A Study on the High-Resolution Full Frequency Shielding Effectiveness Testing Method

Jian-fei Wu[1], Yanfang Lu[2], Zheng YIfei[3], Yang Li[2], Long-fei Zheng[4], and Guanxiang Du[5]

[1]School of Electronic Science and Engineering
[2]Tianjin Institute of Advanced Technology
[3]National University of Defense Technology
[4]Hebei University of Technology
[5]Nanjing University of Posts and Telecommunications

November 30, 2022

Abstract

The shielding effectiveness is a key index to measure the performance of electromagnetic protective materials However, the traditional shielding effectiveness testing methods exist many losses, there by the experimental data varying under different test conditions. This paper aims to provide a novel NV-center based optical high-resolution shielding performance testing method, a method that may directly provide the distribution of the electromagnetic field on the surface of the electromagnetic shielding material. This method was used to test the shielding performance of two different electromagnetic shielding materials, and comparison with the surface scan method has proved the feasibility and reliability of the optical high-resolution test method, providing a new idea for testing the effectiveness of electromagnetic shielding materials more accurately and effectively.

A Study on the High-Resolution Full Frequency Shielding Effectiveness Testing Method

Jianfei Wu,[1] Yanfang Lu,[2] Yifei Zheng,[1] Yang Li,[2] Longfei Zheng,[3] and Guanxiang Du[4]

[1] *National University of Defense Technology, No. 109, Deya Road, Kaifu District, Changsha City, Hunan Province, Changsha 410000,China*
[2] *Tianjin Institute of Advanced Technology, No. 399, Huixiang Road, Tanggu Ocean High tech Zone, Binhai New Area, Tianjin 300459,China*
[3] *Hebei University of Technology, No. 8, Guangrong Road, Hongqiao District, Tianjin, 300131, China*
[4] *Nanjing University of Posts and Telecommunications, No. 9, Wenyuan Road, Qixia District, Nanjing, Jiangsu, Nanjing, 210003, China*

Email: lyflyf5913@163.com

The shielding effectiveness is a key index to measure the performance of electromagnetic protective materials However, the traditional shielding effectiveness testing methods exist many losses, there by the experimental data varying under different test conditions. This paper aims to provide a novel NV-center based optical high-resolution shielding performance testing method, a method that may directly provide the distribution of the electromagnetic field on the surface of the electromagnetic shielding material. This method was used to test the shielding performance of two different electromagnetic shielding materials, and comparison with the surface scan method has proved the feasibility and reliability of the optical high-resolution test method, providing a new idea for testing the effectiveness of electromagnetic shielding materials more accurately and effectively.

Introduction: With the increasingly complex electromagnetic environment, it is very necessary to add shielding materials to the radiation source or parts that need anti-interference[1]. Traditional shielding material effectiveness testing methods include shielding room window testing method, flange coaxial testing method, etc.[2-4]. Although the traditional testing method can provide effective experimental data, the experimental data is not accurate enough due to the long measurement distance and various losses, such as free space field propagation loss, shielding room window loss, shielding room cavity loss, etc[5]. This study aims to provide a novel method for the performance testing of shielding materials. An optical scanning imaging system is constructed by the nitrogen vacancy center (NV) to test the shielding performance of the material, thereby making the test faster with more accurate result. This paper introduces the testing procedure and principle of optical high-resolution testing method, further verifies the feasibility and reliability of optical high-resolution testing method through experimental comparison.

NV-center-based optical High-resolution test principle: The optical scanning imaging system of the test system is constructed with an improved all-optical method, as shown in Figure 1, which shows the connection of the overall optical path equipment of the test system. The testing method consists of four steps: optical focusing, frequency tuning, fluorescence data collection, and imaging reconstruction. In this system, the scanning probe uses a tapered optical fiber as a carrier, with a diamond crystal smaller than 100 μm as a magnetic field sensor fixed on the tapered tip of the optical fiber. By using a laser pulse synchronization control system, the 532 nm wavelength laser is coupled into the tapered tip of the optical fiber through the other end of the optical fiber, to excite the nitrogen vacancy center (NV)[6] and generate a fluorescent signal. The fluorescent signal changes under the influence of the magnetic field, and the changed fluorescent signal passes through the laser confocal microscope system. The charge- coupled device collects the said signal and convert the light into electric charge, so as to convert the change of light into the change of digital signal. Finally, the magnetic field strength of the test equipment is calculated by Rabi frequency and Optically Detected Magnetic Resonance (ODMR).

