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Study of Broadband/Dual-band Stack Prism Absorber

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Abstract—This paper presents a simulation-based study of multilayered absorbers. Such absorber structures can be designed to exhibit broadband absorption performance of 52% fractional bandwidth. We discuss the TE, TM incidence angle dependency characteristics of a doubly periodic arrangement of the square, conical and hexagonal truncated stacked lamination prism arrays. Then further geometry modification is made to achieve a dual-band operation with a low profile. The simulation results show that the frequency ratio can be tuned by controlling the metallic via location. The resultant dual-band design has stable absorption performance at different incident angles.

Index Terms—broadband, dual-band, metamaterial, absorber.

I. INTRODUCTION

Microwave absorbers, since their first application in radar applications, have been widely used for electromagnetic interferences reduction, radar cross-section reduction, antenna cross talk reduction, and electromagnetic compatibility. The earliest development of microwave absorbers started from the Salisbury screen, which consists of a metal ground plane, a dielectric material of thickness d , and a conductive layer [1]. The incident wave is partially reflected at the front surface of the Salisbury screen, while the transmitted wave propagates through the dielectric layer to the metal ground plane. If the dielectric layer thickness is one quarter-wavelength, the transmitted wave will undergo a 180° phase shift; thus, the waves cancel at the outer surface of the absorber. The disadvantages of these screens include limited bandwidth and absorption degradation at off-normal incident angles. The Jauman absorber is a multilayer design with improved bandwidth based on the Salisbury screen. Genetic algorithms can be used to optimize bandwidth, absorption, and overall thickness [2]. However, the dielectric and conductive layers with required thickness and resistance are still complicated to construct. Recently, the advent of the metamaterials has enabled a new class of absorbers. Metamaterial based absorbers commonly consist of two-dimensional periodical unit cells. The deliberately arranged unit cells have unique electric/magnetic responses to the incident waves, thereby creating artificial mediums with arbitrary effective material parameters. There has been significant progress in the improvement of the metamaterial-based absorbers, for example, the bandwidth enhancement and dual-band operation [3]–[8]. In this study, we propose two new variants of the absorber design in [8]. Angular dependency analysis is presented by performing the full-

wave simulation. Furthermore, a novel dual-band absorber structure is described. The resulting absorber structure has been studied for different polarizations under normal incidence as well as for large incident angles.

II. BROADBAND PRISM ABSORBER

A. Unit Cell Design

The schematic view and simulated reflection coefficient of the absorber unit cell are shown in Fig. 1. The unit cell consists of multiple layers of square dielectric sandwiched by copper layers. The ground plane size P is the periodicity of the infinite array. By stacking 20 layers of dielectric and copper, broadband absorption can be realized. The entire absorber array is simulated using the Floquet boundary setup in CST Microwave Studio [9]. Each individual patch absorbs waves in a narrow band. The operating frequency of each patch absorber is defined by the lateral size of the patch. Thus, by stacking multiple patches with continuously changing lateral size, the consecutive narrow frequency bands are cascaded to form a wideband operation band. We choose a 0.2 mm thick FR4 material as the substrate which has a permittivity and loss tangent of 4.4 and 0.02, respectively. As illustrated in Fig. 1, the design exhibits a reflection coefficient below -8 dB over the frequency range of 8.5 to 14.5 GHz, which results in broadband absorption above 85% for the entire band.

Fig. 1. Absorber unit cell configuration and absorption performance of the unit cell (the top patch size is 5 mm, and the bottom dielectric size is 9 mm, $P = 11$ mm).

B. Angular Sensitivity

Next, we discuss the TE and TM incidence absorption characteristics of a doubly periodic arrangement of the square, conical and hexagonal truncated stacked lamination frustum arrays constructed from standard FR4 material, as shown in Fig. 2.

Fig. 2. Schematic views of three broadband absorber unit cells.

All the three absorber unit cells consist of 20 layers of 0.038 mm thick copper cladding deposited on 20 layers of 0.2 mm thick FR4 board, as shown in Fig. 2. The thickness of the substrate should be as small as possible to yield a minimum height of the resulting absorber. The unit cells are simulated using CST Floquet setup, where normal TE/TM incidence waves can be generated to illuminate the infinite arrays. Fig. 3 shows the absorption performance for the square frustum for different incident angles, ≥ 0.9 absorptivity bandwidth obtained at 0° is reduced when θ is larger than 20° and better angular stability is obtained for TE incidence.

Fig. 3. Angular performance of square frustum at TE and TM incidence.

Fig. 4. Angular performance of conical frustum at TE and TM incidence.

