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An Novel Absorber Screen Design Method Based on Receiving Antenna Principle

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Abstract—This paper presents a novel design method to the absorber screen based on the receiving antenna technique. When the electromagnetic waves is incident upon the surface of absorbing structure, part of the electromagnetic energy transforms into current absorbed at the port, and the remaining energy is reflected. The former mechanism is similar to the receiving antenna. Hence, a dual-polarized magneto-electric dipole antenna is selected and optimized to obtain a broadband absorber screen unit after comparing the similarities between the antenna and absorber. The measurement results show that the finite 6×6 array absorber has a 73% bandwidth for 10 dB RCS reduction, while its thickness of substrate is below 1/9 wavelength of the center frequency in free space. The novel absorber screen can also be used in dual polarization because of its symmetrical property. The simulation and measurement are performed at the normal incidence in this paper.

1. INTRODUCTION

To limit the detecting probability of fighting unit in military, it is required to reduce the radar cross-section (RCS) of military objects. One of the effective approaches is to cover them with a lossy material to absorb the electromagnetic energy over a specific range of frequency. The popular scheme is to adopt the Salisbury or Jaumann screen because of its simplicity, and the main disadvantages of the Salisbury screen are relatively large thickness and narrow bandwidth. On the other hand, Jaumann screen uses a multilayer structure for the impedance matching, which can also lead a high-profile [1].

Recently, some researchers have designed thin microwave absorbers by using metamaterials (MMs) [2–4] because MMs have unique reflection or transmission properties compared to conventional materials. MMs have many types in practice, such as high impedance surface (HIS) [5], artificial magnetic conductor (AMC) [6], electromagnetic band-gap (EBG) [7] and left-handed metamaterial (LHM) [8]. However, most of these papers utilize MMs' high-impedance characteristic, and the bandwidths in these papers are still narrow for their resonance bandwidths [9–11]. To achieve broadband absorber screen, the active devices such as pin diodes are inserted in the metal patches joint of the periodic unit [12], which can be varied with an applied electrical or optical control signal to realize active or adaptive performance. But this absorbing structure is somewhat complicated [13]. Another technique is to optimize radar absorbing materials using genetic algorithm (GA) [14]. The absorber designed using this method may have a broad bandwidth, while its implementation is usually complicated because of its multilayered structure.

In this paper, a novel approach based on receiving antenna is introduced to design a wideband absorber screen. Comparing the performance of the absorbing structure and the receiving antenna, it is found that the receiving antenna can be modified and optimized to the absorber screen unit. The size of the proposed absorber screen unit is $57.7 \times 57.7\,\mathrm{mm}^2$, and it consists of four pairs of double-square loops connected to the ground by twenty metallic vias and twelve chip resistors on the top of a dielectric

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substrate. The simulated results show that the designed absorber screen provides a 10 dB RCS reduction over the entire frequency range of 1.5–3.45 GHz, which is equivalent to a relative bandwidth of 78%.

2. DESIGN OF ABSORBER SCREEN UNIT

According to the related antenna theory [15], there is a certain size of the reception area to antenna received signal. That is to say, the area of antenna received signal energy is surrounding antenna, which is not just object itself. And then the receiving antenna is equivalent to several wave-absorbing units as shown in Fig. 1. We can derive some similarities between microwave absorber and receiving antenna.

1) The incident wave upon them as source is the plane wave.
2) Following is their basic operating principle: the metal strips induce electromagnetic wave which forms the current, and then the current flows into the ports.
3) Both ports connect impedance or impedance characteristic of transmission lines to receive energy. If the effect of mutual coupling is ignored, the absorber screen can be considered as the periodical array of the receiving antenna.

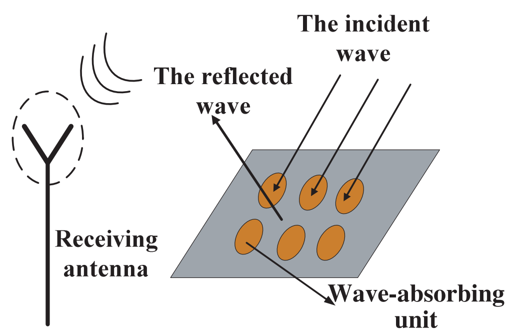

Figure 1. Equivalent wave-absorbing diagram of receiving antenna.

However, there are some differences in the designing.

1) Microwave absorber often employs a periodic array, while the antenna is a single or finite array in most applications.
2) Their basic research methods are not the same. The absorbing structure is usually analyzed by MOM, FDTD and FEM. As for receiving antenna, it is mainly based on the principle of pattern multiplication theorem.
3) The design of absorber screen focuses on how to reduce the reflected energy, but the design of receiving antenna usually adopts the corresponding techniques and methods according to different demands.
4) The voltage standing wave ratio (VSWR) and reflection coefficient are used as the measurements of antenna and absorber screen, respectively. The VSWR of antenna usually requires less than 1.5, which is equated to the reflection coefficient below -15 dB. And the reflection coefficient of absorber screen requires -10 dB. The requirement of the performance index of absorber screen is lower than ordinary antenna.

