DESIGN OF AN IMPROVED ABSORBING STRUCTURE USING JERUSALEM CROSS SLOT

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Abstract: A thin planar absorbing structure of Jerusalem cross slot (JCS) is designed, which has the virtue of wider bandwidth and broader adjustment range. The absorption frequency band can be flexibility adjusted by slot parameters. The influences of various structure parameters of JCS, incident wave polarization and variation of incident angles on the absorption characteristics are analyzed to provide guidance on the theoritical design for practical application. The validation and effectiveness of the proposed design was simulated using high frequency structure simulator (HFSS). The simulation result shows that zero point of reflection phase is at 9.7 GHz and the relative bandwidth is about 15.5%. The improved design is characterized by its wider bandwidth and adjustable by slot parameters. The influences of various structure parameters of JCS, including incident wave polarization and variation of incident angles on the absorption properties, are analyzed to provide guidance on the theoretical design for practical application. The loaded resistance can be adjusted to obtain the optimum absorbing performance.

Index Terms – Equivalent Circuit Model, Jerusalem Cross Slot (JCS), Parameter analysis, Return Loss, Group Delay.

I. INTRODUCTION

The simplest and most ancient absorbing material called Salisbury screen, which is to place a thin resistor in the quarter wavelength of the metal substrate, to put a low dielectric constant material as the partition in the middle, to form the simplest resonant absorbing sandwich structure [1]. How ever the imperfections of the screen are narrow band and high thickness, an isolation layer of $\lambda/4$ is required. Since, then some scholars put forward their own improving plans one after another, such that the frequency band is expanded by repalcing the traditional Salisbury screen with frequency selective surface (FSS) [2]. The resistance loss material layer an be directly attached to the surface of unipolar compact photonic band gap (UC-PBG) structure [3]. Artificial electromagnetic materials, such as frequency selective surface (FSS), photonic band gap (PBG) structure [4-5], and left handed materials [6] are broadly classified as metamaterials, which are typically created by using two or three dimensional periodic metallic and dielectric structures. They have attracted significant research interest in recent years due to their special electromagnetic properties, which are widely aaplicable to antennas and microwave devices . The absorbing frequency band is expanded by replacing the traditional Salisbury screen with FSS . It has been by Engheta that there is the possibility of existing thin absorbing screens using metamaterial surfaces. Kern and Werner in 2003 designed a new ultra thin absorber based on electromag c bandgap materilas by utilizing a genetic algorithm to otimize the pattern. Gao et al. , proposed aultra-thin RAM employing the mushroom like EBG structure . The absorbtion mechanism and polarization sensivity of ultra thin absorbers were discussed and analysed in this paper.

Based on a unipolar compact high impedance (UC-HIS) structure, this paper proposes an improved design of thin planar absorbing structure using Jerusalem cross slot (JCS). The in-phase reflection characteristics support that the resistance loss material layer can be directly attached to the surface of UC-HIS structure. By parameter analyses, the influences of the various structural parameters of JCS, the polarization and incident angles of the incident electromagnetic wave, and loaded resistors on the absorbing properties are studied in depth. The correctness of the design of novel absorbing material is effectively validated by high frequency strucure simulator (HFSS).

II. THEORETICAL ANALYSIS AND DESIGN

The major work of designing the absorbing material is to deal with two problems: how to maximize the incident electromagnetic wave into the material instead of reflecting off, how to absorb and attenuate the incident electromagnetic wave after which enter the material in the fasest way. The first question is essentially the surface matiching problem of absorbing material, another is the attenuation characteristic of the material. These two aspects are mutually conditioned. Generally speaking, the attenuation characteristics of the material is good that the imaginary part of dielectric constant of the material would be large. Thus the interface reflection will be enormous due to impedance mismatch.

It is known that 2D planar electromagnetic band gap (EBG) structures have high impedance surface characteristics. We use this kind of structuresto cof theonstruct high impedance surface, on which electrical loss materials are loaded, the surface of the whole material assumes in-sight impedance of the surface with pure resistance. By adjusting the resistance of electrical loss material, the surface impedance of the whole structure can approach the impedance of free space wave, therefore, the aim of greatly reduction in the reflection coefficient and the result of effective absorption can be achieved. The absorbing equivalent cicuit of the high impedance is shown in Fig. 1.

