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Article

# Novel Testing Method for Absorbing Materials with Comparison of Efficiency and Gain

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**Abstract:** The massive use of electronic equipment has raised concerns about electromagnetic (EM) pollution, leading to increased attention to EM shielding in both civil and military applications. EM absorption materials play a crucial role in reducing the energy of microwaves projected onto their surface. In this work, we propose a novel OTA (over-the-air) antenna test method to evaluate and analyze the functionality of EM absorption materials. This method offers a new and practical way to assess the effectiveness of these materials. Measured results indicate that the presence of the EM absorption material led to a decrease in antenna gain of approximately 2-3 dB, a reduction in efficiency of more than 10-15%, and a smaller radiation pattern during the actual testing process. These findings highlight the impact of EM absorption materials on antenna performance. Compared to the traditional S-parameter testing method, the gain comparison testing method exhibits the advantages of higher accuracy and simpler operation in the lower frequency experiment.

**Keywords:** OTA antenna test; wave absorption; stealth material

## 1. Introduction

Although the rapid growth of microwave technology has brought about scientific and technological prosperity, it has also led to EM pollution [1]. EM absorption materials substantially reduce the energy of EM projected onto their surface. They are widely used in electrical equipment, military equipment stealth, and individual protection [2,3]. The materials are coated with an absorbing layer to reduce the reflection of EM microwaves, thereby avoiding radar detection for important military purposes. With the diversification of practical use environments, structural and functional integration materials are used for preparing EM absorption materials due to their excellent comprehensive performance [4–6].

Carbon materials have always played a crucial role in the field of EM shielding [7–9]. In recent years, there has been extensive research on the absorption properties of graphite oxide (GO) [10,11], carbon fiber [12], and carbon nanotubes (CNTs) [13,14]. GO has garnered significant attention among these materials as a potentially efficient EM shielding material. Li et al. [15] conducted a study on the influence of the doping amount of GO on the crystal structure, surface morphology, and magnetic properties of composite EM absorption materials. Their findings shed light on the potential for enhancing the absorption properties by adjusting the doping amount. Zhan et al. [16] developed sandwich-like graphene nanosheet/Fe<sub>3</sub>O<sub>4</sub> composites using a one-step solvent thermal method. These composites exhibited high saturation magnetization and proclivity, as well as high complex dielectric constant and complex permeability. Moreover, Xu et al. [17] reported that the high density of residual defects and functional groups attached to reduced GO can greatly improve the absorption performance of the material. These works highlight the importance of carbon-based materials, particularly GO, in the development of efficient EM shielding materials. Further research in this area will contribute to the advancement of EM absorption materials and their practical applications.

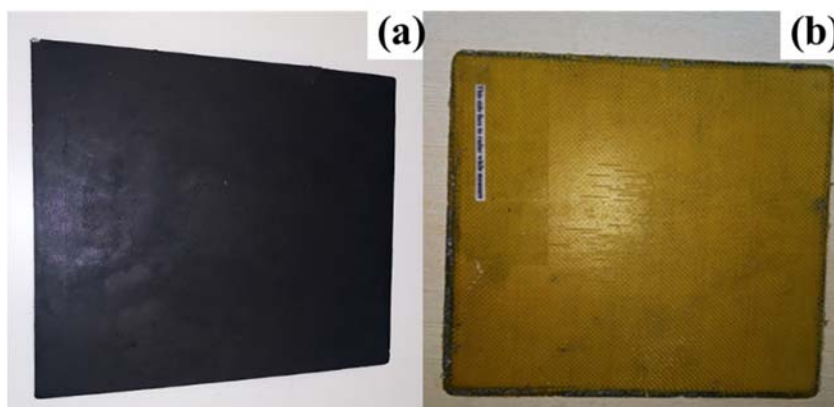
Simultaneous consideration of reflectivity and transmissivity is crucial when evaluating the performance of EM absorption materials [18–20]. This necessitates the constant improvement of evaluation and testing methods to provide a basis for assessing their development and application. The Cellular Telecommunications Industry Association (CTIA) has developed relevant standards for

Over the Air (OTA) testing. OTA testing primarily focuses on assessing the radiation performance of the entire device and has gained recognition as an important test for mobile phone manufacturers. Line gain, which represents the ratio of power density generated by the actual antenna to the ideal radiation unit at the same point in space under equal input power conditions, is used to evaluate the gain of an antenna. The gain is closely related to the antenna's radiation pattern, with a narrower main lobe, smaller side lobes, and higher gain indicating better performance. Antenna efficiency, on the other hand, is defined as the ratio of radiated power to input power. In this work, a comparison test of efficiency and gain was conducted using domestically developed OTA darkroom EM absorption materials. This method provides a means of assessing the effectiveness of the materials in terms of efficiency and gain.