As mentioned above, it is summarized that the structure of the receiving antenna can be modified at following aspects to absorber screen.

1) The echo signal of the absorber screen is lowered by reducing the configuration pattern scattering field of the selected receiving antenna.
2) We need to confirm the smaller size of absorber screen unit on the premise of only single-mode transmission of reflected wave according to Floquet's law.
3) The feed ports of the receiving antenna should be replaced with lumped resistors, which can ensure that the impedance of incident wave matches the original absorber model.

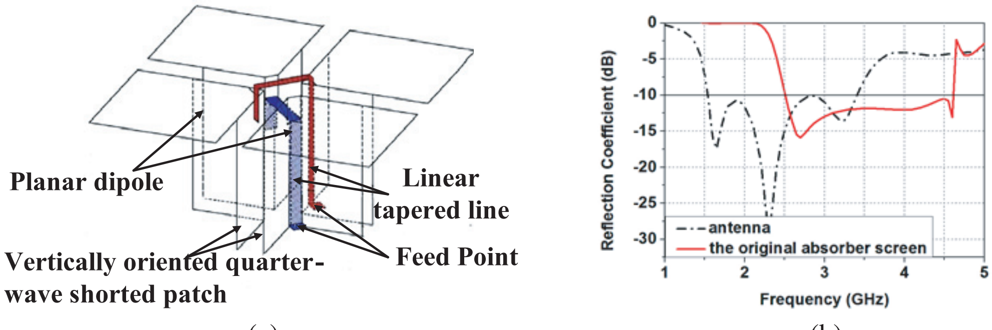

Figure 2. (a) The original model of broadband antenna; (b) Simulated the reflection coefficient of antenna and the original absorber screen.

A suitable model of the broadband antenna is selected as shown in Fig. 2(a) [16]. This broadband dual-polarized magneto-electric dipole antenna has the wideband performance, which can facilitate the design of broadband absorber screen unit. The feed ports of the broadband antenna are replaced with lumped resistors, and the magneto-electric dipoles are respectively etched with a rectangle slot and a pair of isosceles right triangle slot, which develops the original absorber screen unit. Fig. 2(b) is the reflection coefficient of the antenna and the original absorber screen. The whole curve of the original absorber screen shifts toward the high frequency compared with the antenna. It is because the vertically oriented quarter-wave shorted patch and planar dipole of the antenna are etched to reduce reflected energy, which can change the current path.

The designed and optimized broadband absorber screen unit is presented schematically in Fig. 3. In order to broaden absorption bandwidth, the planar dipole etched with a pair of isosceles right triangle slot in the original absorber screen is correspondingly added on a metal loop [17]. It can be observed that four pairs of double-square loops are printed on the front side of a dielectric substrate, which is FR4 ($\varepsilon_r = 4.4$) with a thickness of 12.7 mm. The back side of the dielectric substrate is coated with a continuous thin metal layer. To exhaust the induced current of the outer metal loop, the chip resistors $R_1 (R_1 = 120\,\Omega)$ are inserted in the two sides of the outer loop. And in between each pair of double-square loops, chip resistors $R_2 (R_2 = 43\,\Omega)$ are also inserted to make absorber match with incident wave impedance more. Moreover, the vertically oriented patch etched with a rectangle slot

