A NOVEL HYBRID-ELEMENT FSS FOR RADOME APPLICATIONS

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Abstract—A novel hybrid-element based Frequency selective surface (FSS) structure is presented in this paper for radome applications, which consists of a Jerusalem cross configured within a square loop element. The EM performance analysis of proposed FSS structure is carried out based on equivalent circuit model approach. In order to show the efficacy of the approach, the computed result is validated with that of full wave analysis method. Excellent agreement is obtained between the computed and reported results. The proposed FSS structure exhibits bandpass characteristics characteristic centered at 14.3 GHz associated with two reflection bands centered at 6.98 GHz and 20.74 GHz. In view of streamline radome applications, the EM performance characteristics are studied at oblique angle of incidence for TE and TM polarizations.

Index Terms—Frequency Selective Surfaces, FSS, JC-FSS, Square Loop FSS, Hybrid Element FSS, Equivalent Circuit Model.

I. INTRODUCTION

The frequency selective surfaces (FSS) are periodic structures in either one or two dimensions (i.e. singly or doubly periodic structures), which perform a filter characteristics for an electromagnetic wave impinging on it. Based on their physical geometry and EM characteristics, FSS structures can be divided into four categories namely low-pass, high-pass, band-pass, and band-stop filters [1]. For last four decades, FSS structures have had significant applications in the design of high performance radomes, RAS, reflectors, and antennas. In view of this, various types of FSS structures were reported in open literature [2-3]. Initially, single unit cell based FSS structures (e.g. square loop, Jerusalem cross, cross dipole, etc.) were designed, which exhibit either reflection or transmission type characteristics [4-5]. Further, hybrid unit cell based FSS structures were presented to achieve bandpass/band stop response with significant bandwidth [1], [6].

In this paper, a novel hybrid-element based FSS structure is proposed for airborne radome applications, whose unit cell consists of a Jerusalem cross (JC) configured within a square loop element. Here both square loop and JC FSS exhibits reflection type characteristic and coupled together to form a transmission band associated with two reflection bands. Thus the proposed hybrid-element FSS shows bandpass characteristic, which is very similar to that of the double-square loop (DSL) FSS. Moreover, the proposed hybrid-element FSS allows the designer to employ more tuning of its EM characteristics due to the presence of Jerusalem cross element. Thus the maximization of bandpass transmissivity and choice of bandstop frequency can be achieved simultaneously. The EM analysis of proposed FSS structure is carried out based on equivalent circuit model (ECM) at oblique angle of incidence for TE and TM polarizations. The details of the work are discussed in the subsequent sections.

II. THEORETICAL CONSIDERATIONS

In this work, the analysis of hybrid-element FSS is carried out using equivalent circuit model. For simulation, dielectric backed configuration is considered. The geometry of hybrid-element FSS for dielectric backed case is shown in Fig. 1(a) and (b). Here a JC element is configured within a square loop element forming a hybrid-element FSS structure. According to the equivalent circuit model, the proposed hybrid-element FSS structure can be represented as parallel combination of two series LC resonant circuits as shown in Fig. 2, where \( L_1 \) and \( C_1 \) are the inductance and capacitance, respectively offered by the square-loop element. \( L_2 \) and \( C_2 \) represent the inductance and capacitance, respectively offered by the Jerusalem cross element.

![Fig. 1 Hybrid-element FSS; (a) Schematic, and (b) Hybrid-element array.](image-url)
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The numerical value of $L_1$, $C_1$, $L_2$, and $C_2$ can be determined by the expressions [7], given below,

$$X_1 = \omega L_1 = F(p,2w_1,\lambda)d_1/p$$

$$X_2 = \omega C_2 = F(p,w_2,\lambda)l/p$$

where, $X_1$ and $X_2$ are the inductive reactance of square-loop and Jerusalem cross, respectively. $p$ is the periodicity of hybrid-element unit cell. $w_1$ and $w_2$ are the width of inductive grids of square-loop and JC, respectively, where the reactance is reduced by a factor of $d_1/p$ and $l/p$, respectively owing to the conductor not being continuous [8]. $F$ is the function of periodicity, width, and wavelength, which is defined for TE and TM polarizations in [9].

Further, the capacitive susceptance of square loop and Jerusalem cross can be determined by (3) and (4), respectively as

$$B_1 = \omega C_1 = 0.75 \times B_{g1} \times (d_1/p)$$

$$B_2 = \omega C_2 = (B_{g1} \times B_{g3})/(B_{g1} + B_{g3})$$

where, $B_{g1}$ is given as

$$B_{g1} = 4.0 \times \varepsilon_{\text{eff}} \times F_1(p,g_1,\lambda)$$

and,

$$B_{g3} = B_{g2} + B_g$$

$$B_{g2} = 4.0 \times \varepsilon_{\text{eff}} \times F_1(p,g_2,\lambda)(w_1/p)$$

