An Ultra-Broadband Metamaterial Absorber Design for Large Angle Oblique Incidence

Yan Deng, Nanjing University of Aeronautics and Astronautics

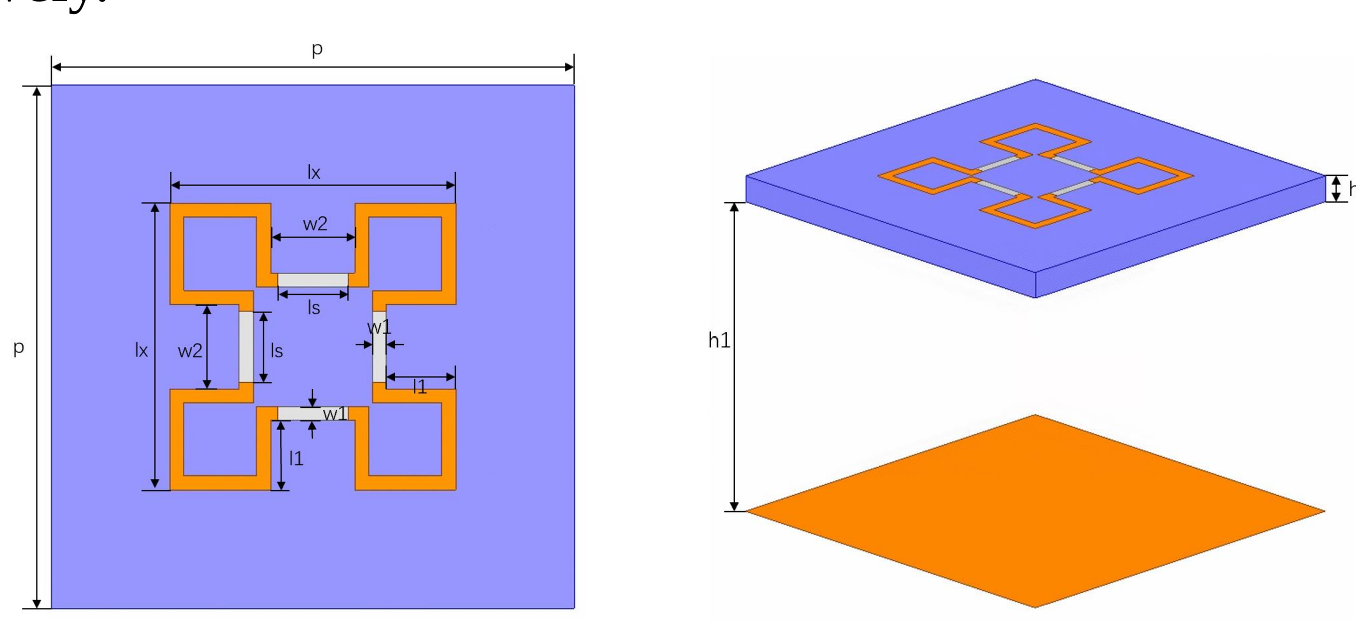
Yang Yang, Nanjing University of Aeronautics and Astronautics

Xiaoxiang He, Nanjing University of Aeronautics and Astronautics

Wenwu Zhang, Research Institute For SPECIAL Structures of Aeronautical Composites AVIC

ABSTRACT

In this letter, a metamaterial absorber (MA) with air cavity loaded with four lumped resistors is proposed and realized for ultra-broadband absorption of transverse electric (TE) polarization mode at large angle of oblique incidence. In order to realize the steady absorption at the large angle range from 50° to 70°, the optimal optimized angle is 62° through the impedance matching formula, and the parameters of the metamaterial absorber are optimized at this angle. The simulation results indicate that all absorption bands of TE mode over 90% in the angle of 50° to 70° are maintained above 9 to 15 GHz and the relative bandwidths are more than 60%, where the maximum and the minimum values are 69.07% and 61.65%, respectively.



(a) (b)

Figure 1. (a) The top view of proposed MA, where ls=1mm, l1=1mm, w1=0.2mm, w2=1.2mm, (b) the 3-D view of the proposed MA, where h=0.5mm, h1=6mm

