

# Novel Absorbers Based on Wideband Antenna Array for RCS Reduction

Fang-Yao Kuo, Pai-Shiuan Wang, and Ruey-Bing Hwang\*

Department of Electrical Engineering, National Chiao-Tung University  
University Road 1001, Hsinchu, Taiwan 300, R.O.C.

**Abstract** — In this paper, a novel wideband absorber for radar cross section (RCS) reduction is presented. Unlike previous absorber designs that use multilayer lossy materials, this study proposes a design based on a planar antenna array that adopts a bowtie dipole structure as the unit cell. Since the desirable features of a wide operation band and a simple design of a bowtie-shaped antenna, the proposed design adopts a bowtie dipole with a lumped resistor as the unit cell of a two-dimensional periodic array. The complete design procedure is explained through the design examples. The measurement result shows that the bandwidth of the design exceeded 81% (RCS reduction > 10 dB) when the thickness is about 11% of the free space wavelength at the lowest operation frequency.

**Index Terms** — RCS reduction, bowtie structure.

## I. INTRODUCTION

A wide variety of design for electromagnetic wave absorption has been studied in the past due to the demand of both military and civil applications. Researchers have developed two main RAM designs. The first approach is to redirect the impinging wave away from the incident direction, producing significant backward RCS reduction [1-4]. Paquay et al. [1] presented a design based on a combination of artificial magnetic conductor (AMC) cells and perfect electric conductor (PEC) cells in a chessboard-like configuration. The waves reflected from the AMC and PEC have opposite phases near the resonant frequency of the AMC. The reflection from an incident plane wave normally impinging on the chessboard structure can be cancelled out by using the approximation of the antenna array factor. However, because the zero reflection phase of an AMC covers a relatively narrow frequency band, it cannot provide a wide operation band. To enhance the bandwidth effectively, other approaches replace the combination of PEC and AMC with a composite AMC structure [2-4] that consists of two types of AMCs with different reflection phase characteristics. Such designs can provide a wide operation band for RCS reduction, but they can't real absorb the energy of incoming wave.

Another approach is to absorb the incoming wave. Dallenbach layers [5] and Salisbury screens [6] represent two of the oldest and simplest types of absorbers. This type of absorber exhibits a narrow operating frequency band and

occupies a thick space for transforming the impedance of the conducting plate to an open circuit. A new metallic electromagnetic structure, which possesses the characteristic of a high impedance surface (HIS) near the resonance frequency, has been recently investigated to replace the PEC ground plane for reducing the thickness of Salisbury screens [7-9]. A surface with a high surface-impedance boundary condition, which is defined as the ratio between the tangential electric and magnetic fields on the surface, can mimic the reflection characteristics of a perfect magnetic conductor (PMC). In this case, the long impedance-transformed path from the ground plane to the resistive sheet is unnecessary. Because the Salisbury screen has a resistor-loaded HIS, it exhibits a broad bandwidth and a wide incident angle. Lossy metallic frequency selective surfaces (FSSs) [10-12], placed above a thin grounded dielectric substrate, can replace the ohmic loss of a resistive sheet to reduce the thickness of the Salisbury screens. However, the design and fabrication of lossy FSSs are complex and uneconomical.

In this paper, a novel design of an antenna-based absorber for the RCS reduction with single polarization in the microwave band is presented. Based on the desirable features of a wide operation band and a simple design of a bowtie-shaped antenna, the proposed design adopts a bowtie dipole with a lumped resistor as the unit cell of a two-dimensional periodic array. This bow-tie structure receives incoming electromagnetic waves at normal incidence and then dissipates these waves by the resistive load in the operating bandwidth, decreasing the scattered energy from the structure. The measurement result shows that the bandwidth of design exceeded 81% (RCS reduction > 10 dB) when the thickness is about 11% of the free space wavelength at the lowest operation frequency.

## II. UNIT CELL DESIGN AND CONFIGURATION

Antennas are generally designed to transform free space impedance to real impedance in either 50 ohm or 75 ohm systems and to transmit the received signal to a back-end system. In this study, the design of an absorber is similar to that of an antenna, but the absorber is terminated by a

resistive load to dissipate the incoming wave. Fig.1 shows the configuration and definition of parameters for one unit cell of the proposed periodic resistive arrays. Because the bowtie dipole possesses a wide operating band and good efficiency in the antenna case, it is a good candidate for matching between the free space and the resistive load in a wide frequency band. This bowtie structure, when printed on a dielectric substrate, is separated from the conducting plate by an air space. In circuitry terminology, the air space is equivalent to a transmission line that transfers the impedance from the short-circuited conducting plate to the bowtie. Therefore the absorber can achieve a wideband response with the proper adjustment of the air space thickness. The thickness of the air space also affects the operating frequency of the absorber because of the coupling of the bowtie dipole image caused by the ground plane. The chip resistor is inserted in the center of the bowtie to absorb incoming waves. The resistive load terminates and consumes the surface current on the bowtie structure, induced by the incident plane wave.

