A Novel Frequency-Selective Surface Generating Two-band Pseudo-Elliptic Frequency Response

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***Abstract*—A novel frequency-selective surface (FSS) is introduced in this paper. The structure proposed is a single-sided printed circuit board (PCB) that generates a pseudo-elliptic type response with two closely spaced passbands. Such a multi-band operating regime is realized owing to additional higher modes excited in the meander-like apertures and involved in electromagnetic interaction. Passbands at the response are independently tuned by adjusting the geometrical parameters of the aperture. Numerical and measured data for X-band FSS are presented for different angles of incidence. Due to the high selectivity, a small frequency ratio of 1.27 for central frequencies of passbands of 4.2% and 5.5% bandwidths is achieved for a normal incidence of linearly polarized wave.**

***Index Terms*—frequency selective surfaces (FSSs), two-band, transmission zeros, resonant coupling.**

I. Introduction

Spatial filters of both reflecting and transmitting or even mixed types are in a great demand in modern communication systems of different civil and military applications [1-4].

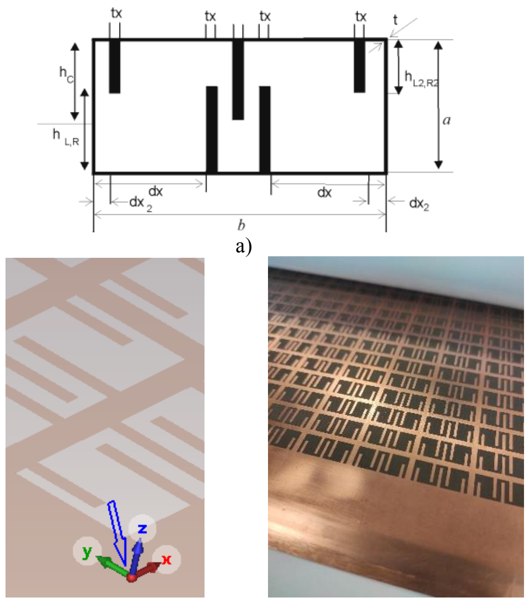
To meet requirements of design compactness, enhanced selectivity of the responses or ability to provide a multi-band performance, a variety of designs were proposed for different frequency ranges, e.g. [5-12].

Varying of the periodicity of unit cells, using of multi-element unit cells and exploring of multi-resonant geometry of the patches or apertures are the ways to make designs more compact. Some designs presented recently use this approach to generate additional resonances to provide a multiband operation. Some of them enable additional transmission zeros (TZs) at the response as well. As a result, a very sharp transmission and very close passband and/or stopband are achieved.

In this paper, we propose a novel single-layer FSS that provides transmission of linearly polarized incident waves at two close passbands. The pseudo-elliptic character of both the bands is a result of the excitation of two higher modes of meander-like apertures. Being involved into electromagnetic interactions independently, two higher modes enable a resonant coupling each and they participate in TZs generation. Note, that such a result is achieved within a single-element configuration whereas usually it is realized within a multi-element unit cell.

II. FSS Design and Discussion

The configuration of the designed FSS is shown in Fig. 1. It consists of a single-sided printed circuit board (PCB). The metallic layer of the FSS contains a set of periodically arranged meander-like apertures. Schematic geometry of the screen elementary cell is shown in Fig. 1a. A rectangular unit cell of $L_x \times L_y$ dimensions contains one centred rectangular aperture of the width a and the height b with five rectangular inserts installed alternately in its broad walls. Three closely spaced inserts of rectangular shape have equal heights ($h_C = h_{L,R}$) and they are located in the centre of the aperture cross-section. One insert is centred whereas two others are installed at the distance dx away from the narrow wall of the aperture. One more pair of lateral inserts of the same rectangular shape of different heights $h_{L2,R2}$ are located at the distance dx_2 away from narrow walls. All five inserts have equal widths tx.



a) b) c)

Fig. 1. Schematic of proposed FSS and problem and fabricated prototype (partially)

The screen is excited by the linearly polarized TM wave with the electric field vector oriented along y-axis with azimuthal angle $\phi = 90°$(Fig. 1b).

To examine the screen proposed, a full-wave simulation of its response was carried out by means of CST MWS software.

