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Hybrid FSS Screens for Broadband Microwave Absorber Design at X-Band

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ABSTRACT

Designing the periodic hybrid metal grid/ferrite FSS screens to construct broad-band microwave absorbers is presented in this paper. In practice, the microwave absorbers consist of interleaved metal grid FSS screens and ferrite FSS screen. There are two types of metal grid FSS screens, strip-grating and mesh, to be introduced to obtain a better bandwidth and absorption. The ferrite FSS made of $Ba(MnTi)Fe_{10}O_{19}$ is used to enhance the performance of absorbers. In the meantime, the decrement method is used to measure reflective response of microwave absorber. Both reflectivity and absorption representations recognize the characterization of microwave absorbers for X-band applications.

Keywords: microwave absorber, FSS screens and ferrite

以複合式頻率選擇平面設計 X-Band 寬頻微波吸收體

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摘　要

本文提出利用金屬網柵與鐵氧磁體複合之頻率選擇平面技術設計寬頻微波吸收體。此微波吸收體係由金屬網柵之頻率選擇平面與鐵氧磁體$Ba(MnTi)Fe_{10}O_{19}$週期排列之頻率選擇平面交錯組成，可呈現出較佳的頻寬及吸波特性。實驗中利用條格狀及網狀兩種不同型態的金屬網柵之頻率選擇平面建構微波吸收體，並利用微波量測技術中的比對法探討微波吸收體的頻率響應。

關鍵字：微波吸收體，頻率選擇平面，鐵氧磁體

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I. INTRODUCTION

The microwave absorbers are extensively applied in special fields, such as anechoic chambers, radar systems, and military utilities. The absorbers are categorized to many types, which the Salisbury screen represents one of the simplest planar types of resonant absorbers and is generally constructed with a lossy screen by quarter wavelength in front of a conducting surface [1]. For the application of using the quarter-wavelength transformer technique, the Salisbury screen can transform the open impedance of the resistive screen into a short impedance of the conducting surface. By reason of its property of inherently narrow band, single layer absorbers will severely limit the physical applications. Therefore, the developing of multi-layer structures, which introduce layers of resistive and dielectric sheets are often employed for broadband absorber [2-6]. Analytical treatments of multiple electric/magnetic Salisbury screen (or Jauman absorber) have been represented by Fante and McCormach to find the corresponding optimum relation of parameter of the influence on the frequency responses of absorbers [2]. A proper choice of the spacer material, screen properties and distance, allow a variety of response to be obtained in this situation, on the basis of the maximally flat binomial characteristics [2] or Chebyshev approximations [5, 6]. The optimal procedures of simulated annealing (SA) technique and genetic algorithm (GA) were also proposed for design [3, 4].

Recently, various approaches were developed to implement the practical microwave absorber. First of all, by adopting ferrite such as magnetic material of $Ba(MnTi)_xFe_{12-2x}O_{19}$ was in the application of thin microwave absorber [7, 8]. Second, the structure of frequency selective surface (FSS) screens would achieve the effect on increasing the bandwidth [9-16]. With respect to the frequency selective properties of periodic structures, the transmission of electromagnetic wave through a thin screen made of periodic metal grids or plates would present the high-pass or low-pass frequency response. Furthermore, cascading complementary screens with metal grids and plates which laid one on top of the other would present a multi-band frequency response [17, 18]. Third, for composite configuration, the design of absorber comprising FSS screen could be also embedded in multilayered dielectric media to enhance the bandwidth [8]; meanwhile, using FSS screen coating with ferrite could also achieve the effect of improving the bandwidth and absorption [15].

In this paper, there is an alternative approach to design and measure broad-band microwave absorber with periodic hybrid metal grid/ferrite FSS screens. In practice, two types of metal grid, strip-grating screen and mesh screen, are interleaved with ferrite unit cells, a new magnetic material composed of $Ba(MnTi)Fe_{10}O_{19}$, to form the hybrid FSS. Then, the hybrid FSS keeps a quarter-wavelength spacing above conducting surface to construct the microwave absorber. Both reflectivity and absorption representation are measured to study the related attenuation of absorber. The experimental results including both E-plane and H-plane are presented and discussed. The frequency responses cover the X-band for applications.

