A Loop Resonator for 3-D Frequency Selective Structure

Ahmed Abdelmottaleb Omar and Zhongxiang Shen
School of Electrical & Electronic Engineering
Nanyang Technological University
50 Nanyang Avenue, Singapore 639798
E-Mail: ahmedabd001@e.ntu.edu.sg, ezxshen@ntu.edu.sg

***Abstract*—A loop resonator for the 3-D frequency selective structure is proposed aiming to reduce the thickness of the structure and introduce a new type of resonator inside the unit cell. The structure is based on the coupling between the two modes concentrated in the unit cell to obtain transmission and reflection zeros. The new resonator reduces the thickness of the structure by 28.5% compared to the previous structures, this resonator open the way for more resonators to be involved in. The proposed resonator shows stable performance under oblique angles of incidence for the single-band and dual-band structures. The operating concept and simulation results are included.**

I. Introduction

Frequency selective surface was known long time ago and it has been used in hybrid radomes, dichroic main reflectors, dichroic sub-reflector and absorbers [1]. It consists of periodic 2-D array of resonant elements, while this traditional design suffers from some drawbacks as pointed out in [2], such as poor selectivity and narrow band width. Several trials have been made to overcome these drawbacks. Instead of using only resonant elements, a combination of resonant and non-resonant elements [3] can be used to achieve a low-profile third-order band-pass frequency selective surface. Based on a fourth-order coupled-resonator filter, where the four poles are split into two groups forming dual-band second-order response used in [4]. Recently, 3-D frequency selective structures (FSS) were presented in [2], [5] based on coupling between modes generated in a dual-mode resonator; pseudo-elliptic response has been achieved. Based on this new structure, several designs have been presented. [6] Proposed a structure that has a band-pass response and produces multiple out-of-band transmission zeros by blocking the air path. [7] Achieved a dual-polarized response with wide out of band rejection and a fractional band widths of 18%, 78% for band-pass and band-reject, respectively. A dual-band response was described in [8] by introducing a new longer path. An idea was suggested in [9] based on multiple resonators in a unit cell that allows multi-band response. Although it has a good performance, the new 3-D FSS is very thick, which may limit its practical applications. One way to reduce the thickness was proposed in [10] using stepped-impedance resonator and it was successful to reduce the thickness by 36%. All these structures use the microstrip line and parallel strip line as a resonator in a unit cell. In this paper we propose a loop resonator instead.

II. The Structure and Simulated Results

Fig.1 shows the 3-D view and unit cell details of the proposed FSS with a circular loop as the resonator. The thickness of the structure is now equal to the diameter of the loop (D) instead of the microstrip line length.

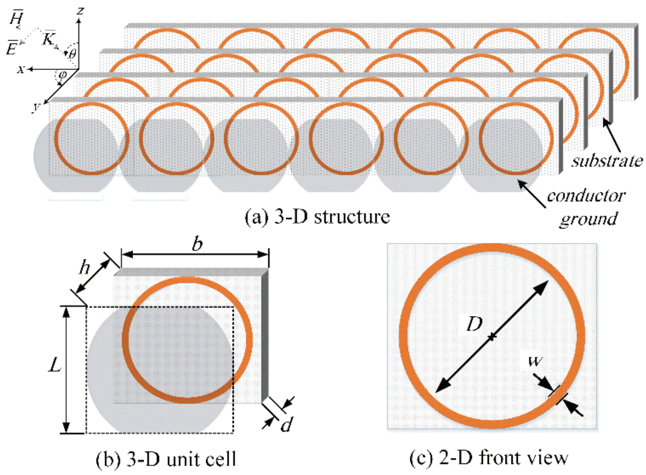

Fig. 1. Structure of the proposed FSS using circular loop resonator.

