Wide Angle Elimination of Specular Reflection Using Metallo-dielectric Structure Based on Sierpinski Carpet Array

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Abstract : This paper presents the scattering behavior of metallo-dielectric structure with 4×4 Sierpinski carpet array based metallisations. Elimination of specular reflection below -10dB is obtained over wide angular range of 57.8^0 by employing second iterated stage of the Sierpinski carpet array. Reduction in specular reflection below-10 dB is achieved over a frequency band of 1.72 GHz for angle of incidence $\theta i = 26^0$ and 1.9 GHz for $\theta i = 39^0$.

***Index Terms* – Specular reflection, sierpinski carpet array**

I. INTRODUCTION

Reflection gratings which can scatter an incident electromagnetic wave into different diffraction orders have been of immense research interest in optical and microwave engineering [1-3]. The period (d) is the important parameter which determines the scattering behavior of the grating. According to Bragg's law of diffraction $\sin \theta_n = \sin\theta_i + n\lambda/d$ where θ_i is the angle of incidence and θ_n is the angle of diffraction where n=0, ±1 ….and λ is the wavelength. When n=0, specular reflection takes place while n = -1 corresponds to blazing. Blazing occurs when an oblique incident electromagnetic wave gets reflected back in the direction of incidence itself. E V Jull et al reported non-planar diffraction gratings constructed using metal grooves for blazing effects [4-5]. The width and depth of the grooves determined the bandwidth of the blazing surface. Reflection gratings with rectangular and triangular grooves were investigated for perfect blazing for both TE and TM polarizations. Blazed gratings have been used in different applications such as frequency scanned reflector antennas, radar cross section (RCS) reduction surfaces, littrow mounts and external cavity lasers.

. Jose et al reported perfectly blazed strip gratings that simulate corrugated reflector effects [6]. Perfect blazing of reflector backed thin strip gratings to n = -1 spectral order for both TE and TM polarizations is compared with metallic corrugated reflection gratings to show that the strip gratings are simulating the effects of rectangular corrugated surfaces.

D.S Stephen et al reported simultaneous elimination of specular reflection and backscattered power from a plane metallic surface by simulated corrugated surfaces of constant period and variable strip width for TM polarization. In [8] a modified strip grating with dual periodicity for RCS reduction is reported. Elimination of specular reflection for wide range aspect angles for TE polarization is achieved. This overcomes the main disadvantage of conventional strip grating which eliminates specular reflection for a limited angle of incidence only. T Mathew et al reported a trapezoidal strip grating surface that eliminates specular reflection almost over the entire X band of frequencies for TM polarization [9]. This metallo-dielectric structure overcomes the bandwidth limitations of conventional rectangular strip grating surfaces. Enhanced bandwidth and circular polarization for blazing were also achieved by V shaped planar gratings [10]. X Li et al reported a blazed metasurface gratings which can reflect most of the incident power back in the path of incidence and with reduced power reflected in the specular direction [11].

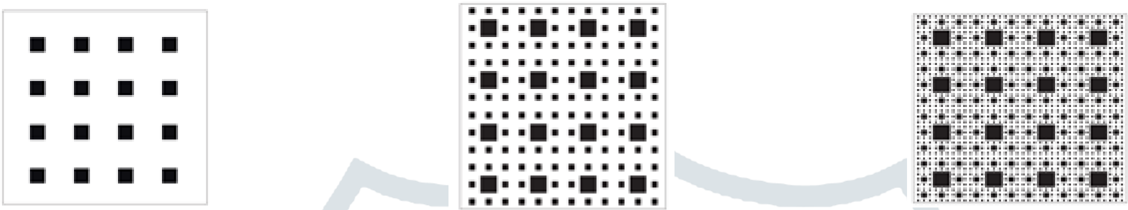
M Memarian et al reported wide band/angle blazed surfaces using multiple coupled blazing resonances [12]. Multiple blazing resonances are combined similar to the case of coupled resonator filters forming a blazing passband between the incident wave and the first grating order. Blazed gratings with single and multiple blazing passbands are fabricated and measured showing increase in band width of specular reflection rejection demonstrated at X band. All these blazed gratings used euclidean geometries of metallizations over a dielectric substrate.