II. DESIGN PROCEDURE AND METHODOLOGY

2.1 Hybrid FSS Screens

2.1.1 Periodic metal grid FSS configurations

FSS techniques have found many applications in filters, diplexers, antennas, and absorbers. The elements reflect the incident microwave of a specific frequency range based on their sizes, geometric shapes, periodicities and the dielectric properties of the substrate. The unit cells including square, circular, cross, Jerusalem cross, ring and square loop [12] can form various element geometries for FSS screens. Two types of FSS screens with metal grids, strip-grating screen and mesh screen, are designed.

a. Strip-grating screen: In this paper, the screen with the configuration of strip-grating is shown in Fig. 1(a). The strip-grating is constructed with parallel metal strips of distance L in each.
b. Mesh screen: The screen with the configuration of mesh is shown in Fig. 1(b), which the mesh is constructed with vertical-crossed metal strips of interval L and W. The identical field coordinate is used for testing.

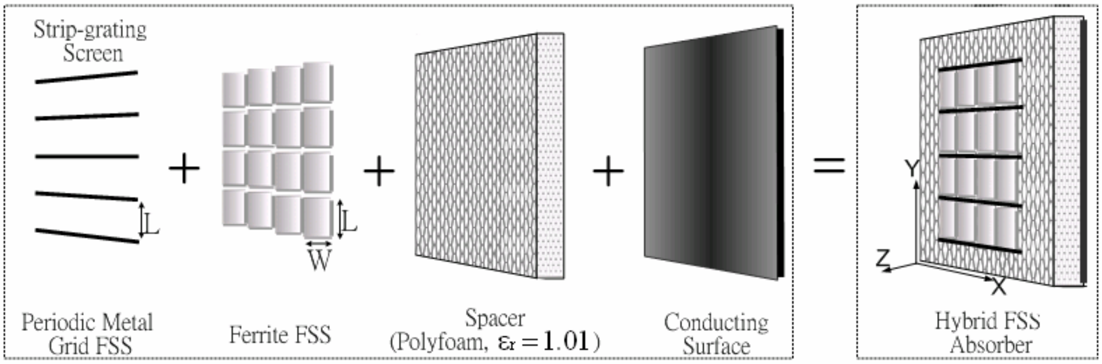
2.1.2 Ferrite FSS

The hexagonal type ferrite was an important magnetic material and developed for applications recently. It was a metal oxide containing magnetic ions arranged in such a manner which would produce spontaneous magnetization while maintaining good dielectric properties and could absorb microwave energy by lossy interaction of the magnetic field of the wave with their individual magnetization. In the experiment, $Ba(MnTi)Fe_{10}O_{19}$ was suitable to be used as an absorbing material due to the properties of hexagonal ferrite materials with a significant value of permeability, high value of magnetization and planar anisotropic behavior in microwave frequencies.

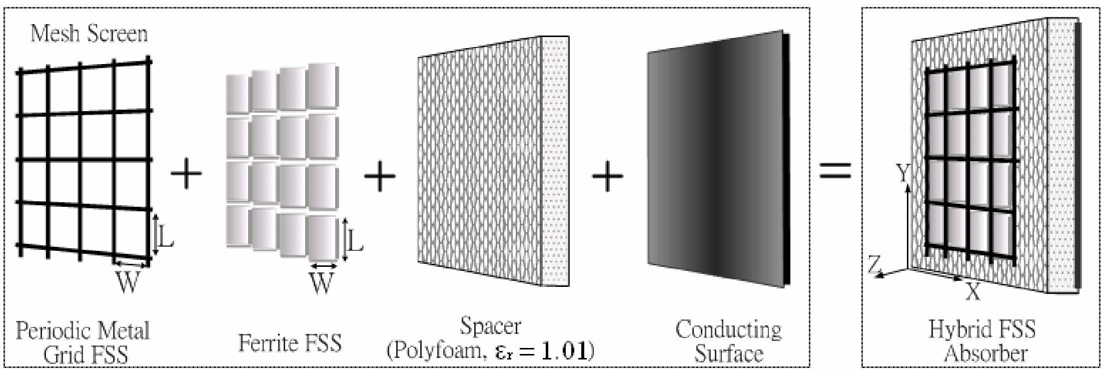
The powder of $Ba(MnTi)Fe_{10}O_{19}$ is prepared by the low temperature combustion syntheses (LCS) and aqueous combustion synthesis (ACS) process. The starting materials are citric acid ($C_6H_8O_7{\cdot}H_2O$), $Ba(NO_3)_2$, $Mn(NO_3)_2{\cdot}4H_2O$, $Ti(OC_2H_5)_4$ and $Fe(NO_3)_3{\cdot}9H_2O$. The powder particles have an average diameter of 50nm, which this kind of nanocomposite absorbing materials have significantly better characteristics; therefore, they could become essential for production of microwave and millimeter-wave absorbers. Using the developed ferrite powder 80% by weight mixed with epoxy resin to form a ferrite unit cell with $L \times W$ dimensions [7, 8], and by arranging with ferrite unit cells, the ferrite FSS is constructed shown in Fig. 1.