ODMR can be used to detect and collect the fluorescence intensity of nitrogen vacancy center (NV center) in diamond, and ODMR spectrum of NV center in diamond can be obtained by applying stable power laser and frequency-sweeping microwave to the NV center [7]. The ground state of diamond NV center is spin triplet state, and there are sub-levels ms= ± 1 and 0. Its Hamiltonian is mainly related to electron spin coupling and Zeeman splitting effect. The ground state Hamiltonian of NV center in an external magnetic field can be expressed as follows:

$$H_0 = DS_z^2 + E(S_x^2 - S_y^2) + k\overrightarrow{B}\cdot\overrightarrow{S} + H_f + H_t \tag{1}$$

Where k is a constant, the value of which is the product of Bohr magneton constant and electron nuclear sping-factor; D is the axial zero-field splitting(ZFS) parameter (2.88 GHz), which is seriously affected by temperature; and E is the transverse ZFS parameter. The sum of the first three items of the equation is related to the spin of the ground state electron, and H_f depends on the hyperfine interaction caused by the coupling of nitrogen nuclei [8]. H_t denotes Zeeman splitting effect caused by nuclear spin, which is small and negligible. The B vector in the equation is affected by the external static magnetic field.

With an external small magnetic field, the quantum state of NV center can be driven from ms= 0 to ms=±1 by applying external resonant microwave, forming two two-level systems. During the driving process of resonant microwave, the distribution numbers between quantum two levels will oscillate, which is called Rabi oscillation. Select any resonance frequency in the passband of the device to be tested in ODMR spectrum, namely a two-In level system of NV center, and set a reasonable microwave pulse scanning length and stepping time in a laser pulse period, then the typical Rabi oscillation curve is obtained with microwave pulse time as abscissa and fluorescence signal as ordinate. The curve fitting function used is as follows:

$$S(B_{mw}, \tau) = I_0 - i_0 \sin(2\pi\gamma B_{mw} \cdot t) \cdot e^{\frac{-t}{\tau}} \quad (2)$$

Where I_0 is the fluorescence intensity of ground state ms= 0; i_0 is the fluorescence amplitude of Rabi oscillation; B_{mw} is the intensity of left-handed circularly polarized microwave field; τ is the attenuation time of Rabi oscillation; γ is the electron gyromagnetic ratio of NV center; S is the fluorescence signal intensity, and t is the microwave pulse time.

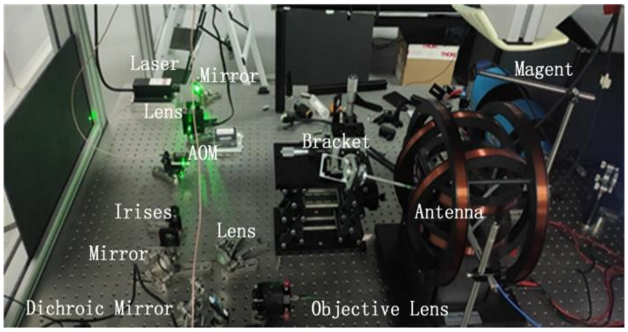

Fig 1 *Optical High-resolution test system.*

The test frequency should be set by external adjustment. Under the action of the external electromagnetic field, the microwave resonance point of the diamond crystal is split into eight resonance peaks. Make sure the resonant frequency remains the same value as the operating frequency of the device under test by adjusting the strength of the external electromagnetic field.By adjusting the external electromagnetic field strength, the test frequency can reach 40 GHz[9], which is one of the advantages of this test method. The current resolution can reach 0.005μm. The software system controls the electric displacement platform to scan, and the sensitivity of the electric displacement platform can reach less than 10μm.

Measurement results of shielding effectiveness by NV-center-based optical High-resolution test method: This paper uses the optical high-resolution test method and surface scanning method to conduct comparative experiments on the omni- directional conductive sponge material and the high analysis shielding material [10]respectively. In terms of size (20mm*30mm), thickness (0.1mm) When the shielding position and other parameters are the same, the test results are shown in Fig.2.

