A Single-layer Metamaterial-based Polarizer and Bandpass Frequency Selective Surface with an Adjacent Transmission Zero

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***Abstract*—In this article, a high order bandpass miniaturized-element frequency selective surface (MEFSS) and a wire-grid polarizer are implemented on a single-layer substrate. This compact spatial filter and polarizer are designed to be incorporated in a 26 GHz UWB rangefinder radar. The spatial filter has a passband at 26 GHz and a transmission zero at 13 GHz. A new single-face miniaturized-element FSS has been proposed to produce the desired frequency response. An accurate circuit model has been developed for this structure to facilitate the filter synthesis process. The structure has been analyzed and optimized with a full-wave EM solver. A prototype of the designed structure has been fabricated and tested. Measurement results show low insertion loss in the passband (<0.5 dB) and high rejection at transmission zero (>20dB).**

***Index Terms*—single-layer, polarizer, bandpass, Ka-band radar, miniturized-element frequency selective surfaces**

I. INTRODUCTION

Frequency selective surface (FSS) structures have been widely used in variety of microwave and millimeter-wave applications to provide spatial filtering [1]-[2]. In particular, FSS structures have been widely investigated for radar applications [3]. Millimeter-wave radar front-end typically has a frequency multiplier or a mixer to up-convert the local oscillator (LO) frequency to the transmit frequency. This non-linear conversion produces different harmonics of the fundamental frequency in the output. Leakage of the undesired harmonics at the output of the radar deteriorates the performance of the system. Therefore, a bandpass filter is needed to pass the desired harmonic of the LO frequency and reject the rest of the harmonics, especially the fundamental harmonic. Multi-pole waveguide filters have been widely used to suppress these undesired harmonics [4]. However, in millimeter- and submillimeter-wave frequencies, these filters are very difficult to realize. To overcome this problem, high-order FSS filters can be used to perform spatial filtering on the transmitted EM wave.

A frequency selective surface is usually made up of planar metallic patterns on a dielectric substrate. The metallic pattern usually forms a 2D periodic array of resonant unit cells which has a certain frequency response for the incident electromagnetic wave. In traditional designs, the frequency behavior of the structure result from mutual interactions of the resonant unit cells in the array. This requires a large number of unit cells in the periodic array to create the desired frequency response. This needs a large screen size which causes limitations in applications where incident EM wave does not have uniform phase front. In addition, in radar applications, the FSS structure needs to be embedded inside the transmitter antenna which does not allow large screen sizes. To address this problem, a new class of frequency selective surfaces called miniaturized-element frequency selective surfaces (MEFSS) has taken a different approach toward the design of unit cells [5]. In this approach, unit cells dimensions are small compared to the wavelength so that their interaction with EM wave can be modeled as lumped inductive and capacitive elements. In the recent years, numerous variations of the miniaturized-element FSSs have been reported [5]-[8]. In these structures, higher order mode spatial filters were realized by cascading two or more layers of periodic arrays. This results in a higher insertion loss at the passband and complexity of the fabrication process. On the other hand, none of the single-face FSS do not provide a transmission zero at a lower frequency than the passband frequency.

In this paper, a new single-face MEFSS structure consisting of loop and patch arrays is proposed to achieve a single passband and a transmission zero at a lower frequency. Then a Ka-band MEFSS and polarizer are designed and implemented on a single substrate. At the end, the designed structure is fabricated and its performance is verified experimentally.

II. DESIGN AND MODEL VERIFICATION

The proposed structure consists of two printed layers separated by a dielectric substrate (Fig. 1). On one surface, a 2D periodic array of patches and square loops are implemented to create the desired bandpass filter. It is shown in [5] that interaction of a loop array with incident EM wave can be modeled as a series LC branch. This series LC branch resonant frequency creates a transmission zero in the frequency response of the FSS. Hence, the transmission zero frequency is

independent of the patch dimensions (Equ. 1). The patch array can be modeled as a capacitor which is in parallel with the loop series LC branch.