Fig. 5. Angular performance of hexagonal frustum at TE and TM incidence.

Figs. 4 and 5 depict the simulated angular sweeping results for the conical and hexagonal structures, respectively. It is noted that conical frustum absorber has a better angular stability performance at oblique incidence than the square type, while the hexagonal type is the best in terms of angular stability since the absorptivity remains stable up to at least 50° for all incidence angles. It is similar to the effect that using hexagonal unit cells in frequency selective surface design has better stability for oblique incidence than the square and circular unit cells. The cross-polarisation levels in the three scenarios are all less than -31 dB. It is worth mentioning that the 90% absorptivity bandwidth for the three absorbers at normal incidence is stable for both TE and TM, and the square frustum absorber has the widest bandwidth. Table I presents the performance comparison of the three types of unit cells.

TABLE I PERFORMANCE COMPARISON OF THREE ABSORBER VARIANTS

Unit cell type	Angular stability (degree)		Bandwidth at normal incidence (%)	
	TE	TM	TE	TM
Square frustum	≤ 20	≤ 20	52.8	52.9
Conical frustum	< 20	≤ 20	46	46.2
Hexagonal frustum	< 40	< 55	46.2	47.9

C. Operating Frequency Scalability

Using the same design concept, we show that the design is scalable to higher frequencies using different fabrication techniques. For example, the square frustum is scaled and simulated using 20 layers of LTCC substrate (Dupont GreenTape951, $\tan \delta = 0.01$, $\epsilon_r = 8$) with copper. Fig. 6 shows the computed absorbing performance is better than 0.9 across the entire E band (60-90 GHz). The design parameters of the E-band absorber on LTCC are listed in Table II.

Fig. 6. Absorption performance for the scaled absorber unit cell at E band.

TABLE II E-BAND UNIT CELL DIMENSIONS

Parameter	tm	ts	wt	wb	wg	h
Values (millimeters)	0.037	0.1	0.6	0.9	1.4	2.7

(tm -copper layer thickness, ts -dielectric thickness, wt and wb are the sizes of the top and bottom dielectric, respectively, wg - size of the ground plane, and h - height of the unit cell)

III. DUAL-BAND ABSORBER

Based on the broadband absorber design in Section II, we can further modify the structure to realize dual-band operation. The broadband absorber described in the previous section requires machining to fabricate the multi-layered structure. For ease of fabrication, an entire panel of the substrate is preferred to be used for each layer without any

cutout. Also, it is beneficial to reduce the overall height of the absorber. Fig. 7 shows the unit cell structure consisting of three dielectric layers and four copper layers. The bottom layer M4 is the periodicity $P = 9$ mm. The size of the other three patches is gradually reduced (8 mm, 7.9 mm, and 7.8 mm). The four metallic vias are symmetrically located at four sides of the absorber unit cell. The vias are thought hole plated from M2 layer to M4 layer.

Fig. 7. Side view and back view of the dual-band unit cell.

Fig. 8. Dual-band performance of the proposed unit cell.

Fig. 9. Effect of moving the metal via from the unit cell center to the edge.

Fig. 10. Angular performance at TE incidence.

Fig. 11. Angular performance at TM incidence.

Fig 8 shows the simulated -15 dB reflection coefficient level is obtained at 8.9 GHz and 12.7 GHz for both the TE and TM incidence. Fig. 9 shows varying the location of the via can change the frequency ratio. The resonance at the lower frequency is caused by the top patch, whereas the higher resonance results from the bottom two patches. It is speculated that a higher-order mode could be excited by introducing the shorting pins and the resonance frequency is related to the location of the pins. The maximum ratio using the proposed unit cell configuration is 1.4 (8.8 GHz/12.4 GHz). It is noted that the lower resonate frequency remains stable when the via is moved from the center to the unit cell edge. The simulated absorptions for TE and TM waves with an oblique incident angle ranging from 0° to 60° are shown in Fig. 10 and Fig. 11. For TE incidence, the higher band performance at 60° is degraded. The angular stability of the TM incident wave is better than the TE case though there is only a slight frequency shift at the higher band.

IV. CONCLUSION

This paper discusses the angular stability performance of three broadband absorbers at up to 60° incident angles. It is concluded that the square frustum type unit cell has the most balanced performance in terms of the bandwidth, angular stability, and fabrication complexity. A further study of a dual-band absorber is also presented in this paper. The three-layer unit cell can be easily designed to achieve a dual-band operation with up to 1.4 frequency ratio. Simulation results indicate that the TM polarised incident has wider angle performance than the TE polarized incidence wave.

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