## 2. Experiment Section

### 2.1. Synthesis of EM absorption film

The hydrophilic graphene and hydrophilic single-walled carbon nanotubes (CNTs) were dissolved in deionized (DI) water at a mass ratio of 3:2. The total mass of graphene and single-walled CNTs ranged from 0.5 wt% to 1.5 wt% of the mass of DI water. The resulting solution was subjected to ultrasonic treatment for 6 to 14 hours. Subsequently, the mixture was added to a polyethylene solution with a mass concentration of 5% to 15%. The mixture was stirred for 2 to 3 hours and then dried for 48 hours to obtain the absorption film. This film exhibited absorption performance and had a certain level of tenacity. For testing purposes, the size of the film used was 25 cm×30 cm, as shown in Figure 1a. The absorption film was placed into the interlayer of yellow fiber material To evaluate the actual application of the absorption, as shown in Figure 1b.



**Figure 1** (a) EM absorption film sample, (b) the film sample was placed into the yellow fiber material interlayer.

### 2.2. Test procedure

The receiving antenna is a standard horn antenna whose frequency is from 600 MHz to 6 GHz. Antenna 2 which is designed and manufactured by the Suzhou NQI used in Italy Electric Power Company Router. An Agilent vector network analyzer (VNA 8753ES) in the frequency range of 100KHz to 6 GHz is employed to measure the S-parameters, covering the frequency band of GSM/CDMA2000/WCDMA/LTE.

One way of the traditional test process is the  $|S_{21}|$  EM absorption film test process. We use the VNA in an anechoic chamber to analyze the performance of EM absorption film. The following is the detail. At first, the transmitting antenna was measured and confirmed. The measurement specification is shown in Tables 1 and 2.

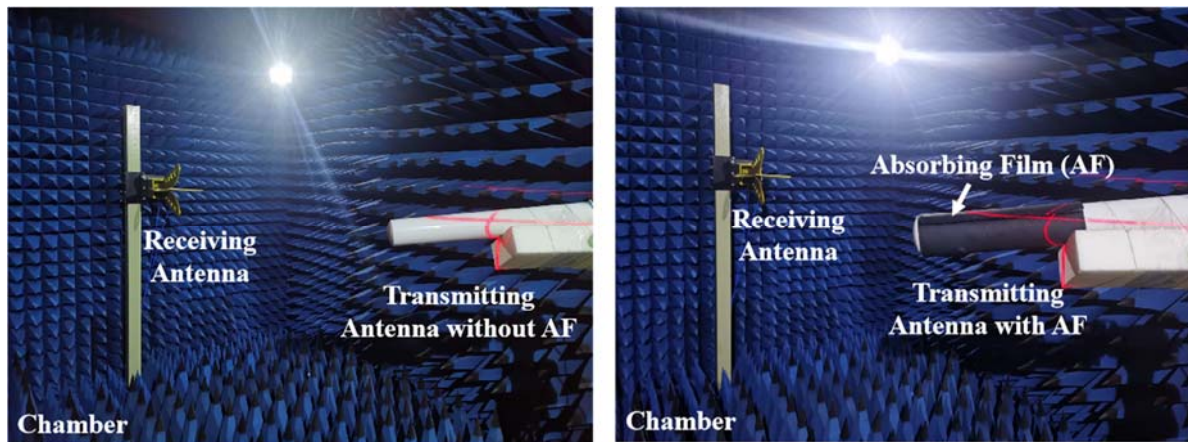
**Table 1.** Electrical parameters

Frequency Range	824-960MHz/1710-1880 MHz /1920-2170MHz
VSWR	GSM-ETACS-NMT $\leq$ 2.2/PCN-GSM $\leq$ 2.2/UMTS $\leq$ 2.2
Characteristic impedance ( $\Omega$ )	50
Minimum gain (dB)	2
Polarization mode	Vertical
Maximum power (W)	10