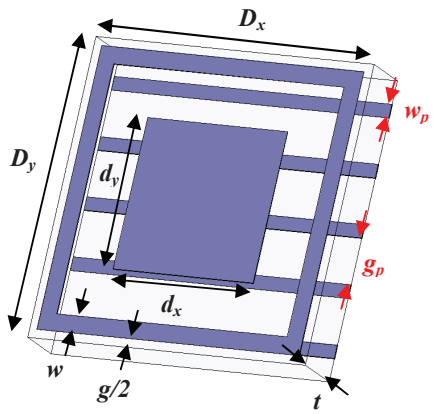

Figure 1. Unit cell of the MEFSS/polarizer structure ($Dx = Dy = 4.5$mm, $dx = dy = 265$mm, $w = 254\mu$m, $g = 254\mu$m, $t = 787\mu$m, $w_p = 0.2$mm, $g_p = 0.7$mm)

The equivalent circuit model is shown in Fig. 2. As can be noted there is no coupling between the two parallel branches. The loop element (series LC branch) resonant frequency is

$$\omega_{zt} = \frac{1}{\sqrt{LC}} \tag{1}$$

The pole frequency can be tuned by changing the patch size while maintaining the same transmission zero frequency as

$$\omega_{bp} = \frac{1}{\sqrt{L(C+C_p)}} \tag{2}$$

It can be noted that the pole frequency is always higher than the transmission zero which is desired in many applications. The ratio is only a function of the ratio of the capacitors as

$$\frac{\omega_{bp}}{\omega_{zt}} = \sqrt{1 + \frac{C_p}{C}} \tag{3}$$

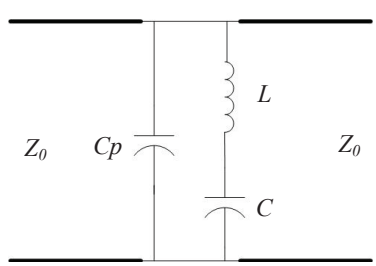

Figure 2. Equivalent circuit model for the patch-loop MEFSS ($L = 2$ nH ,$C = 72$ fF, Cp=32 fF, $Z_0 = 377\ \Omega$)

On the other surface of the substrate, a wire-grid polarizer has been implemented. Dimensions of the wire-grid (w_p and g_p) are optimized so that total transmission of one of the polarizations (TE or TM) and total reflection of the other polarization are achieved in the radar passband.

A full wave analysis of the FSS structure has been performed using Ansoft HFSS to verify the performance of the proposed structure. As can be seen in Fig. 3, the result of the circuit model simulation is in a very good agreement with the full wave analysis results.

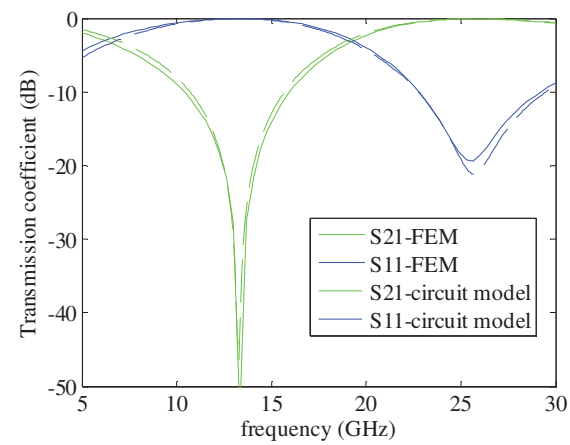

Figure 3. Circuit model simulations vs. full wave analysis

To verify the performance of the combined polarizer and MEFSS, full wave analysis of the complete structure has been performed for both TE and TM polarizations. Fig. 4 shows over 20 dB selectivity in transmission for the two polarizations.

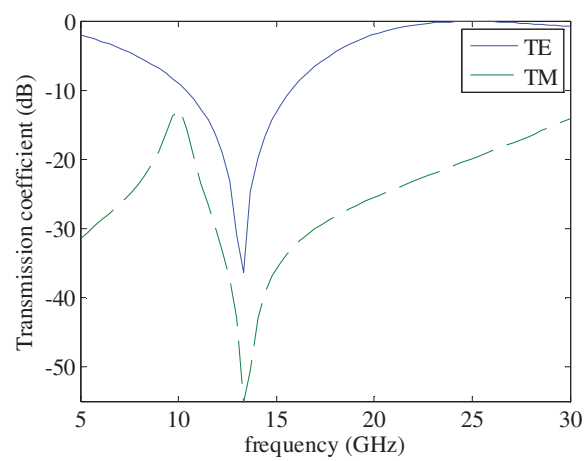

Figure 4. Full wave simulation results of the combined polarizer and MEFSS for TE and TM polarizations

III. EXPERIMENTAL VERIFICATION

To verify the simulation results, a 6-in×6-in prototype of the structure is fabricated and tested using a free-space measurement setup. The structure is fabricated on a 31 mil Duroid 5880 substrate (ε_r=2.2) with ¼ oz. electrodeposited copper foil. To achieve high accuracy for the dimensions of the elements, a thin layer of spin-on photoresist has been utilized, instead of photosensitive laminates, to pattern copper. Patterned substrate is then etched using standard printed circuit board wet etching process. The fabricated prototype is shown in Fig. 5.