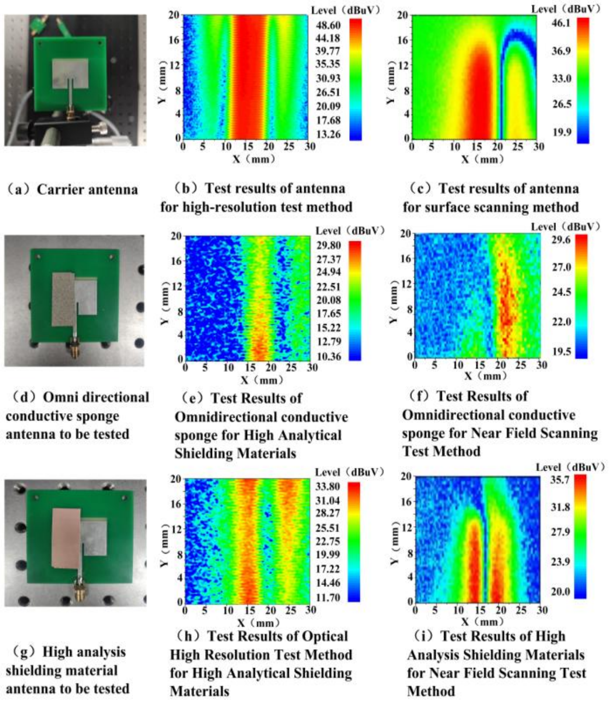

Fig 2 *Antenna to be tested, shielding materials and test results*

In this test, the operating frequency of the antenna to be tested is set to 200 MHz. According to Fig.2(a),(b), and (c), the structure and radiation emission of the antenna are symmetrical. The shielding material is applied to the left half of the antenna and no electromagnetic radiation suppression is applied on the right half of the antenna. The optical high-resolution test method and surface scanning test method are used to compare with the electromagnetic radiation suppression part on the right half of the antenna. The final test diagram and test results are shown in Fig. 2 (d), (e), (f), (g), (h), and (i). The two test methods can visually show the obvious changes of electromagnetic radiation in the electromagnetic radiation suppression area of the antenna, indicating that the electromagnetic shielding material has a good electromagnetic radiation suppression effect.The test results (e) and (h), or (f) and (i) of the two electromagnetic shielding materials were compared and analyzed. By comparing the color scale changes of the test results, it was found that the omni-directional conductive sponge has the best electromagnetic radiation suppression effect, which is better than that of polymer-based electromagnetic shielding material. However, comparison between results (e), (f), (h), and (i) showed that, under the same test conditions, the maximum radiation values of the two methods were basically similar; the minimum radiation values measured by the optical high-resolution test method based on NV center were 10.36 dBuV and 11.70 dBuV, while the minimum radiation values measured by the surface scanning method were 19.5 dBuV and 20.0 dBuV. It can be concluded by comparison that the optical high-resolution test method based on NV center has higher accuracy and higher resolution.

Although both methods can show the intensity distribution of electromagnetic radiation, they have quite different working principles and working frequencies. The surface scanning method uses the surface scanning system to detect point by point with electric field and magnetic field probes, with a measurable frequency range from 100kHz to 10GHz and imaging resolution of 50 μm only. In this paper, an improved all-optical method is adopted to construct the optical scanning imaging system, and the imaging resolution of this test method can reach 0.005 μm. Therefore, the test method in this paper can not only judge its shielding performance more intuitively, but also has higher resolution and high accuracy, which provides a more accurate method for testing the shielding effectiveness of shielding materials.

Conclusion: This paper provides a novel NV-center-based optical high-resolution testing method, a method that can directly and efficiently provide the distribution of the electromagnetic field on the surface of the shielding material, with the test frequency reaching up to 40GHz. Optical high-resolution testing method has the advantages of small size, simple structure, fast scanning speed, high resolution and high sensitivity.Compared with the surface scanning method, the method proposed in this paper can test shielding materials more accurately and effectively, and provide a new idea for testing the shielding effectiveness of shielding materials.

Author contributions: Jianfei Wu: Funding acquisition; Investigation; Methodology; Project administration; Supervision; Validation; Writing-review & editing. Yanfang Lu: Conceptualization; Data curation;Formal analysis; Investigation; Methodology; Writing-original draft; Writing-review & editing. Yifei Zheng: Methodology; Resources; Writing-review & editing. Yang Li: Data curation;Validation. Longfei Zheng: Data curation; Formal analysis; Investigation; Methodology. Guanxiang Du: Conceptualization;Validation.

Acknowledgments: This research is supported by the weaponry technology foundation of the equipment development department of the Central Military Commission 211GF14003.

Conflict of interest: The authors declare that there are no conflict of interests, we do not have any possible conflicts of interest.

Data availability statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. Liu, S. , and W. Liu .: Progress of Relevant Research on Electromagnetic Compatibility and Electromagnetic Protection. High Voltage Engineering 40(6), 1605-1613(2014).
2. IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures. in IEEE Std 299-1997, 1-48(1998).
3. IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures. in IEEE Std 299-2006 (Revision of IEEE Std 299-1997), 1-52(2007).
4. P. Besnier and M. Drissi.: Shielding effectiveness external evaluation concept for small enclosures. 2003 IEEE International Symposium on Electromagnetic Compatibility 2, 958-961(2003).
5. Nguyen, V. T. , M. T. Dam , and J. G. Lee.: Electromagnetic emanation exploration in FPGA-based digital design. Journal of Central South University 26(1), 158-167(2019).
6. Yang, B. , et al.: Non-Invasive Imaging Method of Microwave Near Field Based on Solid State Quantum Sensing. IEEE Transactions on Microwave Theory and Techniques 66(5), 2276-2283(2018).
7. Tetienne, J. P. , et al.: Magnetic-field-dependent photodynamics of single NV defects in diamond: Application to qualitative all-optical magnetic imaging. New Journal of Physics 14(10), 103033-103047(2012).
8. Doherty, M. W. , et al.: The nitrogen-vacancy colour centre in diamond. Physics Reports 528(1), 1-45(2013).
9. Dong, M. M , et al.: A fiber based diamond RF B-field sensor and characterization of a small helical antenna. Applied Physics Letters 113(13), 131105.1-131105.5(2018).
10. Qian, L. , et al.: Modeling Absorbing Materials for EMI Mitigation. 2015 IEEE International Symposium on Electromagnetic Compatibility (EMC), 1548-1552(2015).