A. The Principle of Operation

The proposed structure has the same operating principle as the original structure presented in [2], which depends on the coupling between the two quasi-TEM modes concentrated in the air and substrate regions to produce transmission and reflection zeros. The unit cell proposed in [2] produces one transmission zero and two reflection zeroes. The transmission zero is obtained when the phase difference between these two modes is equal to π. The two reflection zeroes are produced when the propagating path of each mode is equal to π. The length of the microstrip line (the thickness of the structure) is approximately equal to 0.5 λ_{eff}, where $\lambda_{eff} = \lambda_0 / \sqrt{(\varepsilon_r + 1)/2}$ and λ_0 is the free space wavelength at the operating frequency.

The circular loop resonates when its circumference equals to λ_{eff}, ($\pi D = \lambda_{eff}$), which means that $D = 0.32\ \lambda_{eff}$. Using the circular loop as the resonator instead of the microstrip line, the thickness of the structure is equal to 0.32 λ_{eff} instead of 0.5 λ_{eff} in the microstrip line case. Fig. 2 shows the simulated reflection and transmission coefficients associated with the surface current distribution of the proposed resonator using the full-wave High Frequency Structure Simulator (HFSS). It is shown from the simulated current distribution that the new resonator resonates when its circumference equals to λ. Simulated results show 28.5% reduction in the thickness of the structure compared to the microstrip line case using the same unit cell parameters. Simulated results also show a stable filtering performance under oblique incidence.

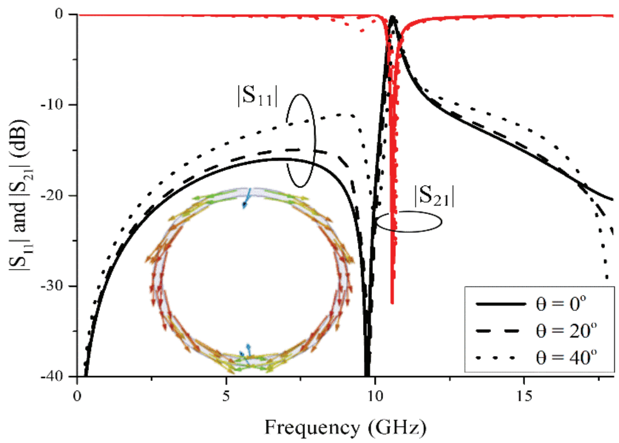

Fig. 2. Simulated reflection and transmission coefficients of the FSS with loop resonator (b = 8 mm, h = 3.524 mm, L = D = 7 mm, d = 1.524 mm, w = 0.4 mm, ε_r = 3).

B. Multi-band and high-order response

Using the idea presented in [9], multi-band response can be achieved by adding more resonators with different resonant frequencies in the same unit cell. Fig. 3 shows a unit cell for a dual-band response as well as the simulated reflection and transmission coefficients with surface current distribution at each band. As shown from the current distribution, each resonator is responsible for one band so the resonant frequencies are independently controlled. This new resonator can also be used in band-pass FSS and absorbers.

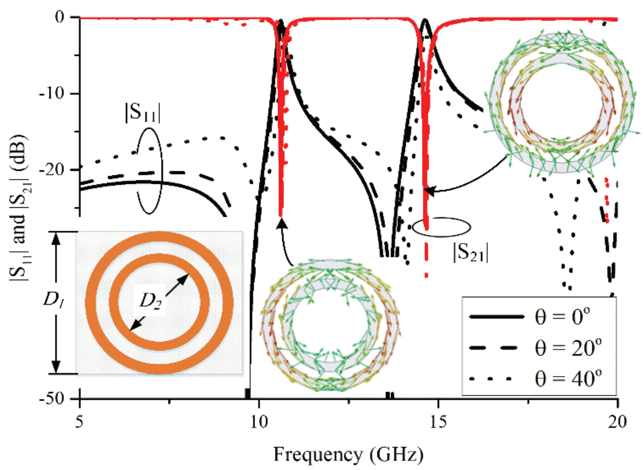

Fig. 3. A unit cell of a dual-band FSS with simulated reflection and transmission coefficients and surface current distribution (b = 8 mm, h = 6 mm, D_1 = 7 mm, D_2 = 5 mm, d = 1.524 mm, ε_r = 3).