MECHANISM ANALYSIS AND ABSORBER DESIGN

A. Oblique Incidence Mechanism Analysis

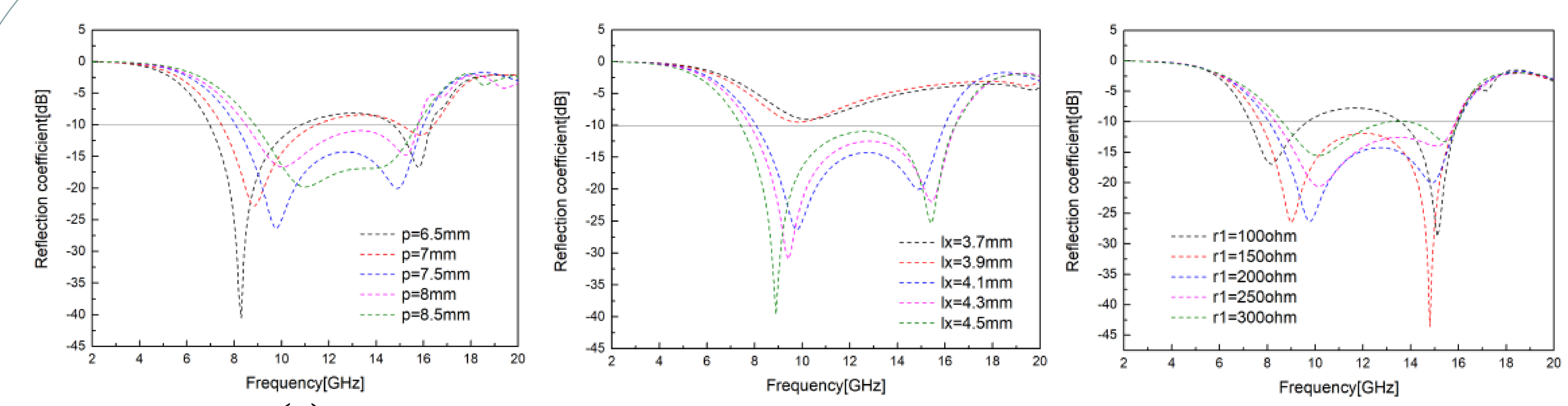
According to the vector transmission line theory, the wave impedance in free space under TE mode oblique incidence is expressed as $Z_0^{TE}(\theta) = 377/\cos\theta$, where θ represents the angle of oblique incidence of electromagnetic wave. When the TE mode is obliquely incident at 50° and 70°, its matching impedance is 586.5 ohms and 1102.3 ohms. By comprehensively analyzing the above two incident angles, it can obtain the free impedance of the optimal optimized angle as $Z_0^{TE}(\theta) = \sqrt{586.5 \times 1102.3} \approx 804$ ohms and put it into above equation to get the optimal optimization angle θ as $\cos^{-1}(377/804) \approx 62^\circ$.

B. Proposed Absorber Design

Figs. 1(a)-(b) exhibit the top view and the overall 3-D cross-section of the proposed metamaterial absorber. There is a square ring with four sides recessed inward and four lumped resistors of equal resistance are embedded in the recessed sides separately, which are symmetrical about the center of the square ring. The proposed absorber is etched on the 0.5 mm thick substrate of FR4 with a relative permittivity of 4.4 and loss tangent of 0.02. And the distance between the absorber and the metal ground h1 is 6 mm.

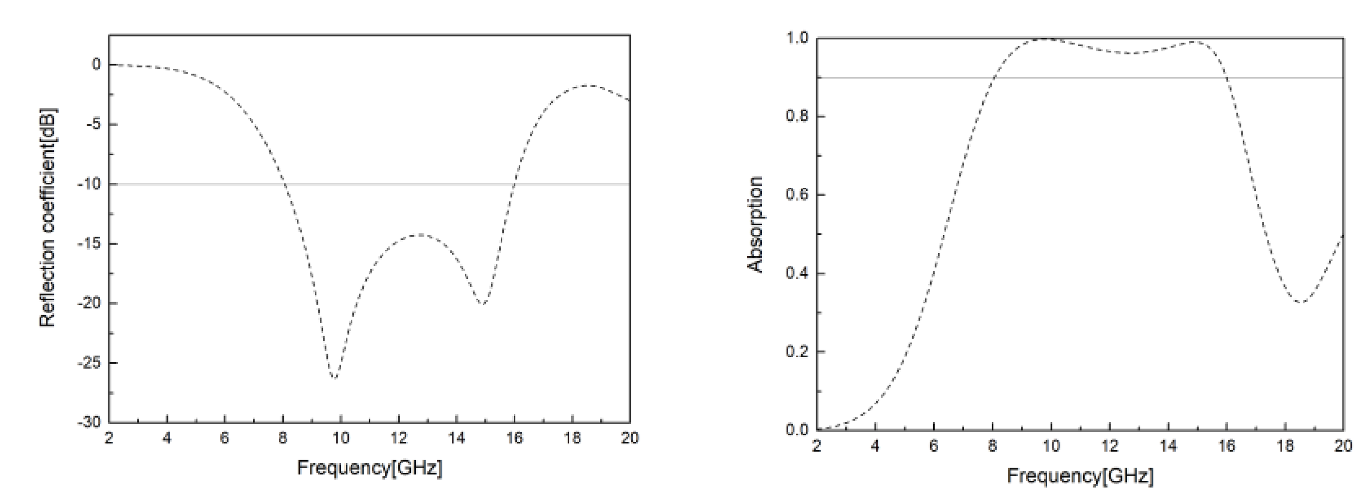
Figs. 2(a)-(c) show the optimization of different parameters when the TE mode wave is incident at an angle of 62°. Taking into account comprehensive factors, we finally select the period of the MA, the length of the square ring and the value of the lumped resistor to be 7.5mm, 4.1mm and 200 ohms, respectively.