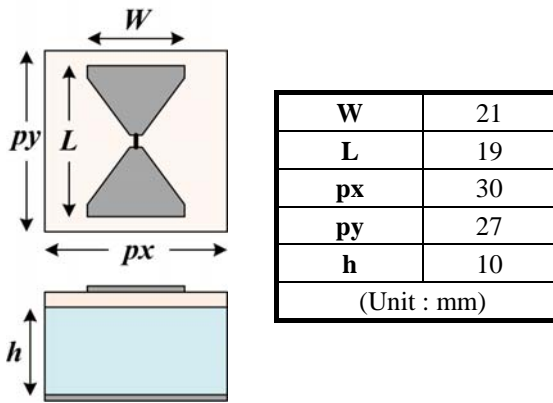


Fig. 1. Unit cell of the proposed periodic structure with detailed dimensions

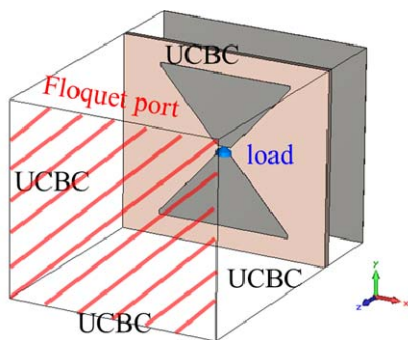


Fig. 2. Unit cell model with Floquet port for simulation in CST MWS

### III. SIMULATION AND ANALYSIS

The proposed bowtie structure is designed on a 0.8 mm FR-4 epoxy substrate with a relative dielectric constant  $\epsilon_r = 4.3$  and a loss tangent  $\tan\delta = 0.02$ . Unit cell analysis and optimization were performed using Computer Simulation Technology (CST) Microwave Studio [13]. Fig.2 shows the unit cell model of Unit Cell I as simulated in CST MWS, where a resistive load at the center serves as the terminator. Unit cell boundary conditions (UCBCs) are applied in both the x- and y-directions, and Floquet port excitations as plane waves are set up in the positive z-direction. Fig.3 shows the predicted frequency response of the proposed unit cell based on the Floquet theory and the simulation result of an ideal Salisbury screen for comparison. The resonance frequency of the conventional Salisbury screen absorber is 5 GHz, and the distance between the thin resistive sheet and conducting plate is 15 mm. The -10 dB reflection coefficient bandwidth of the proposed absorber is wider than that of the Salisbury screen absorber. The proposed absorber can reduce the thickness of the Salisbury screen by approximately 33%, demonstrating that a broadband antenna array can be applied to the design of a RAM.

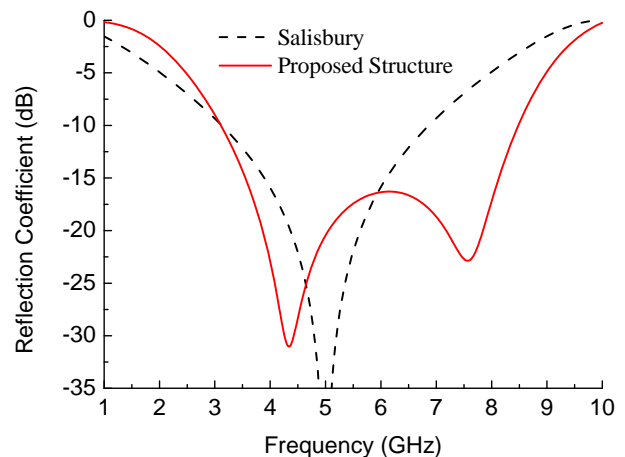


Fig. 3. Predicted frequency response of the proposed structure by using Floquet theory with the simulation result of conventional Salisbury screen absorber included for comparison, where resistance of the terminated load in Fig.1 is  $150\Omega$

Fig. 4 shows the reflectance as a function of frequency at various thicknesses of the air,  $h$ . The dip location shifts to a lower frequency as the thickness increases, and the phenomenon of impedance mismatch becomes more obvious. According to the image theory, a dipole antenna oriented parallel to a perfect ground plane produces an image that carries the same magnitude current but is out of phase. This image dipole degrades the performance of the original dipole, which becomes more serious as the distance between the dipole antenna and the ground plane decreases. Therefore, a tradeoff must be made between the lowest operation frequency and the thickness.