**Table 2.** Mechanical parameters

Antenna Dimensions (mm)	114.8*10
Connector	SMA
Working temperature ( $^{\circ}$ C)	Operating: -40 ~ 75
Storage temperature ( $^{\circ}$ C)	Storage: -40 ~ 85

The block diagram of the test schematic is shown in Figure 2. Each component of the mainframe was connected, and the system was preheated for half an hour after booting before testing. The experiment setup involved using Antenna 1 as the receiving antenna and Antenna 2 as the transmitting antenna, based on the structure and size of the chamber. The efficiency and gain measured results of Antenna 2 were compared with and without the absorption material. Inside the chamber, the arrangement is depicted in Figure 2. The transmitting antenna is completely wrapped inside by absorbing material. The test was carried out in two radiation modes: without the absorption material (see Figure 2a) and with the absorption material (see Figure 2b). Data was collected during the test and plotted for analysis.



(a)

(b)

**Figure 2** Measurement setup. (a) without absorbing film, (b) with absorbing film.

### 3. Results and Discussions

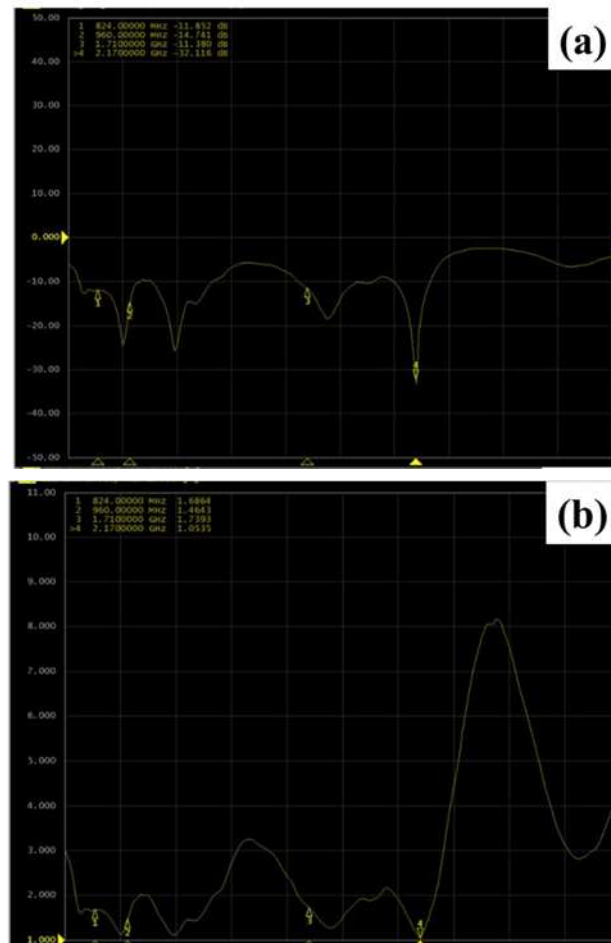
The antenna performance testing can be divided into passive testing and active testing, with OTA testing falling under the category of active testing. The Total Radiated Power (TRP) is obtained by integrating and averaging the transmitting power of the fully radiating sphere, which reflects the transmitting power of the entire device. The Total Isotropic Sensitivity (TIS) reflects the sensitivity index of the fully radiating sphere, which is related to the overall machine's conduction sensitivity and the antenna's radiation performance. The actual performance indicators of the transmitting antenna are installed on the router. These indicators provide information about the tested performance of the transmitting antenna.

Figure 3 exhibits the scattering parameter return loss (RL) and Voltage standing wave ratio (VSWR) of the. VSWR refers to the ratio of standing wave belly voltage to wave valley voltage

amplitude, which is used to indicate whether the antenna matches the radio station. The relationship between VSWR and RL is shown in Equations (1) and (2).

$$\text{VSWR} = \frac{1 + \Gamma}{1 - \Gamma} \quad (1)$$

$$\text{RL} = 20|\lg(\Gamma)| \quad (2)$$



**Figure 3** (a) Return loss, (b) Voltage Standing Wave Ratio of scattering parameter

As depicted in Figure 4, the EM absorption film exhibits a minimum Return Loss (RL) value of approximately 36 dB at a frequency of around 4.5 GHz when the film thickness is 5 mm. However, the corresponding bandwidth with effective attenuation ( $\text{RL} < -10$  dB) is widest at a thickness of 2 mm. For the experimental needs of this work, a thickness of 2 mm is chosen for the absorption film in this work.