Figs. 3(a)-(b) illustrate that in the case of the incident angle is 62°, the reflection coefficient of the proposed MA in the frequency range from 8.06 to 16.01GHz is less than -10dB and the absorption rate is around 100% at 10GHz and 15GHz .



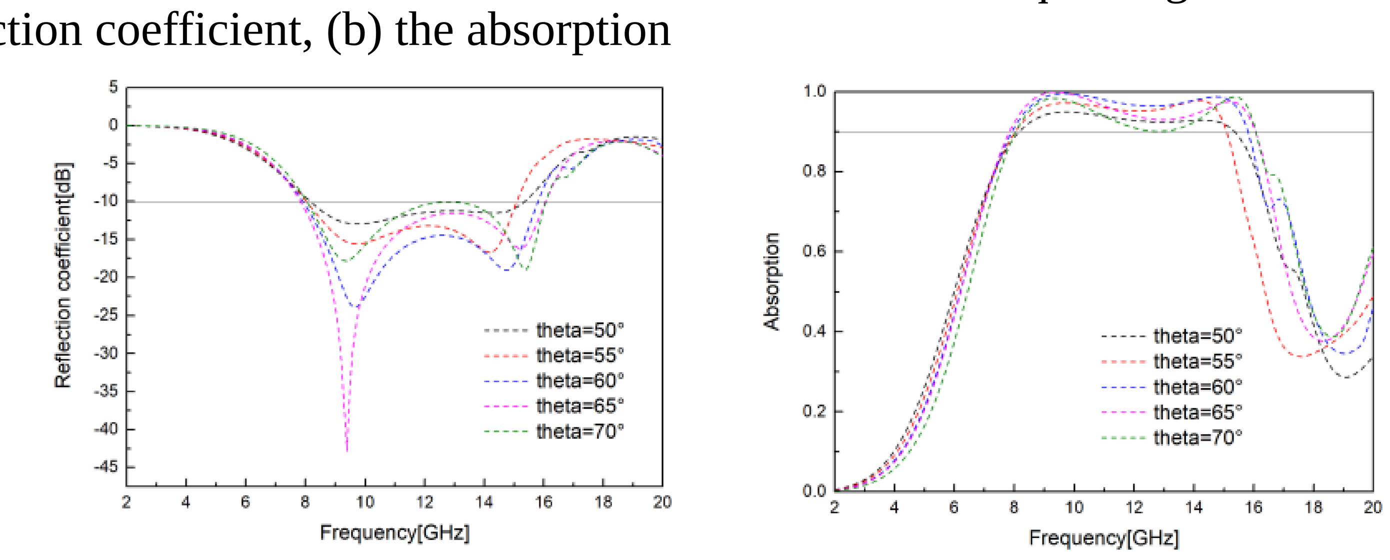
(a) (b) (c)

Figure 2. The optimizing simulation reflection coefficients for an oblique angle of 62° with different (a) (b) period, (c) (d) length of the square ring, (e) (f) resistance



(a) (b)

Figure 3. The final simulation of the MA for an oblique angle of 62° (a) the reflection coefficient, (b) the absorption



(a) (b)

Figure 4. The simulation results for large incident angles from 50° to 70° (a) the reflection coefficient, (b) the absorption

SIMULATION RESULTS

Figs. 4(a)-(b) depict that all the reflection coefficients from 50° to 70° are less than -10dB from 9 to 15GHz and the absorption bandwidths are greater than 90% in this frequency range. The relative absorbing bandwidths of the proposed absorber at different incident angles are specifically calculated in Table I.

TABLE I

The absorption bandwidth of the MA at different incident angles

Incidence angle	Lowest frequency (GHz)	Highest frequency (GHz)	Relative bandwidth
50°	8.11	15.42	62.13%
55°	7.99	15.11	61.65%
60°	7.9	15.82	66.78%
65°	7.82	16.07	69.07%
70°	8.02	16.08	66.89%

CONCLUSION

Based on optimizing the matching impedance of the optimal incident angle, an ultra-broadband stable metamaterial absorber is introduced at large angles of incidence from 50° to 70° .The simulation results indicate that the absorption bandwidth remains almost the same with increasing incidence angle and achieve bandwidths exceeding 90% from 9 to 15GHz. What's more, the proposed absorber is equivalent to a perfect absorber for the incident angle of 60° . Considering the above merits, the design of metamaterial absorber shows great potential application to realize ultra-broadband absorption for large angle oblique incidence.