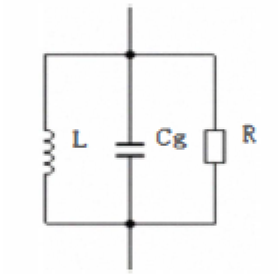

Fig. 1. The absorbing equivalent circuit of high impedance surface

It is the topology of EBG structures which form a parallel resonant circuit, where L is equivalent inductance, C_g is equivent capacitance and R is equivalent loss contains dielctric loss and resistance loss.
The reflection coefficient (Γ) of the structure is calculated using equation (1).

$$\Gamma = \frac{Z_{suf} - \eta_0}{Z_{suf} + \eta_0} \quad (1)$$

Where Z_{suf} is the equivalent surface impedance of the absorbing structure and η_0 is the free space wave impedance.

Design of Absorbing Structure with JCS

A new type of EBG-absorbing structure with Jerusalem cross slot (JCS) is shown in Fig. 2. The simulation model for infinite periodic unit is shown in Fig. 2 (b), around which master 1, master 2, slave 1, slave 2, boundary conditions and floquet ports for excitations are set. The dielectric substrate FR4 is set as metal ground plane having relative permittivity (ε_r) is 4.4 and thickness (h) is 1.5 mm respectively. The designed absorbing structure using JCS has unit period a= 5.08 mm, the side of of square metal w= 4.2 mm, slot width d=n=0.2 mm, slot length l =3.0 mm , m=1.2 mm, patch resistor R= 266 Ohm. After extraction of S-parameters i.e. reflection coefficient $\mathbf{S_{11}}$ and transmission coefficient $\mathbf{S_{21}}$ of the designed structure, the absorbvity (A) calculated using $\mathbf{1\text{-}S_{11}^2\text{-}\ S_{21}^2}$. HFSS full wave simulation is used to obtain the reflection coefficient (S_{11} plot). The magnitude and phase characteristics of reflection coefficient of a plane wave with normal incidence is shown in Fig. 5 and Fig. 6. The group delay at 9.7 GHz is shown in Fig. 7.

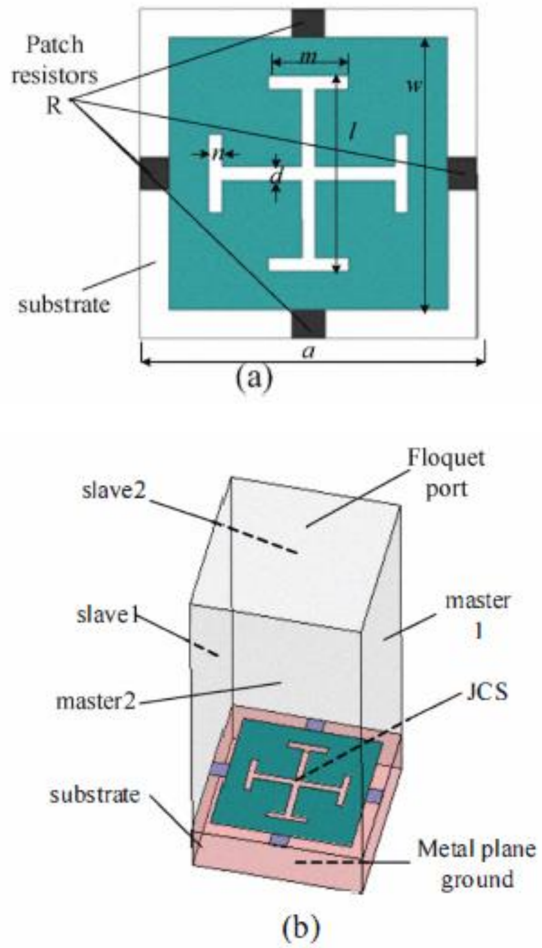

Fig. 2 (a) Element model of JCS (b) Simulation model of infinite periodic element of absorbing structure using JCS.