2.1.3 Periodic hybrid metal grid/ferrite configurations

To interleave the two types of periodic metal grid FSS, strip-grating screen and mesh screen with 16 pieces of ferrite unit cells each, two of the hybrid FSS are constructed individually. Then, the hybrid FSS keeps a quarter-wavelength spacing above conducting surface to construct the microwave absorber. Field coordinate for measurement is set-up either where the absorber is located on the X-Y plane and pointed to the direction of Z-axis. E-plane pattern is in the X-Z-plane, and H-plane pattern is in the Y-Z-plane shown in Fig. 1.



(a)



(b)

Fig. 1. Hybrid FSS absorbers structures: (a) Strip-grating/ferrite screen, (b) Mesh screen/ferrite screen.

2.2 Decrement Method

Decrement methods are based on comparison of an unknown value of the measured quantity with a known value of this quantity related to the measured quantity by a well-known functional relationship. Their main advantages are high sensitivities to the measured quantity change, and environmental disturbance [15].

The schematic diagram of the test set-up shown in Fig. 2 consists of conducting surface, absorber under test, standard horn antenna, and network analyzer (Anritsu 37347C). For recognizing the attenuation behavior of an absorber by the application of decrement method of microwave measurement technique, the influence from external environment has to be excluded. Structurally, the conducting surface can be denoted as both the reference ground for measuring and the part of absorber. Therefore, related to the reference ground, the methods of reflectivity and absorption are applied to analyze the absorbing effect.

Reflectivity (R) and relative absorption (A_R) of attenuation are determined from reflection coefficient of the absorber and conducting surface expressed as follows:

$$R\ (dB) = 20 \times log(S_{11} / M_1) \qquad (1)$$

$$A_R\ (dB) = 20 \times log\left|S_{11} - M_2\right| \qquad (2)$$

where S_{11} is the reflection coefficient of absorber, M_1 is the reflection coefficients of conducting surface with polyfoam, and M_2 is the reflection coefficient of the conducting surface only.

Reflectivity is obtained by comparing with the reflection coefficients of both absorber and conducting surface. When *R (dB)* is less than 0 dB, the absorber represents the attenuating characterization of incident wave.

Absorption is the result of subtracting the reflection of the conducting surface from absorber; meanwhile, the environmental causes have been eliminated so that the property of attenuating of absorber is recognized.

Physically, the equation (2) holds for the reference to the conducting surface, thus a characteristic description of related attenuation of absorption is improved and written as

$$A\ (dB) = 20 \times log\left[1 + (M_2 - S_{11})\right] \qquad (3)$$

The value of *A (dB)* is between 0-6 dB, and the Maximum value of *A (dB)* is 6 dB when $S_{11}=0$. That is, the absorber presents the character of fully absorption of incident wave. In addition, when $S_{11}=M_2$, the minimum value of *A (dB)* is 0 dB and the absorber shows the character of total reflection of incident wave.