Anupam et al studied metallo-dielectric structure with fractal based metallization for backscattering reduction [13-15]. Backscattering reduction for both TE and TM polarization is achieved by employing a metallo-dielectric structure with a Sierpinski carpet fractal based metallizations in [13]. A reduction in backscattered power of ~30 dB is obtained for normal incidence in the X band with third iterated stage of the fractal geometry. In [14] scattering behavior of metallo-dielectric structures based on Sierpinski carpet fractal geometry with superstrate loading is reported. The frequency for backscattering minimum can be controlled with the superstrate thickness for both TE and TM polarizations. The application of fractal based metallo-dielectric structures for the control of RCS for various objects have been reported in [15].

This paper presents scattering behavior of metallo-dielectric structures based on Sierpinski carpet arrays of different iterated stages in the X- band. Elimination of specular reflection is achieved over wide ranges of angle of incidence with broadband characteristics by employing second iterated stage of the Sierpinski carpet array

II. METHODOLOGY AND EXPERIMENTAL SETUP

III. Figure 1 shows the schematic diagram of the 4×4 array of Sierpinski carpets of first, second and third stages utilized in this work. Metallizations based on 4×4 array of Sierpinski carpets are formed by photo etching the structure on 30 cm × 30 cm FR-4 substrate(ε_r =4.4) with dielectric thickness h1=0.8mm. This structure is placed over a flat metallic plate of same dimensions with dielectric sheet of ε_r = 2.5 of thickness h2 loaded in between the metal plate and the Sierpinski carpet array structure. The dielectric thickness h2 is varied to optimize the performance the metallo-dielectric structure. The schematic diagram of the metallo-dielectric structure with second iterated stage of the Sierpinski carpet array is shown in figure 2



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(a) (b) (c)

Fig. 1 Schematic diagram of the 4×4 array of Sierpinski carpets.

(a) first iteration (b) second iteration (c) third iteration.

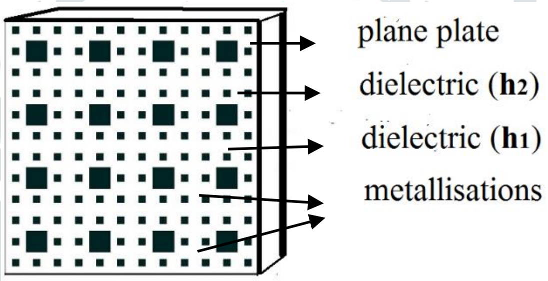

Fig.2 Schematic view of the metallo-dielectric structure based on 4×4 Sierpinski carpet array with second iterated stage.

Photograph of the fabricated metallo-dielectric structures based on the different iterated stages of the Sierpinski carpet array are shown in figure 3.

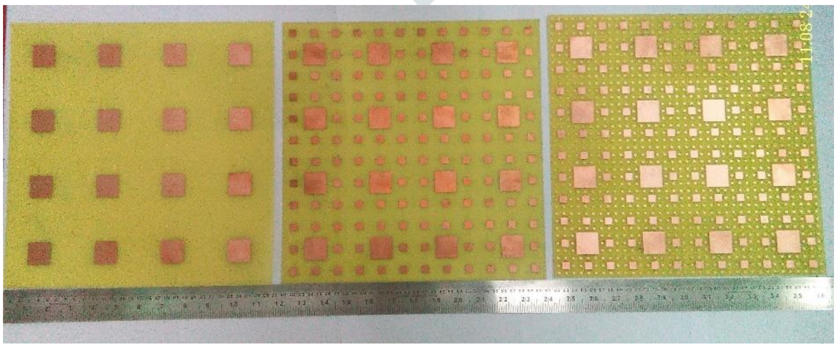

Fig.3 Photograph of the fabricated metallo-dielectric structures based on different iterated stages of the Sierpinski carpet array.

An arch method is used for evaluating the scattering behaviour of the Sierpinski carpet structure in the X band. Two identical X band horns are connected to the two ports of a vector network Analyser Rohde & Schwarz ZVB20 calibrated for a 30 cm × 30 cm flat metal plate at normal incidence. The metallo-dielectric structure based on Sierpinski carpet array is loaded at the centre of the arch. By moving the transmitting and receiving antennas along the arch, scattering power is measured at various angles. The dielectric thickness h_2 between the structure and flat metal plate is varied and the scattering measurements are taken to optimise the performance for elimination of specular reflection over wide angular ranges. Measurements are repeated for the three iterated stages of the Sierpinski carpet array.