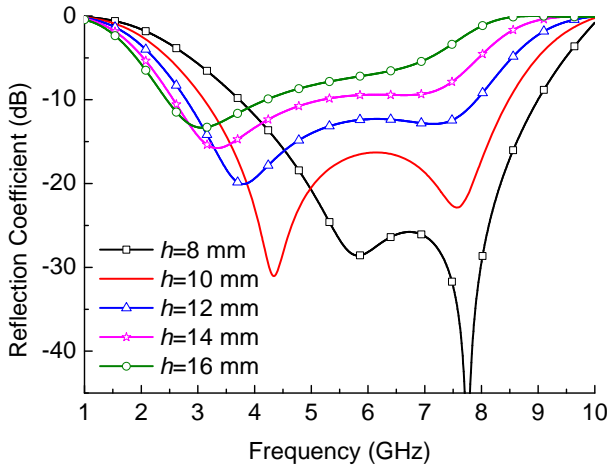


Fig. 4. Reflection coefficient as a function of frequency for thickness of the air foam,  $h$ .



Fig. 5. Photographs of the manufactured prototypes composed by the unit cell in Fig.1

IV. DESIGN EXAMPLES AND EXPERIMENTAL VERIFICATION

This section presents an absorbers for RCS reduction. Fig. 5 shows that a 540 mm x 324 mm planar absorber has 18-by-12 unit cells composed of a bowtie in Fig. 1. Fig. 6 shows the simulated bi-static RCS of this absorber on the xz- and yz-planes at 5 GHz, where the excitation is a plane wave with vertical polarization propagating from the +z to the -z direction at a normal incidence. This figure also shows the bi-static RCS for the PEC plate of the same size for comparison. The absorber dissipates the impinging wave rather than redirecting it away from the incident direction.

Fig.7 shows the simulated and measured RCS reductions at a normal incidence, demonstrating excellent agreement between both results. The RCS reduction is the ratio of the mono-static RCS of the proposed absorber to that of the same size PEC plate. The operating band extends from 3.4 GHz up to 8.07 GHz for 10 dB RCS reduction, corresponding to an 81 % bandwidth.

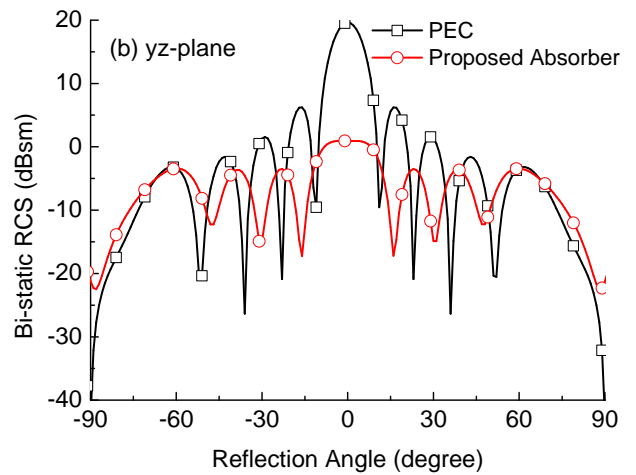
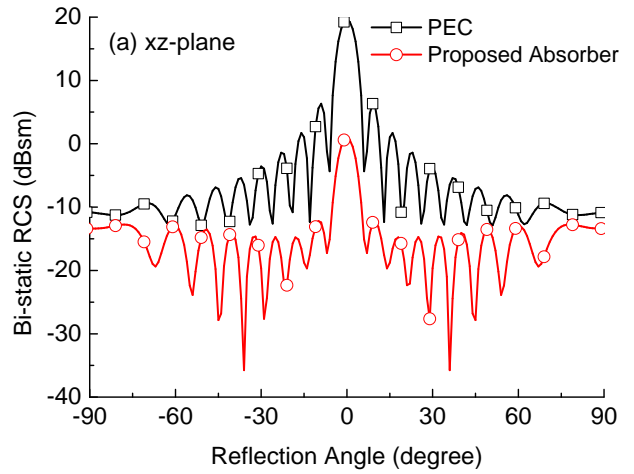


Fig. 6. Simulated bi-static RCS of the proposed absorber in Fig.5 for vertical polarized (e-field along y-axis) incident wave on (a) xz- and (b) yz-plane at 5 GHz