The first-order response of loop resonator can be extended to second-order response by inserting two via holes at the location of maximum current. Then they can control the separation between the two transmission zeros by changing via hole radius (r). Fig. 4 shows a unit cell of single-band second-order band-stop FSS with simulated reflection and transmission coefficients.

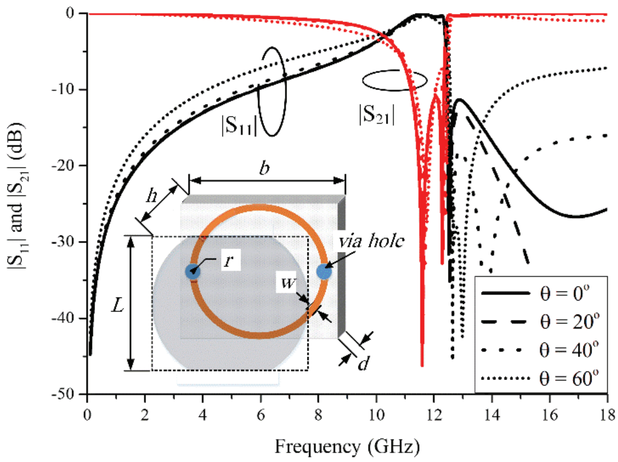

Fig. 4. Simulated reflection and transmission coefficients of single-band second-order FSS (b = 8 mm, h = 3.524 mm, L = D = 7 mm, d = 1.524 mm, w = 0.3 mm, r = 0.9 mm, ε_r = 3).

REFERENCES

[1] B. A.Munk, *Frequency-Selective Surfaces: Theory and Design*. New York, NY, USA: Wiley, 2000.

[2] A. K. Rashid and Z. Shen, “A novel band-reject frequency selective surface with pseudo-elliptic response,” *IEEE Trans. Antennas Propag.*, vol. 58, no. 4, pp. 1220–1226, Apr. 2010.

[3] N. Behdad, M. Al-Joumayly, and M. Salehi, “A low-profile third-order bandpass frequency selective surface,” *IEEE Trans. Antennas Propag.*, vol. 57, no. 2, pp. 460–466, Feb. 2009.

[4] M. A. Al-Joumayly and N. Behdad, “Low-profile, highly-selective, dual-band frequency selective surfaces with closely spaced bands of operation,” *IEEE Trans. Antennas Progag.*, vol. 58, no. 12, pp.4042–4050, Dec. 2010.

[5] A. K. Rashid, B. Li and Z. Shen, “An overview of three-dimensional frequency-selective structures,” *IEEE Antennas and Propagation Magazine*, vol. 56, no. 3, pp. 43-67, Jun. 2014.

[6] B. Li and Z. Shen, “Three-dimensional bandpass frequency selective structures with multiple transmission zeros,” *IEEE Trans. Microw. Theory Tech.*, vol. 61, no. 10, pp. 3678–3589, Oct. 2013.

[7] B. Li and Z. Shen, “Three-dimensional dual-polarized frequency selective structures with wide out-of-band rejection,” *IEEE Trans. Antennas Progag.*, vol. 62, no. 1, pp.130–137, Jan. 2014.

[8] B. Li and Z. Shen, “Dual-band bandpass frequency-selective structures with arbitrary band ratios,” *IEEE Trans. Antennas Propag.*, vol. 62, no. 11, pp. 5504–5512, Nov. 2014.

[9] A. A. Omar and Z. Shen, “Multi-band second-order bandstop frequency selective structure with controllable band ratios,” to be presented in *IEEE Antennas and Prog. Symp.*, Vancouver, British Columbia, Canada, July 2015.

[10] B. Li and Z. Shen, “Miniaturized bandstop frequency-selective structure using stepped-impedance resonators,” *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 1112–1115, 2012.