Research on asymmetric “Jerusalem” unit

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Received September 22, 2008

An asymmetric Jerusalem unit and the frequency selective surface (FSS) structure composed of such units are designed. The transmittance of the designed FSS structure is calculated by mode-matching method and compared with the test results. The comparison results show that the FSS center frequency of the asymmetric structure unit drifts little with the variation of the incident angles of the electromagnetic waves and keeps relatively stable. The research offers a new choice for the application of FSS under the large scanning angle of electromagnetic waves.

OCIS codes: 160.0160, 260.2110, 310.0310.

doi: 10.3788/COL20090705.0419.

Frequency selective surface (FSS) is a periodic structure arranged in two-dimensional (2D) order by certain units[1]. Being able to filter out incident electromagnetic waves, its application has been extended from microwave band to terahertz region, and even to optical band[2,3]. The transmission characteristics of FSS are described by the parameters such as center frequency and bandwidth etc., which are functions of unit form, geometric size and layout[4,5], and the incident angle of electromagnetic waves[6−9]. In practical applications, the center frequency of FSS is required to be relatively stable, especially when FSS is applied to a hyperboloid radome. At this time, the incident angle of the electromagnetic wave varies within a very large range. Under such circumstance, the way to maintain the stability of the center frequency is the decisive factor on the engineering application of FSS. Based on the unit constructive form of FSS, we design an asymmetric “Jerusalem” unit and a FSS structure. By simulation calculations and experimental researches, it is found that the center frequency of this structure basically will not change with the variation of the incident angle.

The familiar FSS units diversify in characteristics as well as in forms, such as circular ring, partition ring, Y-aperture, and Jerusalem unit, etc.. But with no medium matching, the center frequency of these FSS units drifts drastically with the variation of the incident angles of electromagnetic waves, no matter what the from of the unit is.

Jerusalem unit is developed from cross-element. According to the transmission-line theory, the equivalent capacity of adjacent units has been improved when a “wishbone” ($a + c$ and $a + d$ in Fig. 1) is added to the cross-element, which decreases the sensitivity of inductor-capacitor (LC) equivalent circuit to the incident angles of electromagnetic waves. Even though the equivalent capacity relates to the added arm-length, the Jerusalem units studied in the given literatures, being central rotatable symmetric and improved in the stability of central frequency compared with cross-elements, still cannot be applied to engineering.

An asymmetric Jerusalem unit and a FSS structure are designed to improve the stability of central frequency, as shown in Fig. 1. For the Jerusalem unit, the cycle of the square array $T = 7.2$ mm, the geometric sizes $a = 3.825$ mm, $b = 2.25$ mm, $c = 1.575$ mm, $d = 1.125$ mm, $w = 0.45$ mm. For the FSS structure, the dielectric substrate thickness $h = 10$ mm and the dielectric constant is 2.2. The tangent of loss angle is of the order of magnitude of 10^{-3}.

The mode matching method expands the free space vector field beyond the planar periodic array, the medium intra-regional field in the form of Floquet space-harmonics, and the field of FSS unit in the form of waveguide mode. Meanwhile, it can realize the matching of fields by imposing the boundary conditions of electromagnetic field on either medium-FSS boundary or FSS-space boundary. Matrix equation is obtained by solving the integral equation describing the FSS frequency response. Furthermore, the transmission and reflection coefficients[2] of FSS structure have been obtained, from which the unit’s field can be obtained by finite element method[10].

By the mode matching method, the transmittance of FSS structure is simulated, for which the incident electromagnetic wave is a TE polarization wave and the incident angles are 0°, 45°, and 60°, respectively. The simulation results are shown in Fig. 2. The center frequencies are 10.3 GHz for the incident angles of 0° and 45°, and 10.35 GHz for the incident angle

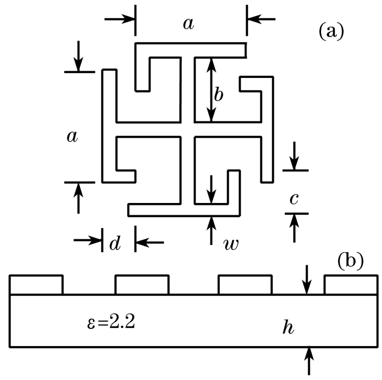

Fig. 1. (a) Asymmetric “Jerusalem” unit, (b) side schematic diagram of FSS.