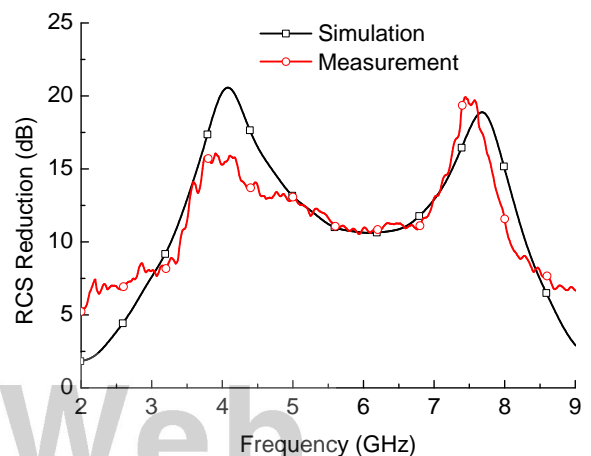


Fig. 7. Simulated and measured RCS reductions at normal incident

## V. CONCLUSION

A novel design of ultra-thin absorber based on a wideband antenna array for absorption of normal incident wave with single- or dual-polarization is presented in this paper. Through analysis of unit cell of this wideband antenna array, the design of the absorber can be simplified. The design example has been simulated, fabricated, and measured. The proposed absorber exhibits the bandwidth of over 81% (RCS reduction > 10 dB ) when the thickness is about 11% of the free space wavelength at the lowest operation frequency.

## ACKNOWLEDGEMENT

The corresponding author of this paper wish to acknowledge CST® for their support in providing software for numerical simulation.

## REFERENCES

- [1] M. Paquay, J.C. Iriarte, I. Ederria, R. Gonzalo and P. de Maagt, "Thin AMC Structure for Radar Cross-Section Reduction." *IEEE Trans. Antennas Propag.*, Vol.55, No.12, pp.3630-3638, Dec. 2007.
- [2] Y. Zhang, R. Mittra, and B. Z. Wang, "Novel Design for Low-RCS Screens using a Combination of Dual-AMC," 2009 IEEE International Symposium on Antennas and Propagation, pp. 1-4, June 2009.
- [3] Y. Zhang, R. Mittra, B. Z. Wang, and N.T. Huang, "AMCs for ultra-thin and broadband RAM design," *Electronics Letters*, vol.45, pp. 484 - 485, May 2009.
- [4] Y.-L. Tsai and R.-B. Hwang, "RCS reduction of a composite AMC structure," *IEEE International Workshop on Electromagnetics, IWEM 2011*, pp. 210-213, August 2011.
- [5] E. F. Knott, J. F. Shaeffer, and M. T. Tuley, *Radar Cross Section*, Artech House, 1993.
- [6] W. W. Salisbury, " Absorbent Body for Electromagnetic Waves" U.S. Patent No. 2, 599, 944, June 10, 1952.
- [7] F.C. Seman, R. Cahill, and V. Fusco, "Performance enhancement of Salisbury screen absorber using a resistively loaded high impedance ground plane," *Proceedings of 4th European Conference on Antenna and Propagation (EUCAP 2010)*, Barcelona, Spain, 2010.
- [8] F.C. Seman and R. Cahill, "Performance Enhancement of Salisbury Screen Absorber Using Resistively Loaded Spiral FSS," *Microwave and Optical Technology Letters*, vol.53, pp. 1538–1541, July 2011
- [9] F.C. Seman, R. Cahill, V. Fusco, and G. Goussetis, "Design of Salisbury screen absorber using frequency selective surfaces to improve bandwidth and angular stability performance," *IET Microwaves, Antennas & Propagation*, vol.5, pp. 149–156, Jan. 2010
- [10] F. Costa, A. Monorchio, and G. Manara, "Analysis and Design of Ultra Thin Electromagnetic Absorbers Comprising Resistively Loaded High Impedance Surface," *IEEE Transactions on Antennas and Propagation*, vol.58, pp. 1551-1558, 2010
- [11] Y.-Q. Pang, Y.-J. Zhou, and J. Wang, "Equivalent Circuit Method Analysis of the Influence of Frequency Selective Surface Resistance on the Frequency Response of Metamaterial Absorbers," *J. Appl. Phys.*, vol.110, pp.023704-1 - 023704-5, 2011
- [12] W.-J. Lee, J.-W. Lee and C. G. Kim, "Characteristics of an Electromagnetic Wave Absorbing Composite Structure with a Conducting Polymer Electromagnetic Bandgap (EBG) in the X-band," *Composites Sci. Technol.*, vol. 68, pp.2485-2489 , 2008.
- [13] CST Studio Suite 2012, [www.cst.com](http://www.cst.com)