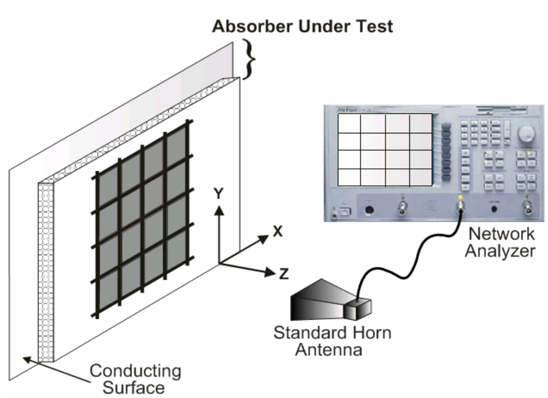


Fig. 2. Measurement set-up system.

III. EXPERIMENTS AND RESULTS

For experiments, each unit cell of ferrite FSS is made by using $Ba(MnTi)Fe_{10}O_{19}$ in 25 mm × 37.5 mm dimensions , and with 16 pieces of unit cell to construct various FSS screens. One of the configurations is strip-grating which the interval L = 25 mm, and each unit cells is separated by 2mm. The comparative configuration is mesh which the interval L = 25 mm and W = 37.5 mm with the total dimensions of 11cm×16cm that approaches to the dimensions of square-lattice screen absorber [15]. According to the basis of Salisbury screen, the spacer keeps a quarter-wavelength of 9.1 mm thickness with polyfoam material (ε_r = 1.01) and is attached on a conducting surface as a DUT (device under test) shown in Fig. 1. The measured reflection coefficient S_{11} of the absorber with the coordinate is shown in Fig. 2. An electromagnetic wave propagating along the negative z-direction is incident normally on the absorber. The S_{11} frequency responses of transverse electric or magnetic polarization in incident wave are measured and presented in Figs. 3 and 4, which the frequency responses cover the X-band for applications.

The frequency responses of *R (dB)*, A_R *(dB)* and *A (dB)* in E-plane and H-plane of strip-grating/ferrite screen absorber and mesh/ferrite screen absorber are shown in Figs. 3 and 4, respectively. It is evident that periodic hybrid metal grid/ferrite FSS screen absorbers present the phenomenon of broad-band, and obviously that the frequency responses of E-plane and H-plane of the mesh/ferrite screen absorber in *R (dB)* and *A (dB)* have better performance than in the strip-grating/ferrite screen absorber. Meanwhile, for these two types of the absorbers, there are approximate properties of broad-band in E-plane and H-plane in *A (dB)*, there is better performance in H-plane than in E-plane comparatively.

In conclusion, to present the behaviors of strip-grating/ferrite FSS and mesh/ferrite FSS absorbers, as well as the coating ferrite square-lattice FSS absorber [15], the frequency responses of E-plane and H-plane are tabulated as Table 1, and 2. It shows that there are wider bandwidths in E-plane of *R (dB)* than in H-plane for coating ferrite square-lattice FSS absorber. On the contrary, there is wider bandwidth in H-plane of *R (dB)* for mesh/ferrite FSS absorber. Besides, for *R (dB)* below -5 dB in E-plane, the responses of coating ferrite square-lattice FSS absorber present wider bandwidth than the mesh/ferrite FSS absorber; however in H-plane, the results are opposite. Meanwhile, for *A (dB)* above 3 dB in E-plane, the responses of mesh/ferrite FSS absorber present wider bandwidth than the coating ferrite square-lattice FSS absorber, but the results are opposite in H-plane.

All the measurements above are at near field (~0.1λ), but the results of the measurement at far field (~5λ) have no significant difference between E-plane and H-plane.

IV. CONCLUSION

The design of broad-band microwave absorber using the periodic hybrid metal grid/ferrite FSS screens in contrast multilayer screens in the past, could increase not only the bandwidths but also obtain better attenuation known from the measurement of the reflectivity and absorption representations on this experiment.