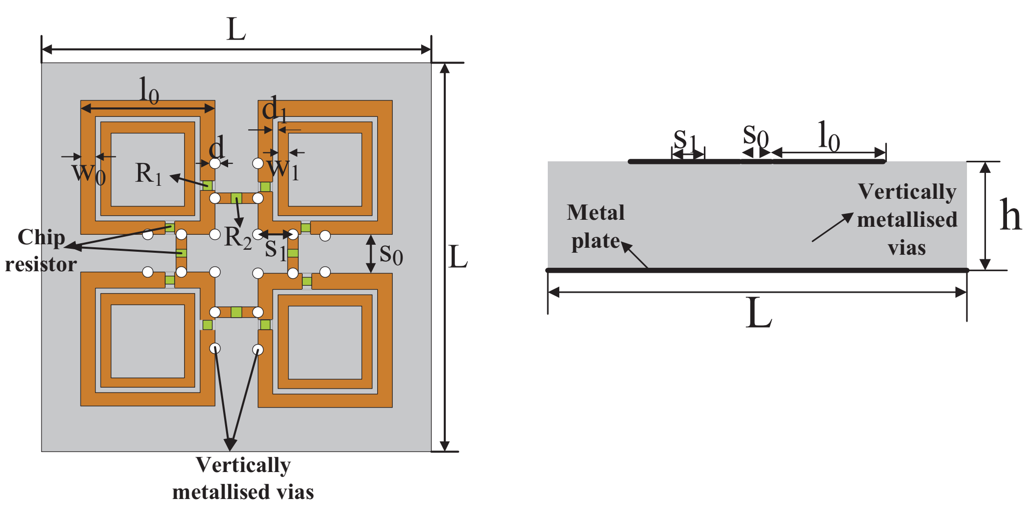

Figure 3. (a) Front-view of the unit cell of absorber; (b) Side-view of the unit cell of absorber.

is replaced with metallised vias to create an inductive effect. Eventually optimized parameters of the designed absorber screen are listed as follows: $L = 57.7\,\mathrm{mm}$, $l = 17.3\,\mathrm{mm}$, $w = 2\,\mathrm{mm}$, $w_1 = 1.75\,\mathrm{mm}$, $d = 1\,\mathrm{mm}$, $d_1 = 0.2\,\mathrm{mm}$, $s = 4.1\,\mathrm{mm}$, $s_1 = 5.1\,\mathrm{mm}$, $h = 12.7\,\mathrm{mm}$.

3. SIMULATION AND ANALYSES OF ABSORBER SCREEN

The proposed absorber screen is simulated by software HFSS, which is based on the commercial finite element method (FEM) solver. A master-slave (M/S) relationship is defined between the periodic boundary conditions (PBC's) pairs of HFSS. The simulated reflection coefficient of absorber screen with different l_0 is shown in Fig. 4, and it is found that the first resonant frequency f_1 shifts toward the low frequency with the increase of l_0. The second resonant frequency f_2 also slightly shifts toward the low frequency with the increase of l_0. It is then concluded that the resonance length of outer loop mainly affects f_1. Furthermore, the reflection coefficient increases at f_2 and the third resonant frequency f_3 with the increase of l_0. The reflection coefficient of the absorber screen for different values of R_1 is given in Fig. 5. As can be seen, f_2 shifts toward the low frequency with the increase of R_1. It is also observed that when increasing R_1, the reflection coefficient near f_2 decreases accordingly, but f_1 slightly increases. Fig. 6 displays the reflection coefficient varying with the S_0. It is clearly indicated that the resonant frequency f_3 shifts toward the low frequency with the increase of S_0, and the reflection coefficients near f_1 and f_2 respectively increase.

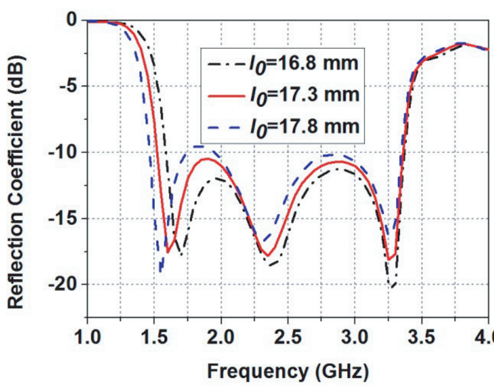

Figure 4. Simulated reflection coefficient of absorber screen with different l_0.

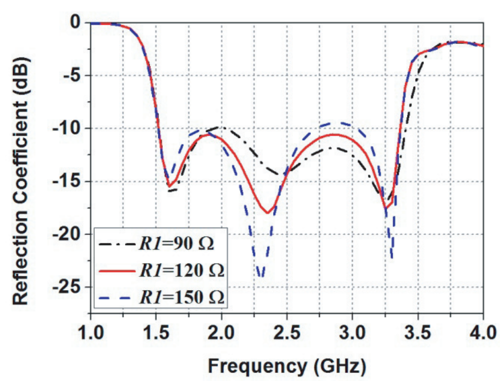

Figure 5. Simulated reflection coefficient of absorber screen with different R_1.

4. FABRICATION AND MEASUREMENTS

An absorber screen composed of 6×6 unit cells ($346.2\,\mathrm{mm} \times 346.2\,\mathrm{mm} \times 12.7\,\mathrm{mm}$) is fabricated to validate the method proposed in this paper, whose photo is shown in Fig. 7(a). It is found that the thickness of an absorber screen is about half of the diameter of one coin, and the diameter of a coin is 24.99 mm. Fig. 7(b) shows a schematic diagram of the RCS measurement of a 6×6 absorber screen. Here, the transmission is zero in the whole frequency range because of the shielding of the copper film, and thus the reflection is the only factor determining the absorption. Therefore, the absorption rate is calculated by $A(w) = 1 - R(w) = 1|S_{11}|^2$ [18]. The simulated and measured RCS results are given in Fig. 7(c). The frequency range is from 1.54 GHz to 3.31 GHz for the measured 10 dB RCS reduction. It is seen that the measured results agree fairly well with the simulation but with a little narrower bandwidth. It is because the third resonant frequency shifts toward the low frequency in experimental result. There is a little difference in 2.5–3.1 GHz between the simulated and measured results. It is because the fabrication error, and coarse soldering process for inserting the resistors into the loops maybe causes the measurement error.