Comparing Figure 5a,b, it can be observed that the addition of the absorption material leads to a deterioration in the radiation pattern of the transmitting antenna in the direction where the absorption material is present, while there is a slight enhancement in the direction without the absorption material. This suggests that the absorption material significantly alters the antenna pattern of the transmitting antenna.

In Figure 6a, it is evident that the absorption material has a noticeable impact on the antenna gain in the frequency range of 2300 MHz to 2600 MHz, resulting in a gain attenuation of approximately 3 dB. The comparison diagram of antenna efficiency change also shows that the absorption material has a significant absorption effect on the antenna efficiency in the same frequency range, absorbing about 15% of the efficiency performance.

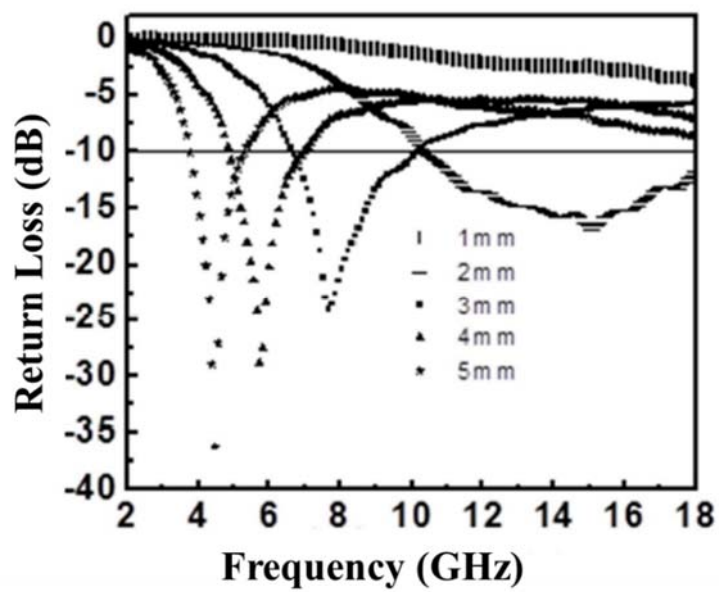
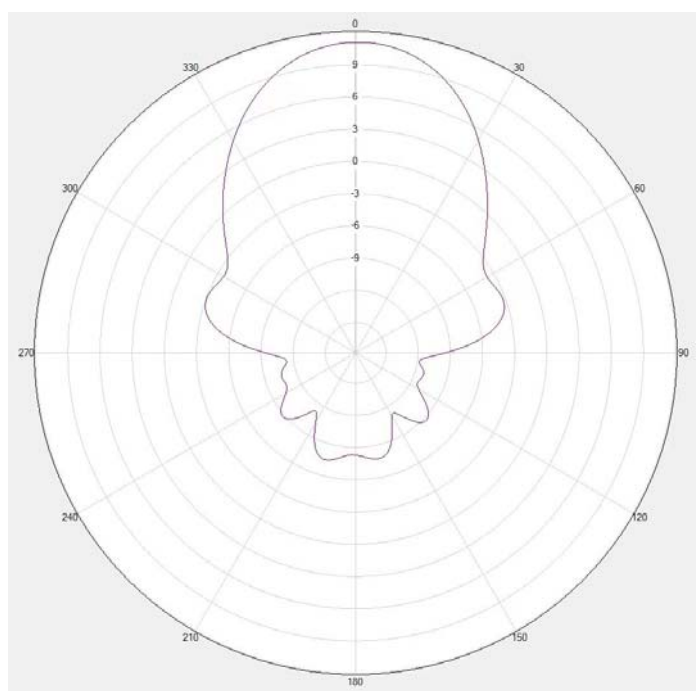
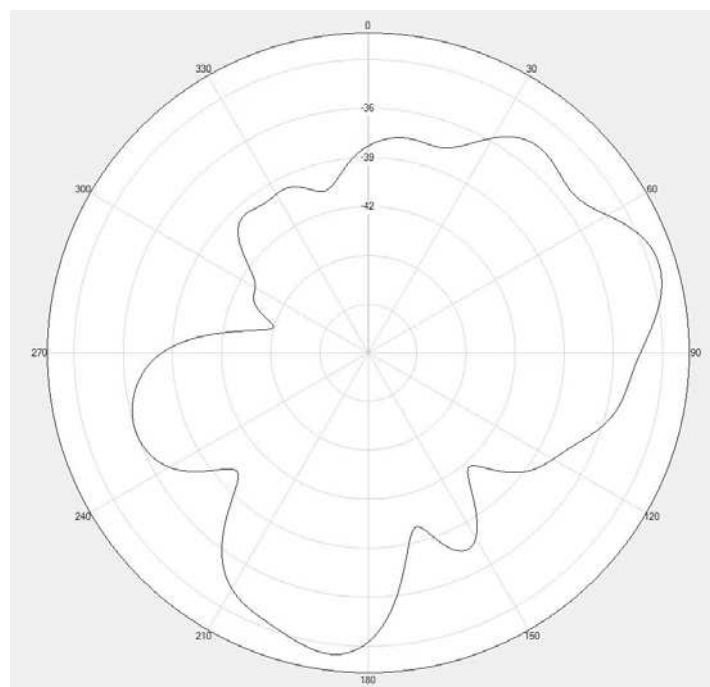