The single-sided PCB consist of a dielectric layer Taconic TLY-5 of t_s= 1.52 mm thick with dielectric constant ε=2.2 and tan δ = 0.0009 laminated by a copper layer of thickness t=0.035 mm. The unit cell is characterized by the following geometry: cell dimensions $L_x \times L_y$ = 20.0 mm × 10.0 mm; aperture dimensions $a \times b$ =18.0 mm × 10.0 mm; tx=1.0 mm, $h_C = h_{L,R}$ = 7.0 mm, dx = 6.0 mm, $h_{L2,\ R2}$ =5 mm, dx_2 = 1.0 mm.

Such a screen provides a multi-band response with several transmission zeros (TZs) and transmission poles (TPs). Depending on the design specification the response can be tailored as a multi-stopband or/and a multi-passband one. The structure under consideration was optimized for a double-band transmission.

The calculated transmission response of the screen for the case of normal incidence is plotted in Fig. 2. Here, normal incidence is the case of zeroth angle between z-axis and the electric field vector of a linearly polarized wave that is incident in ZoY plane, i.e. azimuthal angle $\phi = 90°$ (see Fig.1b).

As it can be seen from the figure, the response contains two closely spaced passbands of pseudo-elliptic type. Both transmission resonances TP_1 and TP_2 are located alternating between three TZs TZ_1, TZ_2 and TZ_3 equally spaced with respect to the resonances.

To validate the proposed design, a prototype containing 14×28 unit cells was fabricated (see Fig. 1c). The prototype was established between a pair of horn antennas separated by 1.5 meters from FSS sides and measured in a free space environment. Transmission characteristics was measured by using a network analyzer and normalized with the data obtained without FSS. The measured response of fabricated FSS is plotted in Fig. 2 as well. A good agreement between the measured and simulated data is observed. Measured resonances are centered at $f(TP_1)$ = 9.16 GHz and $f(TP_2)$ = 11.28 GHz with an insertion loss of 1.7 dB and 0.7 dB, respectively. Fractional bandwidths measured by 3dB level are 4.2% and 5.5% for lower and upper bands, respectively. Effective isolation of the channels is provided by the second TZ (TZ_2) that achieves 20 dB attenuation level within 4% stopband. All three TZs located at $f(TZ_1)$ = 7.55 GHz, $f(TZ_2)$ = 10.09 GHz and $f(TP_1)$ = 13.07 GHz enable not only high out-of-band suppression but make all the skirts of the passbands sharp as well.

Both transmission resonances are achieved here owing to two different higher-order modes of the cell apertures that provide resonant couplings between the input and output. Transversal electric field distributions in the FSS cross-section were examined with the aim of identifying these modes. It was revealed that the distribution at the first resonance was very close to the distribution of the third mode of the cell aperture whereas the distribution at the second resonance was very close to one of the fourth mode.

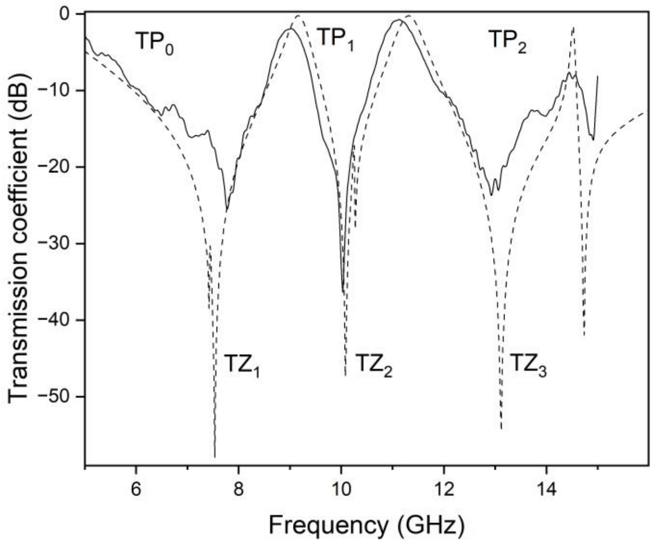


Fig. 2. Simulated and measured transmission coefficient of proposed FSS under the normal incidence