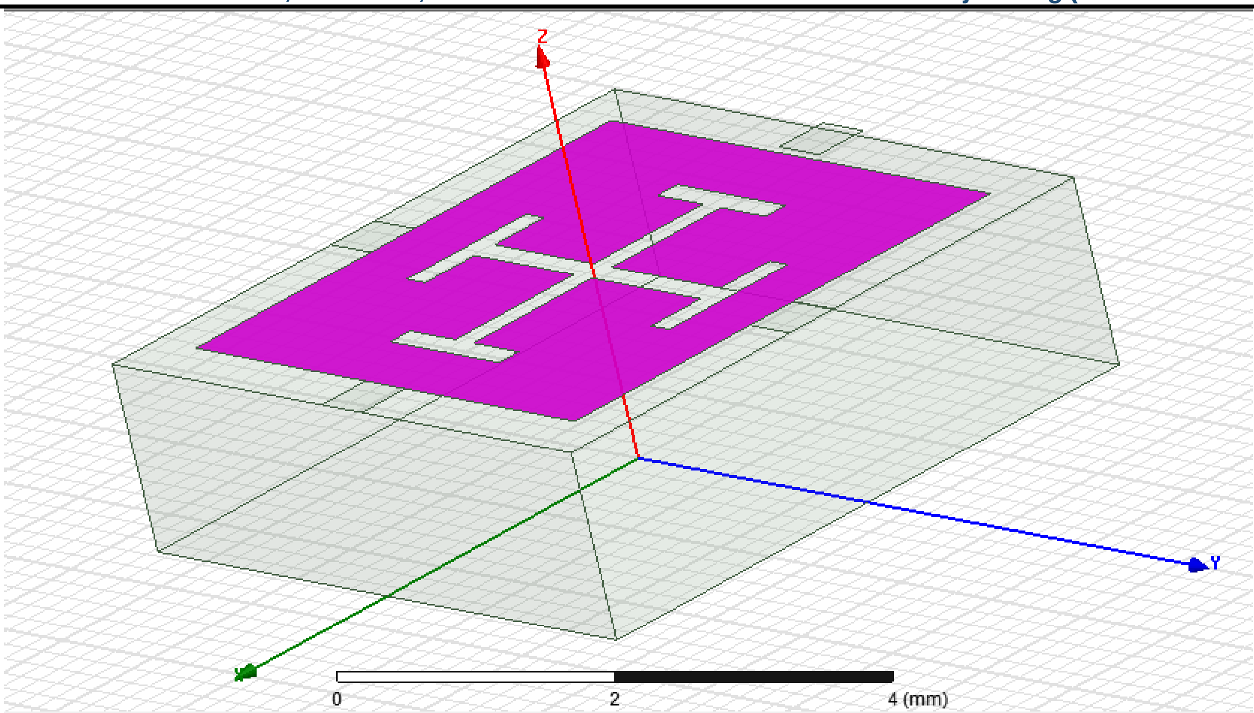

Fig. 2. An absorbing Structure using JCS using HFSS

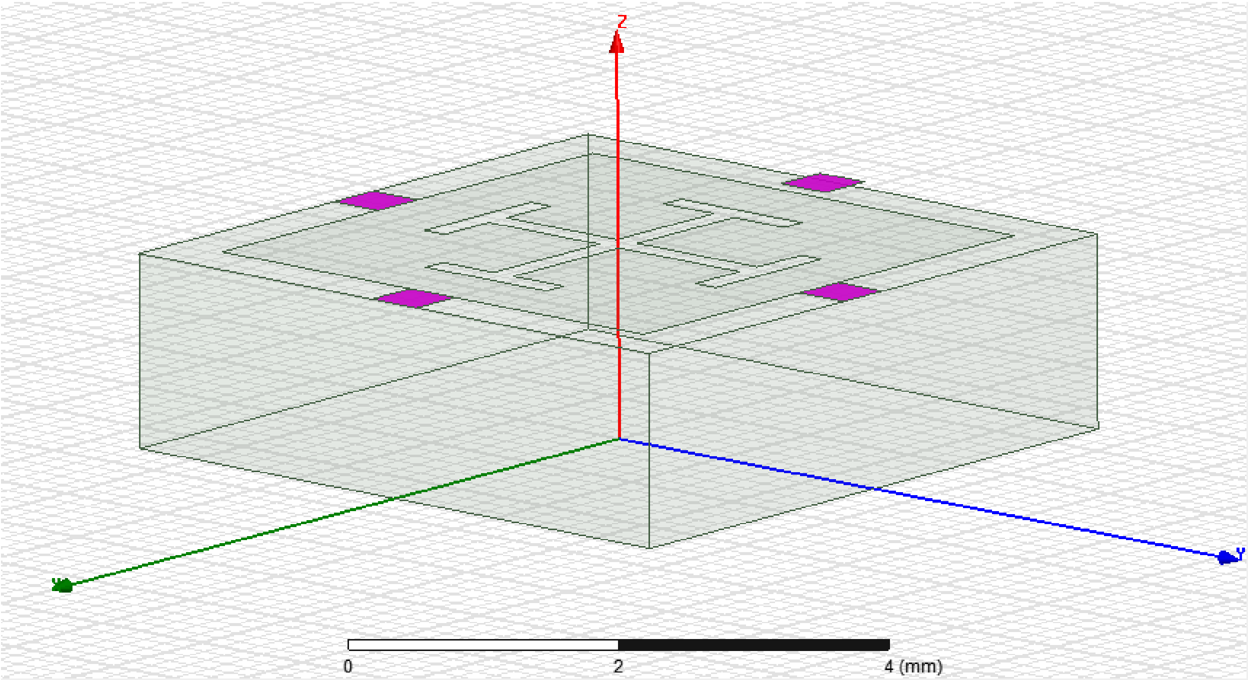

Fig. 3. Identification of patch resistors across the four sides using HFSS

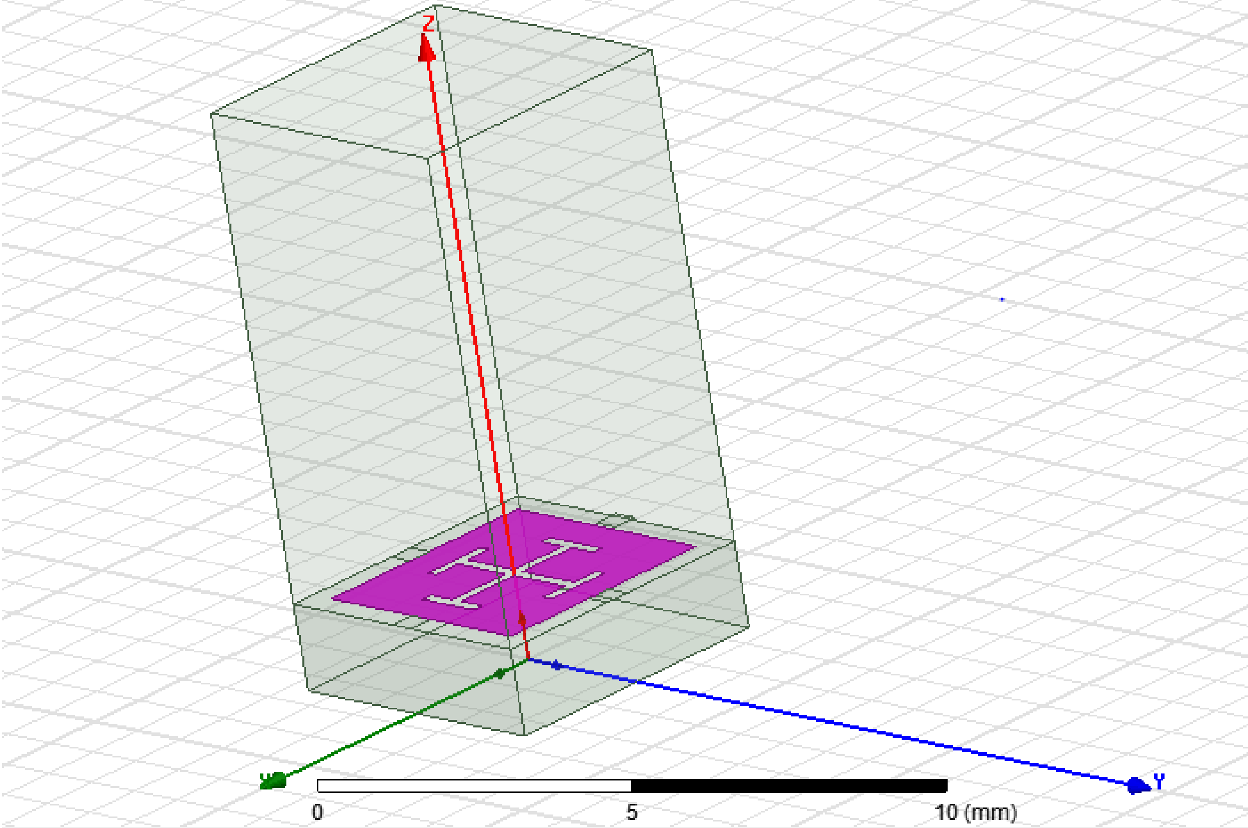

Fig. 4. Simulation model for infinite periodic unit using HFSS

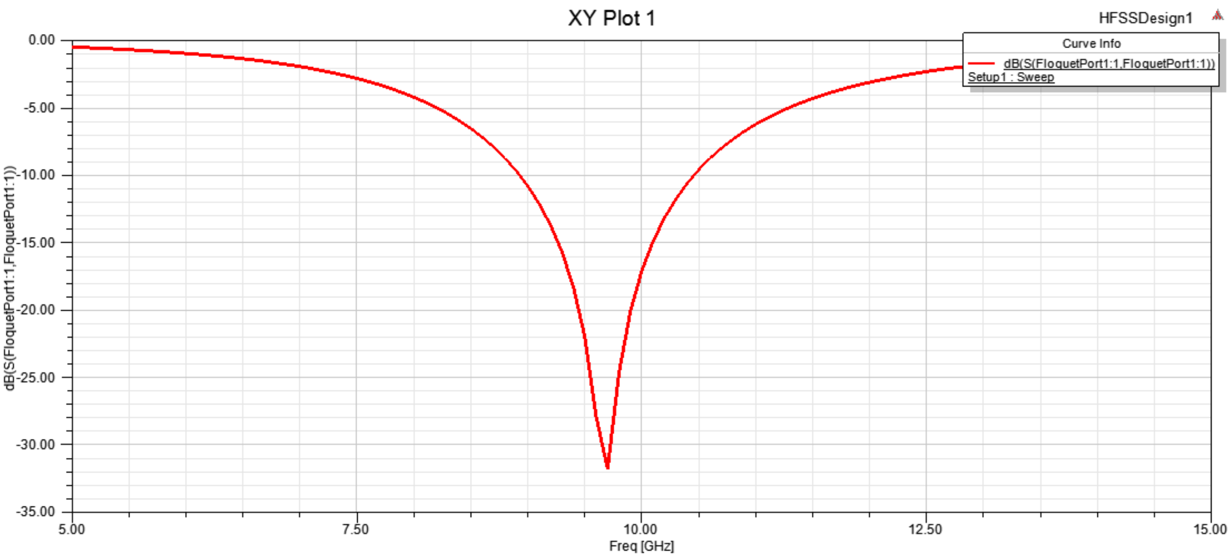