Figure 4 The reflection coefficient of the absorption film varying with different thicknesses.

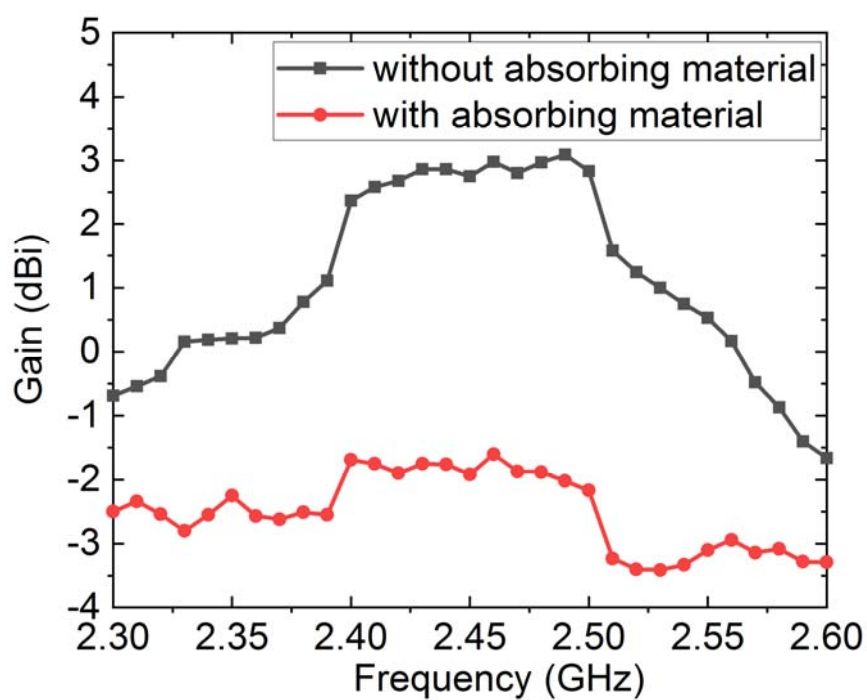


(a)