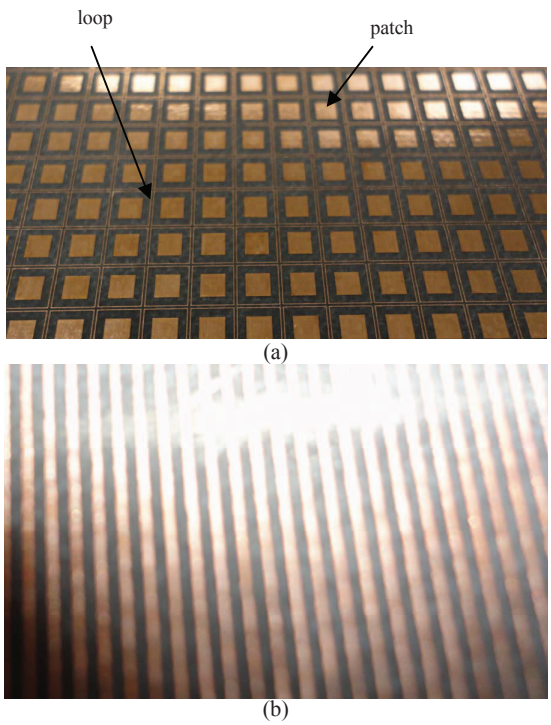

Figure 5. Fabricated structure (a) patch-loop MEFSS (b) wire-grid polarizer

A free space measurement setup has been utilized to test the performance of the fabricated prototype. The setup consists of a lens-horn as the transmitting antenna for creation of collimated beam and a high gain horn as the receiving antenna at far-field (Fig. 6).

The measurement result is shown in Fig. 7. A good agreement between simulation and measurement results can be observed. The measured results show less than 0.5 dB insertion loss at the pass band and more than 20 dB rejection at transmission zero frequency.

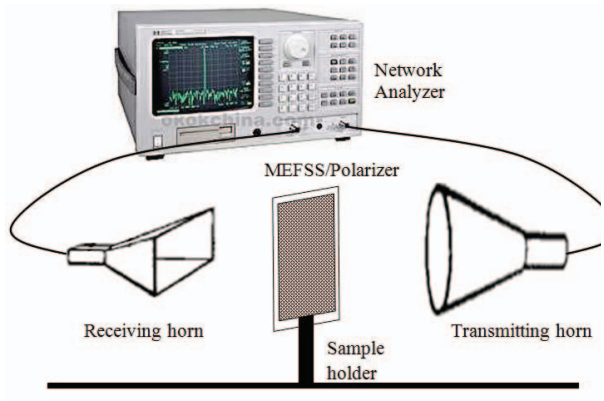

Figure 6. Free space measurement setup

A slight difference in transmission zero frequency can be noted between simulation and measurement. This is result of copper undercut in wet etching process which affects the equivalent inductance and capacitance values of the loop element.

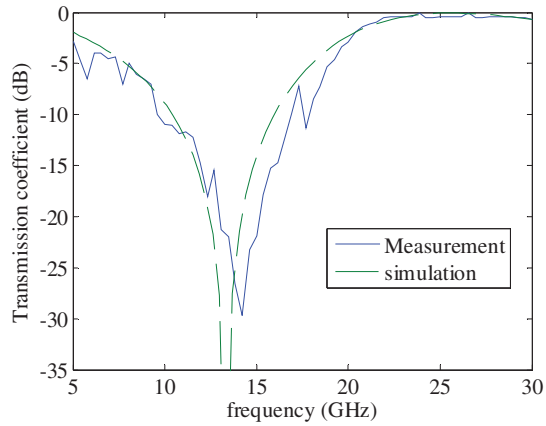

Figure 7. Measured and simulated responses of the MEFSS structure

IV. CONCLUSION

A single-layer polarizer and miniaturized-element patch-loop frequency selective surface has been presented. The structure is based on the idea of using miniaturized elements which can be modeled as lumped elements with the capability to control the transmission zero and the pole individually. It has been designed to pass the desired second harmonic at 26 GHz and reject the fundamental harmonic at 13 GHz. A prototype of the designed FSS has been fabricated using printed circuit technology and the performance has been verified experimentally.

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