Fig. 5. S_{11} -Magnitude (dB) vs frequency

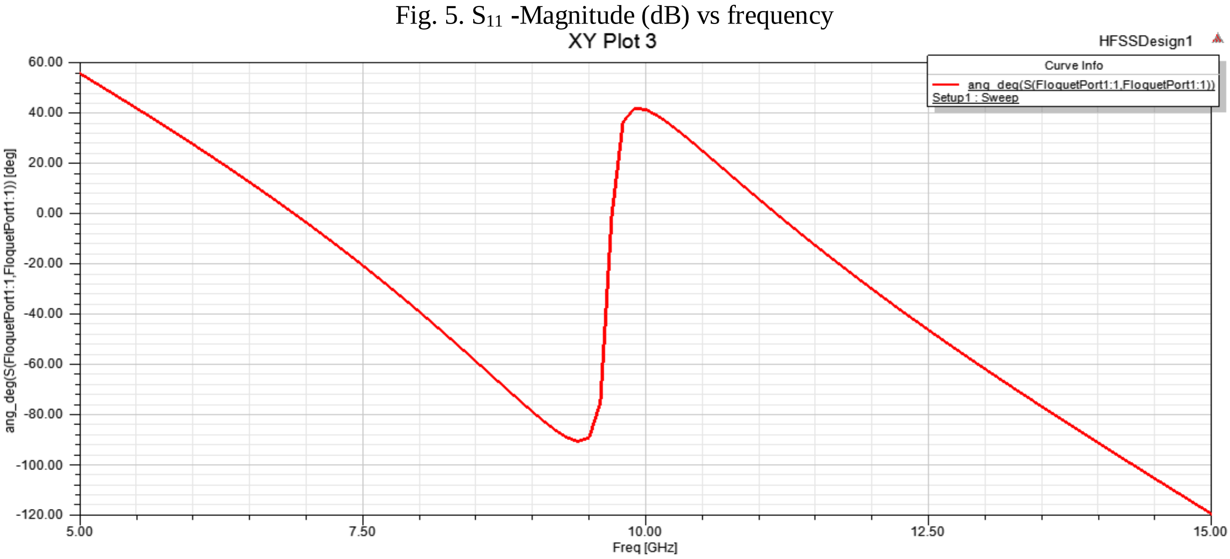

Fig. 6. S_{11}-Phase vs frequency

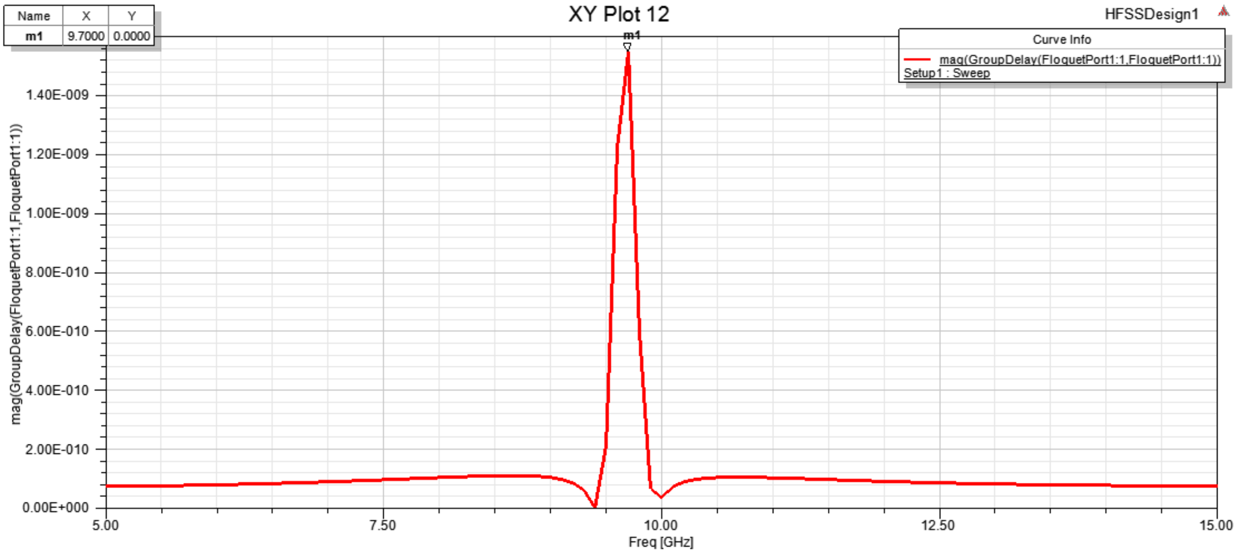

Fig. 7. Group delay vs frequency

It can be seen that the absorbing peak of the structure is in accordance with the reflection phase zero-point, which takes on the characteristics of a magnetic wall. After adding appropriate lumped loss resistors, the reflection coefficient reduces to -30 dB below at the central frequency, which shows that the better absorbing effect can be achieved and the absorption bandwidth depends on band gap of JCS structure. Zero point of reflection phase is approximately at 9.7 GHz and the relative bandwidth is about 15.5%. Compared with the structure using cross slot proposed by [1], the absorbing frequency band is wider and the unit size is smaller.

Parameters Analysis
We discussed the different values of JCS structure parameters, such as width of slot (d and n), length of slot (*l* and m), side of square metal cell (w) and loaded resistor (R).