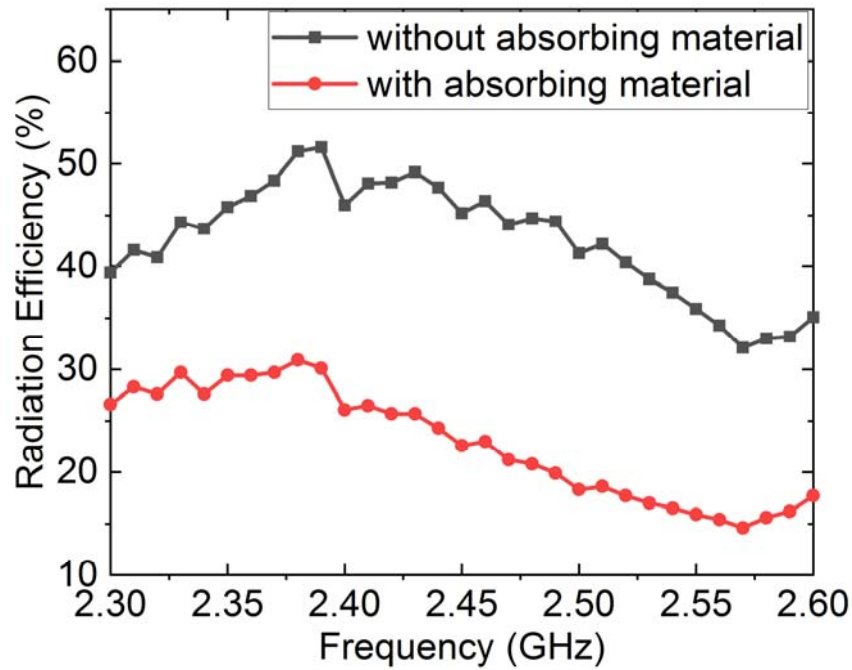


(b)

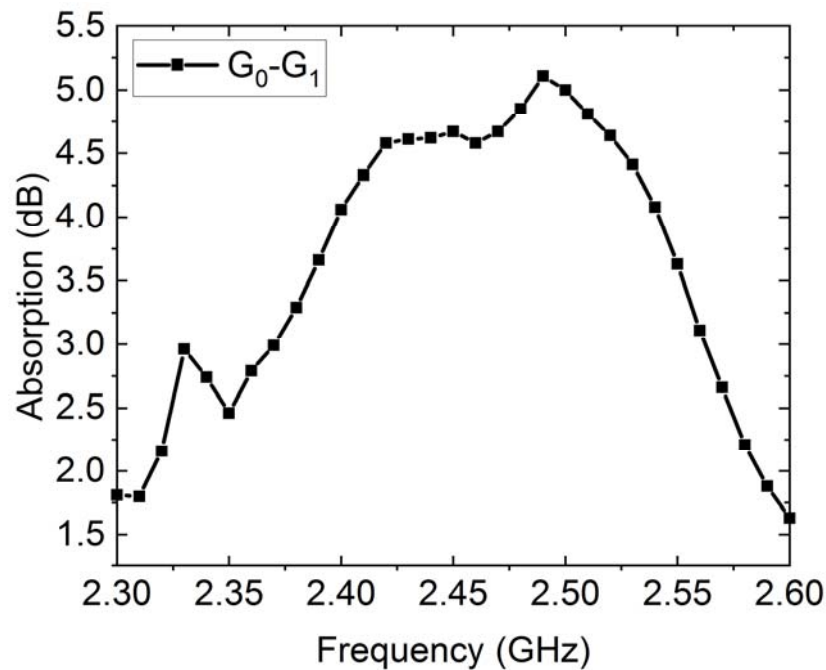
**Figure 5** Radiation pattern of the transmitting antenna. (a) without absorption film, (b) with absorption film.



(a)



(b)



(c)

**Figure 6** Performance changes of the transmitting antenna with and without the absorbing film. (a) Gain, (b) radiation efficiency, (c) absorption performance.

#### 4. Conclusion

In this paper, the EM absorption material was tested by comparing the antenna gain and efficiency of a wireless antenna. The test results of the standardized antenna led to the proposal of a new test method under the condition of incomplete shielding of the EM absorption material. This new test method provides a foundation for the use of absorption materials in various civil applications.

In the actual test results, it was observed that when the absorption material does not cover the entire surface of the objects (only covering one side), the performance of antenna gain dropped by 2-3 dB and efficiency decreased by more than 10% - 15%. However, it was also found that the gain and efficiency of some frequency bands and directional antennas increased. This finding highlights the significance of the new test method, as it allows for a better understanding of the practical properties of absorption materials in real-world applications.

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**Conflicts of interest:** There are no conflicts to declare.

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