Fig.4 Photograph of the Arch method for scattering measurements of metallo-dielectric structures

IV. RESULTS AND DISCUSSION

Figure 5(a) and (b) illustrates the variations of relative reflected power and backscattered power with angle of incidence for the second iterated stage of the Sierpinski carpet array with h_1=0.8mm and h_2= 4.5 mm, at frequency 9.8 GHz. From figure 5(a) it is evident that the elimination of specular reflection below -10 dB occurs over a wide angular range of 57.8^0. Maximum reduction in reflected power of -34.5 dB is observed at an angle of incidence of 26^0. From figure 5(b) it is clear that maximum backscattered power is -4dB at an angle of incidence of 39^0

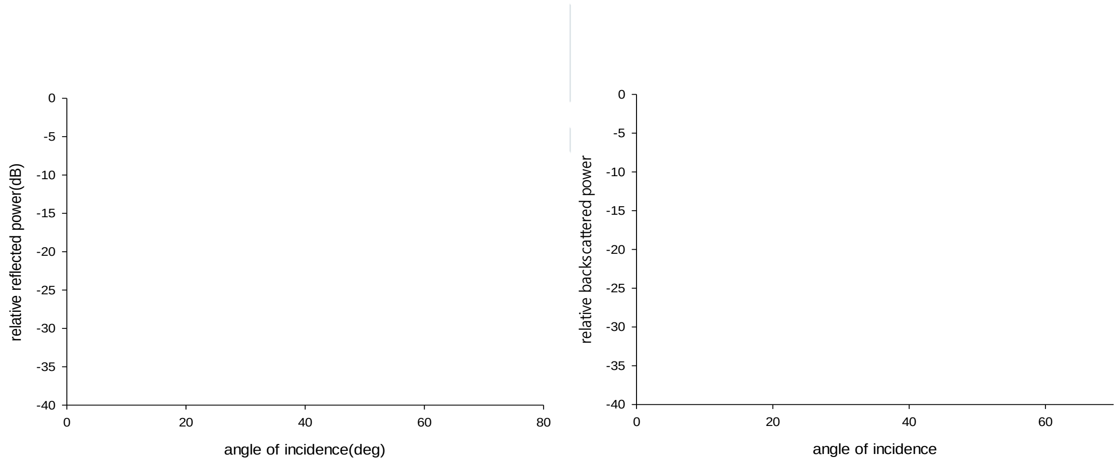

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Fig. 5. Variation of relative reflected power and backscattered power with angle of incidence for the second iterated stage of the Sierpinski carpet array at 9.8 GHz .(h_1=0.8mm & h_2=4.5mm).

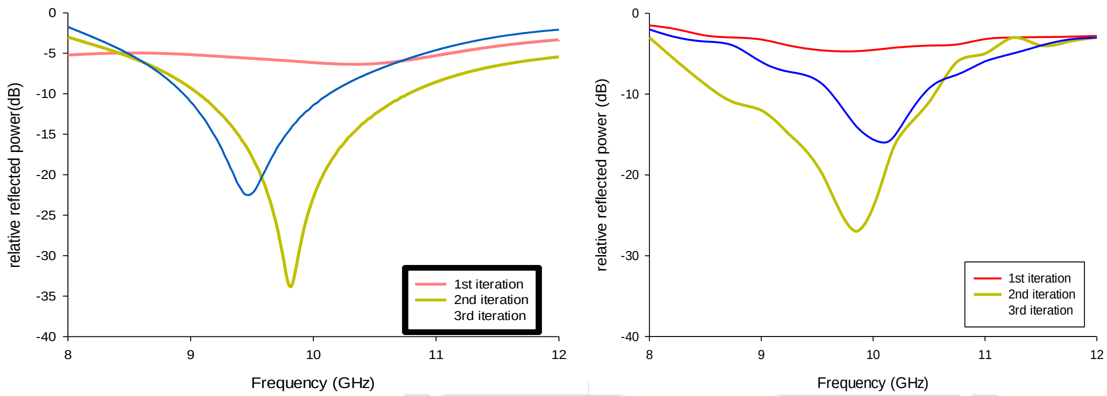

Fig.6 Variation of relative reflected power with frequency for different iterated stages of the Sierpinski carpet arrays for (a) $\theta_i = 26^0$ (b) $\theta_i = 39^0$.(h_1=0.8mm & h_2=4.5mm)