a. Slot Length Effect

Slot length plays an important in determining the absorbing frequency band. To study the effect of the JCS length, other parameters are kept same as previous value. First, the slot length l is changed from 2.7 mm to 3.6 mm, the amplitude of reflection coefficient and equivalent surface impedance of absorbing structures with different slot length *l* are observed.
The results show that zero-point of reflection phase, the same as absorbing peak, shifts to lower frequency with increasing JCS length, frequency f_0 decreases from 9.7 to 9 GHz. When *l* is changing as 2.7, 3.0, 3.3, and 3.6 mm, the corresponding values of magnitude of S_{11} are -26, -34, -31, and -23.5 dB respectively. It is observed that the equivalent surface impedance Z_{suf} of JCS reduces as increasing JCS length *l* from 418 to 332 Ohm. When *l* =3.0 mm, Z_{suf} is much closer to η_0 that absorption effect is the best. Second, the length m of JCS is changing as 1.2, 1.4, 1.6, and 1.8 mm respectively. The reflection coefficient of absorbing structures varies with m, as shown in Fig. 8. It can be seen that the effect of m is the same as *l*, the resonant frequency will decrease from 9.7 to 9.0 GHz, when m increases from 1.2 to 1.8 mm.

b. Slot Width Effect
When the width d of JCS is set as 0.2, 0.4, 0.6, and 0.8 mm, respectively, the magnitude of S_{11} of absorbing structure are simulated. It can be seen that there is only a slight fluctuation, which means that the d of JCS has a little influence on the absorbing properties.

While the width of n of Jerusalem cross slot is set as 0.2, 0.4, 0.6, and 0.8 mm, respectively, the resonant frequency shifts to lower frequency from 9.7 GHz to 9.0 GHz.

c. Square Metal Cell Effect
The side of square metal cell w is an important parameter to determine the absorbing frequency range. When other parameters are kept same as previous value, the cell size changing from 3.8 to 4.4 mm, which is restricted by the period of JCS. The reflection coefficient of JCS absorbing structures with different w are shown in Fig. 10. The results show that the zero point of reflection phase corresponding to absorbing peak will shift to lower frequency with increase of square metal cell size w, i.e. from 10.8 to 8.9 GHz. The relative bandwidth has a decrease from 15.7% to 14.3%.

d. Loaded Resistance Effect
The loaded resistance R should be adjusted to get the optimum absorbing property. When R=0 Ohm which is a short circuit and equivalent to a small metal film connected each unit. The real part of surface equivalent impedance of JCS structure is zero, and the imaginary parts to infinity, which appears a total reflection. When R=5000 Ohm, as in an open circuit and equivalent to coupling capacitive connection between the various units. When the structure is resonant, the surface impedance is a large real resistance and appears hardly total reflection. Thus, even if the large loss resistor is loaded, the effective absorption characteristics would not be achieved, due to mismatching. But the reflection phase characteristics also appear in-phase reflection property in two situations, which are equivalent magnetic conductor characteristics of UC-EBG structure. When *R* is set as 226, 246, 266, and 286 Ohm, respectively, the absorbing

properties are all excellent. When R is selected as 266 Ohm, Z_{suf} is much closer to η_0 that the maximum absorbing ratio can be obtained.

III. ANALYSIS OF OBLIQUE INCIDENT PLANE WAVE

This paper takes into account the influence of various plane wave polarization and angles of incidence on absorbing characteristics of JCS. The structure parameters are selected as previous value. First TE polarized plane wave is oblique incident on the JCS structure. Angles of incident are set as 30^0, 45^0, and 60^0 respectively. The reflection coefficient of the JCS of TM polarized plane wave incident was observed. Similarly, the results of TM polarized plane wave incidence were analyzed for comparison and compared with normal incidence (theta=0 deg), the absorbing peak shifts to high frequency for both TE and TM polarization with increasing angles of oblique incident theta. The resonant frequency of TE polarized incidence increases from 9.7 t0 10 GHz, but increases from 9.7 to 10.2 GHz for TM polarized incidence. The absorbing property of TE polarization is in accordance with that of TM polarization. However, when the incident angle is larger than $45^{0,}$ the JCS absorbing structure cannot work well.

IV. CONCLUSIONS

A detailed analysis and design of absorbing structure with Jerusalem cross slot based on UC-EBG structure was proposed. The influence of structure parameters of JCS on absorbing characteristics is studied deeply. It is found that the increasing width of Jerusalem cross slot causes the shift of zero-point of reflection phase to high frequency, and that the increasing slot length results in the shift of zero point of reflection phase to low frequency. The absorbing frequency band is determined by the resonant frequency of JCS structure. The loaded resistor can be directly attached to the surface of JCS which is significantly used to adjust the matching and absorption ration. Adjustable parameters of the JCS absorbing structure are more than that of structure with cross slot, as well as the wider bandwidth and good absorbing effect.

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