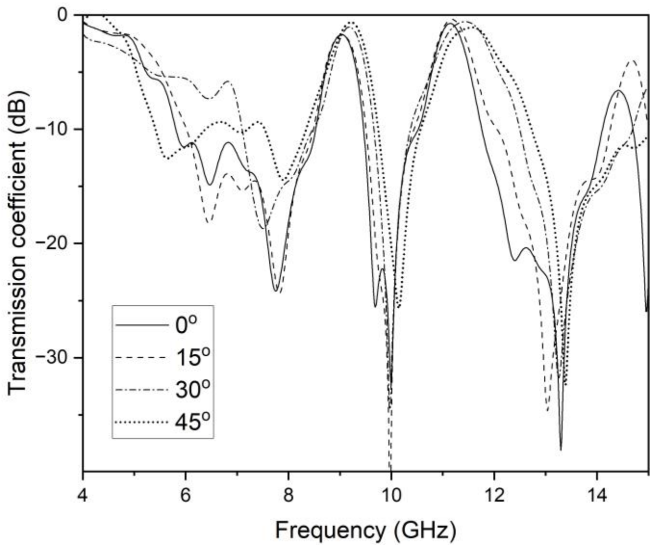


Fig. 3. Transmission characteristics for various values of incident angle ϴ=0°, 10°, 30°, 45°, azimuthal angle $\phi = 90°$

The most attractive feature of the FSS proposed is the possibility of tuning frequencies of TZs independently. The resonant frequency of lower frequency resonance TP_1 is controlled mainly by a group of three ‘internal’ equal height inserts by changing their height and the distance between them. In turn, the resonant frequency of higher frequency resonance TP_2 is controlled mainly by a pair of lateral inserts by properly adjusting their dimensions and positions relative to the side walls of the aperture. Thus, the design procedure for the FSS proposed is divided into several stages. The first stage is to design a screen that enables a single passband pseudo-elliptic response centred at $f(TP_1)$. Here, the FSS periodical cell should contain a rectangular aperture with only an internal group of three inserts. Such a procedure being applied to a waveguide design has been performed before [13, 14]. The 2nd stage is to adjust the cell aperture cross-section by inserting a pair of additional lateral inserts. Finally, an optimization procedure should be applied to satisfy the specification.

To test the angular stability of the proposed FSS, simulation and measurement were carried out for different angles of incidence. Both resonances and all TZs remain to be stable up to the incident angle of 20 degrees. It is observed that both the resonances shift up and become wider with the increase in the incident angle. Fig. 3 illustrates the evolution of the FSS response obtained from measurements. The transmission coefficient is presented for different values of incident angle θ=0°, 15°, 30° and 45°. At the angle of 45 degree, the first resonance shifts by 2.5% from its initial frequency 9.02 GHz up to 9.24 GHz (for a half of its bandwidth approximately). In turn, its bandwidth becomes wider from its initial 4.2% up to 6.5%. The second resonance shifts by 3% from its initial frequency of 11.14 GHz up to 11.49 GHz. Its bandwidth is evidently more sensitive to the incident angle variation and is changing from its initial 5.5% up to 14.2%.

III. CONCLUSION

In this work, a novel single-layer FSS providing frequency response with two closely spaced passbands of pseudo-elliptic type was proposed. The proposed FSS is a single-sided PCB with periodic meander-like apertures. The apertures are designed to allow two resonant couplings via two different higher modes. Besides, these higher modes were responsible for the generation of three transmission zeros. As a result, a two-band operating regime was achieved without any enlargement of both transversal and longitudinal dimensions of FSS. The proposed FSS demonstrated a very promising design for multi-band operation. Namely, it allows independent control of the positions of transmission resonances and transmission zeros by adjusting the dimensions and positions of the inserts in the cross-section of the rectangular aperture. X-band FSS was numerically investigated, fabricated, and measured for different angles of linearly polarized wave incidence. Numerical and measured data are demonstrated to be in good agreement.

ACKNOWLEDGMENT

This contribution was partially supported by the British Academy Researchers at Risk Fellowship No 100118 and the Department for the Economy of Northern Ireland under US Ireland R&D Partnership grant no. USI 199.

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