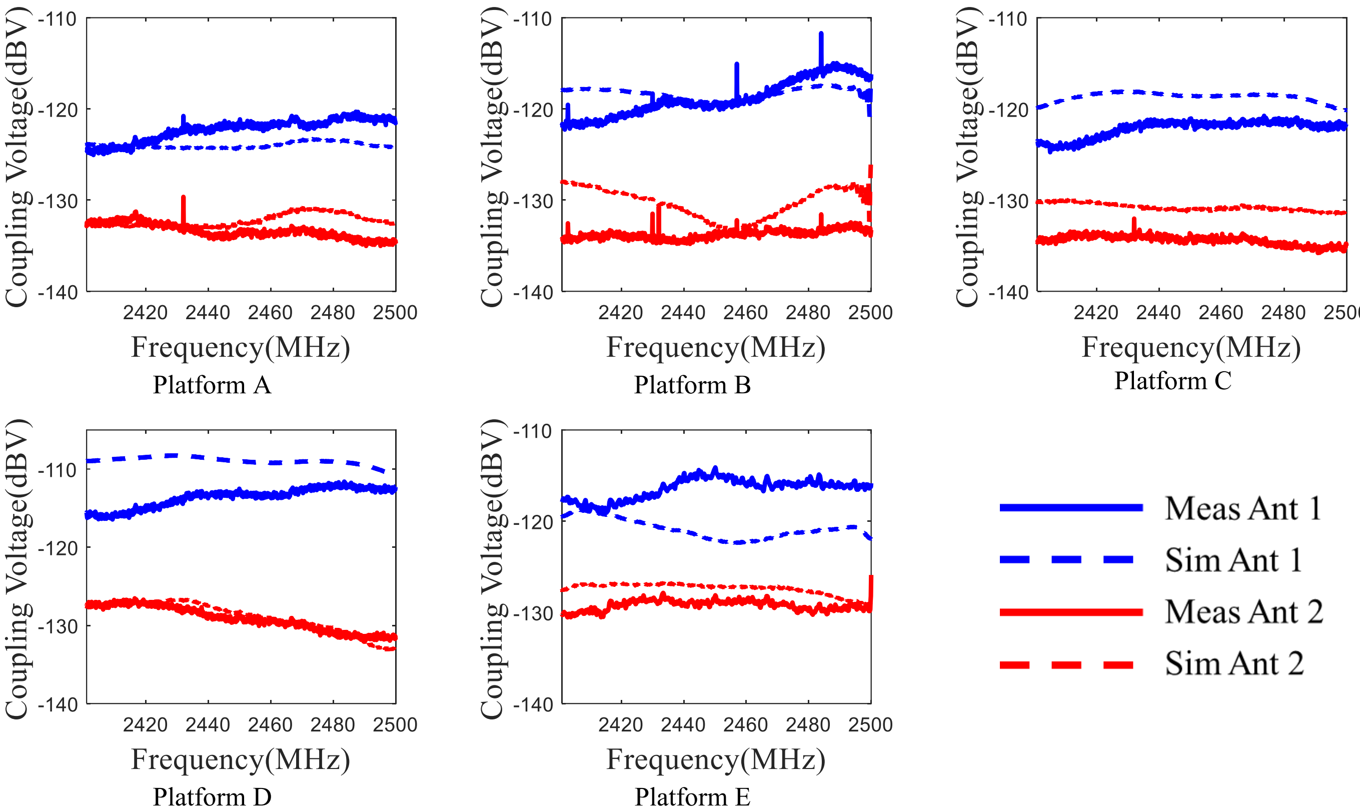

Fig. 9. Comparison of measured coupling and simulated coupling on the victim antenna 1 and antenna 2.

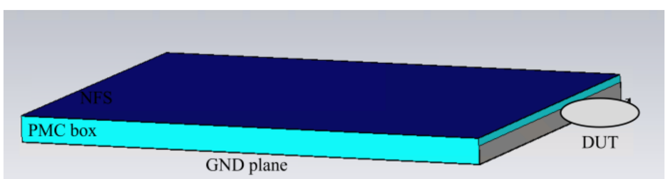

Fig. 7. Diagram of full wave simulation model.

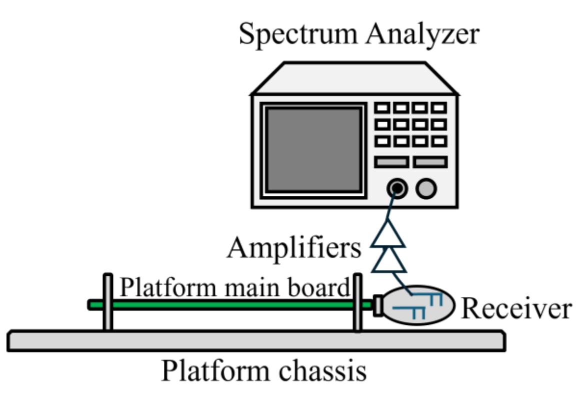

Fig. 8. Diagram of coupling measurement setup.

The coupling measurement setup is illustrated in Fig. 8. During the measurement, the platform was powered on, and the receiving antenna was connected to a SA via a semi-rigid cable soldered to the antenna port. While one antenna was measured, the other was terminated with a 50-ohm load. The frequency range of interest was the Wi-Fi band, spanning from 2.4 GHz to 2.5 GHz, and the SA's resolution bandwidth was set to 30 kHz.

The noise floor of the measurement system was not explicitly considered in the simulation, which may introduce some error, particularly for the coupling on antenna 2, as its level is close to the noise floor. To account for this effect, the measured noise floor was added to the simulation results. The comparison between the measured and simulated coupled voltages is shown in Fig. 9. Notably, the coupling on antenna 1 is consistently higher than that on antenna 2, as the main beam of antenna 1 is directed toward the platform.

The coupled noise band power provides a clear and direct measure of RF interference risk, reflecting the extent of RF desensitization. To evaluate accuracy, we calculated the band power within the 2.4 GHz Wi-Fi channel. The average error is defined as the difference in band power obtained from measurement compared to simulation. As shown in Table 1, the simulation achieves an accuracy within 5 dB. However, this error may arise from certain limitations of the method. First, only the top surface was considered in the equivalent field box. Second, the phase information derived from an ideal P_z dipole may not accurately represent the actual phase characteristics.

TABLE 1
AVERAGE ERROR OF THE SIMULATION RESULTS TO THE MEASUREMETN RESULTS

Average Error	Antenna 1	Antenna 2
Platform A	1.0 dB	0.6 dB
Platform B	1.4 dB	3.7 dB
Platform C	3.6 dB	3.4 dB
Platform D	5 dB	0.1 dB
Platform E	4.2 dB	2.0 dB

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IV. CONCLUSION

This paper presents a noise source reconstruction method utilizing magnitude-only near-field data. The phase information is derived through analytical calculations based on a comprehensive understanding of the radiation mechanism. This reconstruction method can be applied in RF desensitization analysis. The approach was implemented to reconstruct the noise source across five platforms. The reconstructed equivalent field box effectively represents the noise and estimates the coupling at the receiver with an error of less than 5 dB. While these results are promising, further improvements in accuracy may be achieved through implementation of dynamic scanning heights, though this would require more sophisticated measurement setup. The enhanced proximity to the noise source landscape offered by such an approach is expected to yield more precise field pattern characterization.

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