Table 1. Frequency response of E-plane

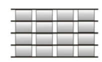
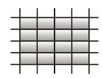
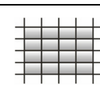
Configuration	*R (dB)*	A_R *(dB)*	*A (dB)*
	-5dB BW (%)	-10dB BW (%)	3dB BW (%)
	E	E	E
	13.1	81.0	30.8
	30.1	70.7	25.1
	57.2	27.8	40.3

Table 2. Frequency response of H-plane

Configuration	*R (dB)*	A_R *(dB)*	*A (dB)*
	-5dB BW (%)	-10dB BW (%)	3dB BW (%)
	H	H	H
	20.3	49.6	13.9
	48.4	30.6	11.8
	13.7	67.0	8.7

The measured results at X-band are showed to acquire that there are 57.2% bandwidths below -5 dB in *R (dB)* and 40.3% bandwidths above 3 dB in *A (dB)* for E-plane of the coating ferrite square-lattice FSS absorber. Relatively, there are 48.4% bandwidths below -5 dB in *R (dB)* and

11.8% bandwidths above 3 dB in *A (dB)* for H-plane of the mesh/ferrite FSS absorber. Therefore, the applications of FSS screens incorporated with ferrite can enhance the performance of frequency responses to improve the responses of microwave absorbers.

In terms of the properties of nonflammable, high temperature endurance and good dielectric ferrite which is an inorganic substance possessed, the hybrid metal grid/ferrite FSS screen absorbers are suitable for military applications such as using on the surface of buildings to prevent the overlapping images on the screen caused by the reflections of electromagnetic wave, camouflage the target or prevent EMP, etc.. It also can be applied to the microwave communication systems.