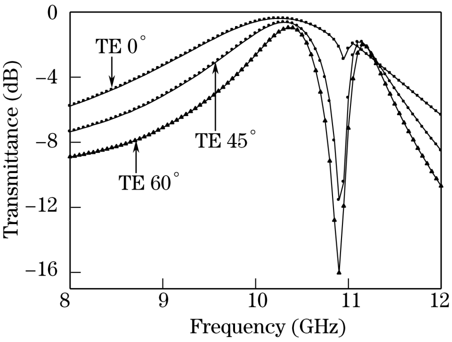

Fig. 2. Transmittance calculation results of FSS composed of asymmetric Jerusalem units.

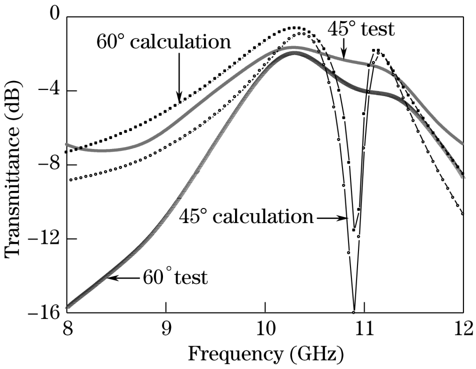

Fig. 4. Comparison of test results and calculation results.

of 60°, which shows a relative stability because the center frequency of this asymmetric Jerusalem unit FSS drifts little with the variation of incident angle.

To verify the design results, copper films were fabricated on a 500×500 (mm) dielectric plate by vacuum deposition technology. Meanwhile, the photolithography technology was used in etching FSS figures. Then the transmittances of TE polarization at 0°, 45°, and 60° were tested in a microwave anechoic chamber. The results are shown in Fig. 3 and the comparison between theoretical calculation and test results is shown in Fig. 4. The center frequencies are 10.2, 10.3, and 10.3 GHz when the incident angles are 0°, 45°, and 60°, respectively. It is clear that the test results basically match the theoretical calculation results, that is, the center frequency does not change with the variation of incident angle of the electromagnetic waves. But Fig. 5 shows that the transmittance value at the center frequency is relatively low compared with the calculation value. In simulation curves, Wood's anomaly occurs at 10.9 GHz. But it is not reflected clearly in the test curve. The non-half-wave wall thickness of substrate material leads to the increase of reflection on the interface, which results in the relatively low transmittance. In the processing of FSS graphics, both the periods between units and unit sizes have machining tolerances. With the substrate being non-half-wave wall thickness and the machining tolerance being 0.3 mm, the deviation of voltage phase between adjacent units is an integral multiple of 2π, which cannot satisfy Wood's singular condition. Therefore, in the simulation curves, no deep null takes place.

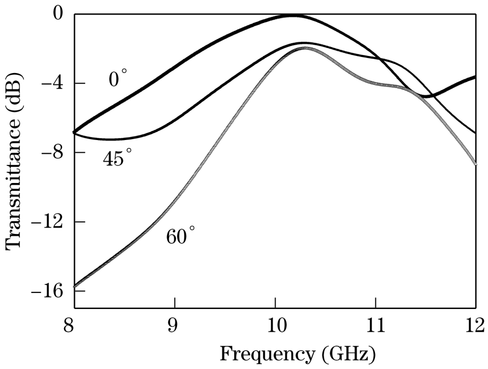

Fig. 3. Transmittance test results of FSS composed of asymmetric Jerusalem units.

For the "Jerusalem" units evolving from cross-elements, most of the designs are about central rotatable symmetry, which is quite different from our design on non-central rotatable symmetry of "Jerusalem" unit. Based on the simulation and test results, we can draw the conclusion that the structure under this proportion can keep the center frequency relatively stable, meanwhile it offers a new choice for the application of FSS under large scanning angle of electromagnetic waves.

This work was supported by the National Natural Science Foundation of China under Grant No. 10647105.

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