$$B_g = 4.0 \times \varepsilon_{\text{eff}} \times F_1(p,g_3,\lambda)(w_3/p)$$

where, $B_{g2}$ is the susceptance offered due to the gap $g_2$, between Jerusalem cross and square loop and $B_g$ is susceptance due to the gap $g_3$, between vertical end cap of JC-FSS and square loop FSS as shown in the Fig. 1(b). The function $F_1(p,g,\lambda)$ corresponding to the capacitive susceptance and the effective dielectric constant, $\varepsilon_{\text{eff}}$ is given by [10]

$$\varepsilon_{\text{eff}} = \varepsilon_{r-1} + (\varepsilon_{r-1})^{-1} \left[\frac{1}{N} \exp(N(x))\right]$$

where $\varepsilon_{r-h} = \varepsilon_r + 1/2$, and $x = 10h/p$ (10)

The equation (12) can be used to estimate the transmission and reflection characteristics of proposed FSS structure.

III. EM DESIGN CONSIDERATIONS OF HYBRID-ELEMENT FSS

In this work, the hybrid-element FSS structure is designed at centre frequency, 14 GHz using equivalent circuit model. The design parameters of proposed FSS structure are determined based on equivalent circuit model. Since Jerusalem cross element is configured within the square loop, the square loop resonates at lower frequency and JC resonates at higher frequency. Thus with the combined effect, a bandpass characteristic is achieved over the desired frequency range. The optimized design parameters of hybrid-FSS structure are given in Table I.

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<th>Table I: Designed parameters of hybrid-element FSS</th>
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<tr>
<td>Design parameters</td>
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<tr>
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<td>Width of horizontal arm of JC-FSS, $w_2$</td>
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<td>Length of the square-loop, $d_1$</td>
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<td>Length of horizontal arm of JC-FSS, $L$</td>
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<td>Length of vertical arm of JC-FSS, $W$</td>
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IV. EM PERFORMANCE ANALYSIS OF HYBRID-ELEMENT FSS

In this section, the EM analysis of dielectric backed hybrid-element FSS is carried out for TE and TM polarizations. The height of the dielectric substrate is taken to be 1.5 mm. The transmission characteristic of proposed FSS structure is studied at normal incidence using equivalent circuit approach. This exhibits a bandpass characteristic with centre frequency, 14.3 GHz associated with two reflection bands centered at
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6.98 GHz and 20.74 GHz (Fig. 3). To show the efficacy of the approach, the computed result is validated with the result, which is obtained based on full-wave method. A good agreement is observed between equivalent circuit approach and full-wave method as shown in the Fig. 3. However, the centre frequency of passband characteristics in ECM is shifted to 14.3 GHz instead of 14 GHz and the resonance frequency of lower reflection band is shifted to 7.0 GHz instead of 7.4 GHz. These variations may be due to the considerations of approximate lumped parameters in equivalent circuit model.

In view of streamline radome applications, the transmission and reflection characteristics of proposed FSS structure are studied at oblique angle of incidence for TE and TM polarizations. Fig. 4(a) and (b) show transmission and reflection characteristics, respectively for TE mode of polarization at different angle of incidence (0°, 30°, 45°, and 60°). Fig. 5(a) and (b) show the frequency responses of dielectric backed hybrid-element FSS for TM mode of polarization at different incident angles (0°, 30°, 45°, and 60°). It is observed that the resonance frequencies of hybrid-element FSS structure do not vary w.r.t. the angle of incidence and polarizations.

In order to show the tuning capability of proposed FSS structure, the effect of designed parameters of Jerusalem cross on transmission characteristic is studied by varying the length of the horizontal inductive grid, \( L \) and width of vertical inductive grid, \( w_3 \) of JC-element. It is observed that the second reflection resonance corresponding to JC-element...
shifts towards the lower frequency side as the length of the inductive grid increases (Fig. 6), while the first reflection resonance is observed to be stable. Hence the transmission bandwidth of proposed FSS structure decreases with the increase in horizontal inductive grid of JC-element. The similar phenomena are also observed by increasing the width of the vertical inductive grid, \( w_3 \) of JC-element as shown in Fig. 7. Thus the bandwidth of transmission characteristic of proposed FSS structure can be tuned by varying the dimensions of JC-element such as \( L \) and \( w_3 \). This is the advantage of proposed hybrid-element FSS over double square loop FSS.

**CONCLUSION**

The EM analysis of a novel hybrid-element FSS structure has been carried out in this paper using equivalent circuit model. To show the efficacy of the proposed approach, the computed result is validated against to full-wave analysis method for dielectric backed case. A good agreement is achieved between proposed approach and full-wave method. The proposed FSS structure exhibited a bandpass characteristic coupled with the two band-stop characteristics. It showed more than 90% transmission over the frequency range 13.8 GHz to 14.9 GHz at oblique incidence for TE and TM polarizations, which confirms usability of proposed FSS structure for streamline radome applications. Moreover, the choice of JC-element would allow the designer to tune its EM characteristics over the desired frequency range.

**REFERENCES**