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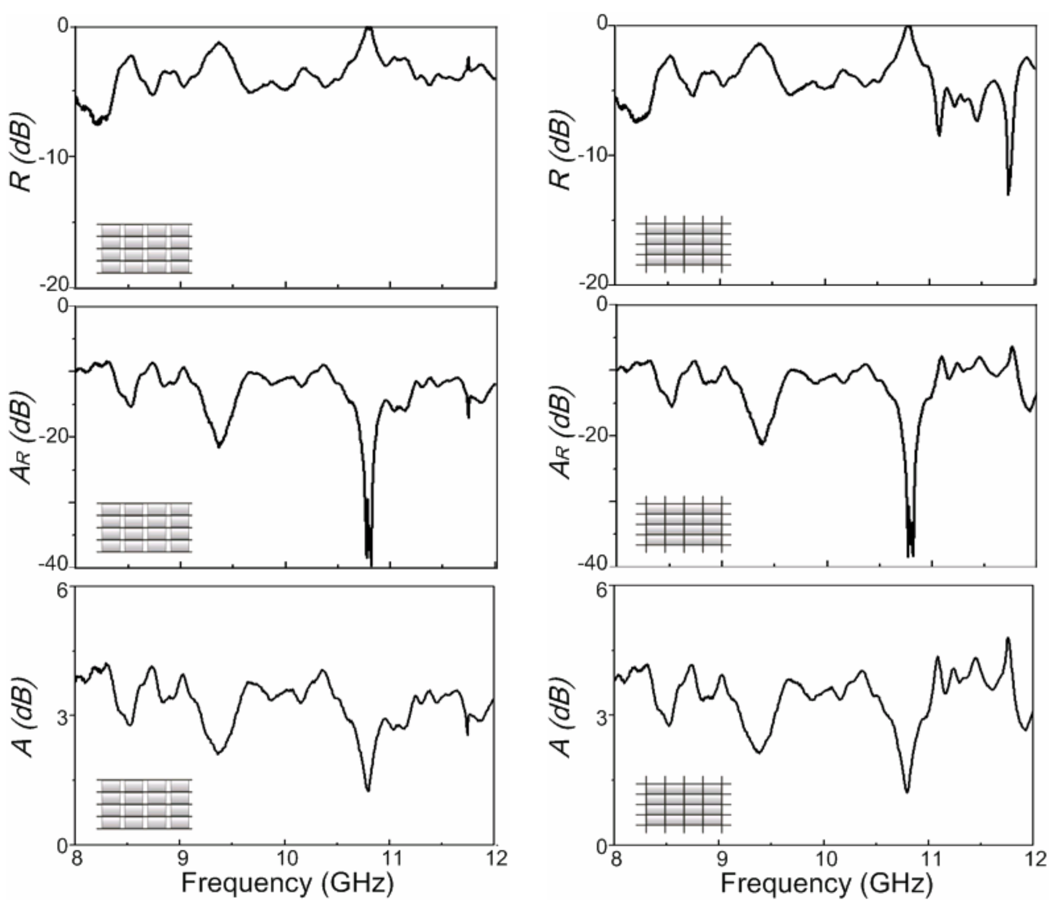
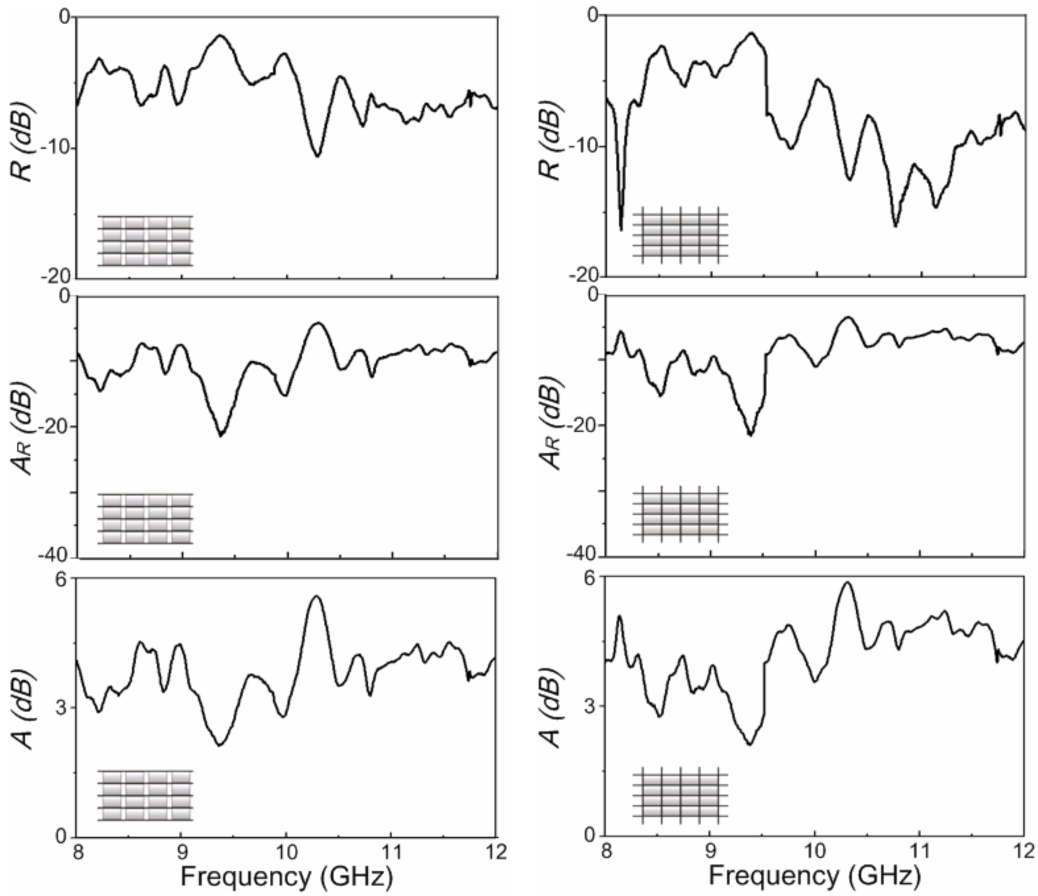


(a) (b)

Fig. 3. Frequency responses of E-plane: (a) Strip-grating/ferrite FSS absorber, (b) Mesh/ferrite FSS absorber.



(a) (b)

Fig. 4. Frequency responses of H-plane: (a) Strip-grating/ferrite FSS absorber, (b) Mesh/ferrite FSS absorber.

REFERENCES

[1] Knott, E. F., Shaeffer, J. F., and Tuley, M. T., Radar Cross Section, MA, Artech House, Chap. 8, pp.297-359, 1985.

[2] Fante, R. L., and McCormack, M. T., "Reflection Properties of Salisbuty Screen," IEEE Trans. Antennas Propagat., Vol. 36, No. 10, pp. 1443-1454, 1988.

[3] Michielssen, E., Sajer, J. M., Ranjithan, S., and Mittra, R., "Design of Lightweight Broadband Microwave Absorbers Using Genetic Algorithms," IEEE Trans. Antennas Propagat., Vol. 41, No. 6, pp. 1024-1030, 1993.