Figure 6 (a) and (b) illustrate the measured variation of relative reflected power with frequency for angles of incidence $\theta_i = 26^0$ and 39^0 respectively for different iterated stages of the Sierpinski carpet array. From figure 6(a) it is clear that the second iterated stage of the Sierpinski carpet array structure produces a maximum reduction in specular reflection of -34.5 dB at 9.8 GHz. Reduction of relative reflected power below -10 dB is achieved for a frequency band of 1.72 GHz for an angle of incidence 26^0. From figure 6(b) it can be seen that for angle of incidence $\theta_i = 39^0$ the reduction of specular reflection below -10 dB is obtained over a frequency band of 1.9 GHz, with a maximum reduction of -27 dB at 9.8 GHz.

Figure 7 shows the relative backscattered power with frequency for angles of incidence 26^0 and 39^0 respectively for the second iterated stage of the Sierpinski carpet array. For $\theta_i = 39^0$ relative backscatterd power of -4 dB is obtained at 9.8 GHz while for $\theta_i = 26^0$ the backscattered power remains low throughout the X band. The above measurement results show that the proposed metallo-dielectric structure is effective in wide angle elimination of specular reflection over a wide frequency band.

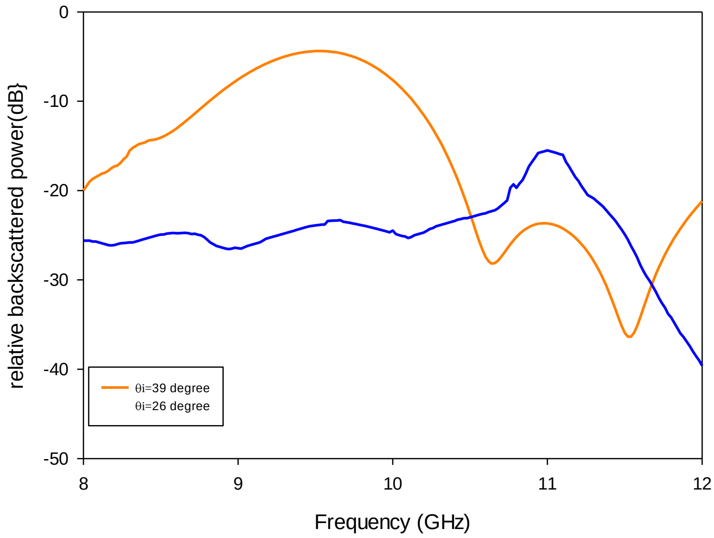

Fig. 7. Relative backscattered power with frequency at angle of incidence $\theta_i = 39^0$ and $\theta_i = 26^0$ for the second iterated stage of Sierpinski carpet array. (h_1=0.8mm & h_2=4.5mm)

Figure 8 shows the variation of relative reflected power with dielectric thickness for the second iterated stage of the structure at an angle of incidence $\theta_{i=}$ 26^0.From the figure it is clear that specular reflection is minimum for h_2/λ=0.132.

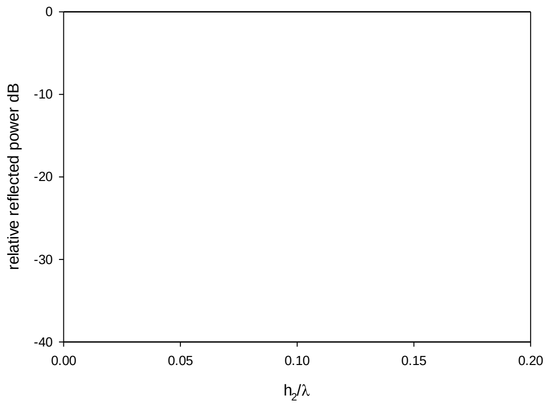

Fig. 8. Variation of relative reflected power with dielectric thickness (h_2) for the second iterated stage of the Sierpinski carpet array based metallo-dielectric structure with h_1=0.8mm.

4, CONCLUSION

Metallo-dielectric structure based on second iterated stage of 4×4 Sierpinski carpet array for eliminating specular reflection over wide angular range with broad band characteristics is presented. Elimination of specular reflection below -10 dB is achieved over an angular range of 57.8^0 at 9.8 GHz.These surfaces may find applications in RCS control and in frequency scanned reflectors.

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