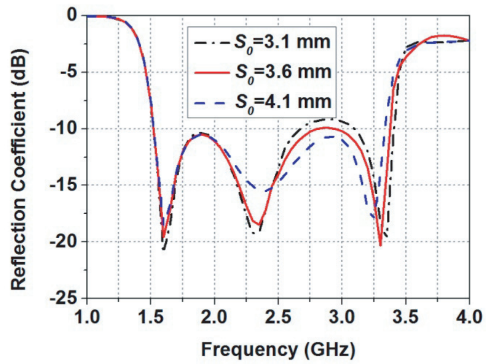

Figure 6. Simulated reflection coefficient of absorber screen with different S_0.

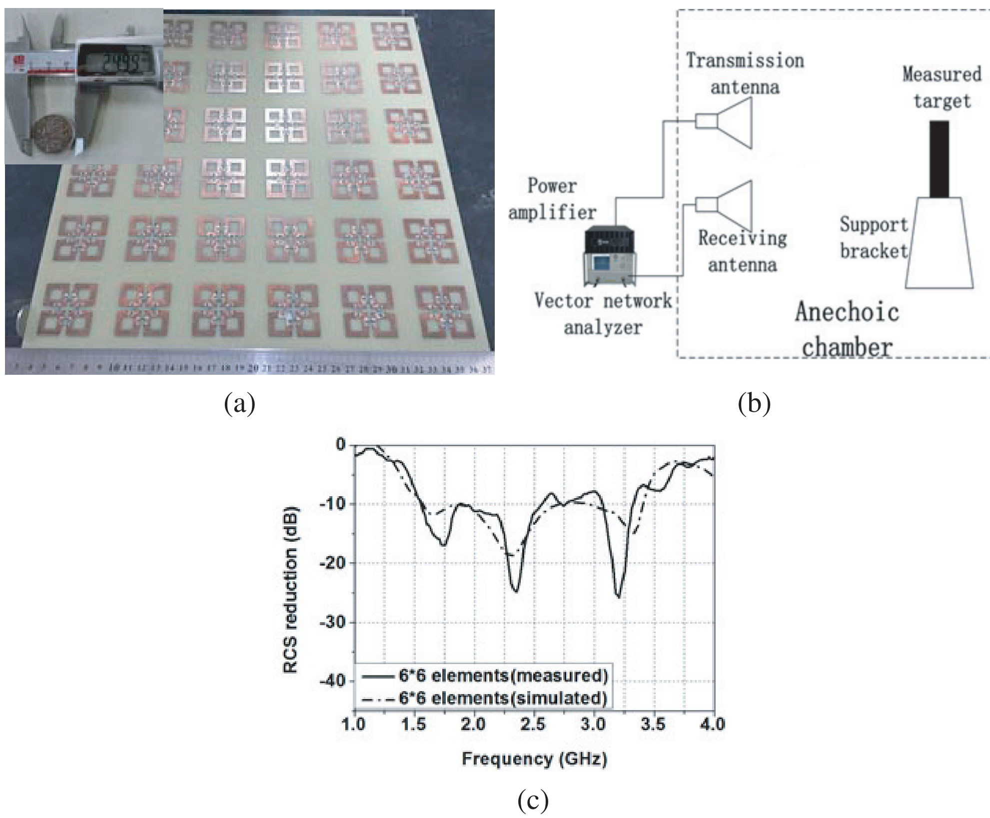

Figure 7. (a) Photo of the fabricated 6×6 absorber screen; (b) Schematic diagram of RCS measurement; (c) Simulated and measured RCS results of a 6 × 6 absorber screen.

5. CONCLUSION

By comparing the similarities and differences in principle between absorber screen and broadband receiving antenna, a novel design method for the wideband absorber is proposed by revising the wideband antenna. A 6×6 unit cell sample with low profile and wideband RCS reduction function is presented. The measured RCS results show that the absorber exhibits a 10 dB RCS reduction bandwidth more than 73%. It covers the absorption frequency band from 1.54 GHz to 3.31 GHz. Moreover, its thickness is below $1/9\lambda_0$ of the center frequency point. The novel absorber can also be used in dual polarizations because of the symmetry property. In conclusion, the simulated and measured results prove the correctness and rationality of the proposed method in this paper.

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