[4] Pesque, J. J., Bouche, D. P., and Mittra, R., "Optimization of Multilayer Antireflection Coating Using an Optimal Control Method," IEEE Trans. Microwave Theory Tech., Vol. 40, No. 9, pp. 1789-1796, 1992.

[5] Liu, J.C., Ho, S.S., Bor, S.S. and Lu, P.C., "Tchebyshev Approximation Method for Salisbury Screen Design," IEE Proc-H, Microwaves, Antennas Propagat., Vol. 140, No. 5, pp. 414-416, 1993.

[6] Toit, L. J., "The Design of Jauman Absorbers," IEEE Antennas Propagat. Magazine, Vol. 36, No. 6, pp. 17-25, 1994.

[7] Meshram, M. R., Sinha, B., Agrawal, N. K., and Misra, P. S., "Development and Characterization of (Ba-Mn-Ti) Based Hexagonal Ferrite for Microwave Absorbing Paint," IEEE Antennas Propagat. Society Int. Symp., Vol. 2, pp. 790 -793, 2002.

[8] Naito, Y., Anzai, H., and Mizumoto, T., "Ferrite Grid Electromagnetic Wave Absorbers," IEEE Int. Symp. Electromagnetic Compatibility, pp. 254-259, 1993.

[9] Mittra, R., Chan, C. H., and Cwik, T., "Techniques for Analyzing Frequency Selective Surfaces – a review," Proc. IEEE, Vol. 76, No. 12, pp. 1593-1615, 1988.

[10] Chakravarty, S., Mittra, R., and Williams, N. R., "On the Application of the Microgentic Algorithm to the Design of Broad-band Microwave Absorbers Comprising Frequency-selective Surfaces Embedded in Multilayered Dielectric Media," IEEE Trans. Microwave Theory Tech., Vol. 49, No. 6, pp. 1050-1059, 2001.

[11] Ito, A., Ebara, H., Nakajima, H., Wada, K., and Hashimoto, O., "An Experimental Study of a λ/4 Wave Absorber Using a Frequency-selective Surface," Microwave Opt. Tech. Lett., Vol. 28, No. 5, pp. 321-323, 2001.

[12] Chakravarty, S., Mittra, R., and Williams, N. R., "Application of a Microgentic Algorithm (MGA) to the Design of Broad-band Microwave Absorbers Using Multiple Frequency-selective Surface Screens Buried in Dielectrics," IEEE Trans. Antennas Propagat., Vol. 50, No. 3, pp. 284-296, 2002.

[13] Ito, A., Wada, K., and Hashimoto, O., "Fundamental Study of a λ/4 Wave Absorber Using FSS for Two Frequencies," Microwave Opt. Tech. Lett., Vol. 33, No. 5, pp. 321-322, 2002.

[14] Kern, D. J., and Werner, D. H., "A Genetic Algorithm Approach to the Design of Ultra-thin Electromagnetic Bandgap Absorbers," Microwave Opt. Tech. Lett., Vol. 38, No. 1, pp. 61-64, 2003.

[15] Liu, J. C., Liu, C. Y., Wu, C. Y., and Hsu, H. Y., "Implementations of Broad-band Microwave Absorber Using FSS Screens Coated with $Ba(MnTi)Fe_{10}O_{19}$ Ferrite," Microwave Opt. Tech. Lett., Vol. 41, No. 4, pp. 323-326, 2004.

[16] Yeo, J., Ma, J. F., and Mittra, R., "Ga-based Design of Artificial Magnetic Ground Planes (AMGS) Utilizing Frequency-selective Surface for Bandwidth Enhancement of Microstrip Antennas," Microwave Opt. Tech. Lett., Vol. 44, No. 1, pp. 6-13, 2005.

[17] Whitbourn, L. B., and Compton, R. C., "Equivalent-circuit Formulas for Metal Grid Reflectors at a Dielectric Boundary," Appl. Opt., Vol. 24, No. 2, pp. 217-220, 1985.

[18] Lee, S. W., Zarrillo, G., and Law, C. L., "Simple Formulas for Transmission Through Periodic Metal Grids or Plates," IEEE Trans. Antennas Propagat., Vol. 30, No. 5, pp. 904-909, 1982.