# Terahertz Bandpass Frequency Selective Surface with Improved Out-of-Band Response

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***Abstract*—A second-order bandpass frequency selective surface (FSS) for terahertz applications is experimentally demonstrated in this paper. The proposed FSS is designed using miniaturized element unit cells that enable analysis of their frequency by an equivalent circuit model. A transmission zero is introduced in the upper stopband of the transmission response for improving the out-of-band performance. Numerical and experimental results show a harmonic-free response up to three times the passband center frequency.**

## I. Introduction

FREQUENCY selective surfaces (FSSs) are the key components in many terahertz and millimetre wave applications such as radars, sensors, imaging, etc. [1], [2]. A common feature among most of the conventional FSSs is their unit cell size that is comparable to half the operational wavelength [3], [4]. This makes their frequency response sensitive to the angle of the incidence [5]. Here, a second-order terahertz FSS (THz-FSS) is presented that uses the miniaturized unit cell to circumvent this drawback.

The front and back layer unit cells of the proposed FSS are depicted in Fig. 1. Both of the front and back layers are composed of capacitive square patches surrounded by an inductive wire grid. A complementary cross-shaped resonator is embedded is the back layer capacitive patch for improving the out-of-band response of the FSS [6]. The unit cell size in 130 $\mu$m, which is equal to $\lambda_0/5$, where $\lambda_0$ is the free space wavelength at the central frequency of the FSS. Since the proposed FSS is designed based on miniaturized unit cells, its frequency response can be modelled using a lumped-elements equivalent circuit [7], [8]. The equivalent circuit model of the proposed FSS is presented in Fig. 2. In this figure, the transmission line section of length $h$ models the dielectric spacer, the front layer is modelled by $C_{L1}$, $L_1$, $R_1$ and the back layer is modelled by $C_{L2}$, $L_2$ and $R_2$. Additionally, the complementary cross-shaped resonator is modelled with $C_3$, $L_3$ and $R_3$. The resistors $R_1$, $R_2$ and $R_3$ represent the ohmic loss associated with the front and back layers resonators. Furthermore, the characteristic impedance of the transmission line section is $Z_T = Z_0/\sqrt{\epsilon_r}$, where $Z_0 = 377\ \Omega$ is the free-space characteristic impedance and $\epsilon_r = 2.35$ is the relative permittivity of the PDMS dielectric spacer.

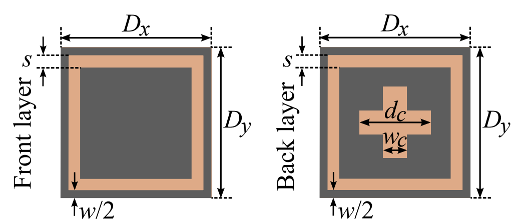


Fig. 1. Unit cell of the designed THz-FSS. The dimensions are as follows: $D_x = D_y = 130\ \mu$m, $w = 10\ \mu$m, $s = 5\ \mu$m, $w_c = 20\ \mu$m, $d_c = 65\ \mu$m. Metal parts, fabricated using 200 nm gold, are shown in dark grey. The substrate is a 100 $\mu$m thick PDMS.

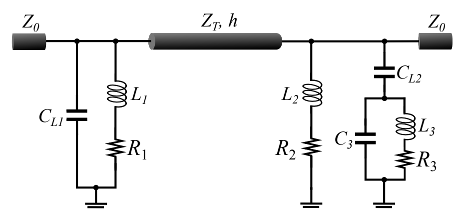


Fig. 2. Equivalent circuit model of the proposed FSS. The parameters are: $Z_T = 245.9\ \Omega$, $C_{L1} = C_{L2} = 4.2$ fF, $L_1 = L_2 = 45$ pH, $R_1 = 6.5\ \Omega$, $R_2 = 1.2\ \Omega$, $h = 100\ \mu$m, $L_3 = 3$ pH, $C_3 = 2.9$ fF and $R_3 = 4.25\ \Omega$.

## II. Results

For validating the presented concept of the THz-FSS, a prototype has been fabricated and measured. The FSS is fabricated based on multi-layer photolithography techniques using a combination of metal and dielectric layers. Fig. 3 shows an optical micrograph of the front and back layers of the fabricated FSS and the final sample supported in a clamp for testing.

The simulated transmission response of the FSS together with the measurement result under normally incidence plotted in Fig. 4 show a good agreement. Based on the results, a fractional bandwidth of around $45\%$ is achieved around $0.42$ THz center frequency. The complementary resonator adds a transmission zero in the upper stopband that widens out of band rejection below $-25$ dB up to $1.4$ THz. The maximum measured loss within the passband is less than $5$ dB, and is mainly attributed to the dielectric loss in PDMS spacer.

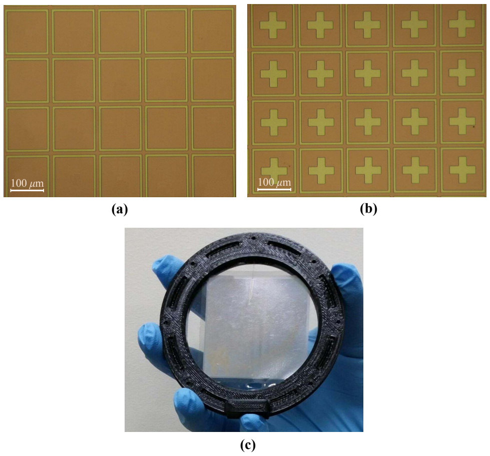


Fig. 3. The fabricated second-order terahertz FSS. Optical micrographs of the (a) front and (b) back layers. (c) Frame supported FSS after release.

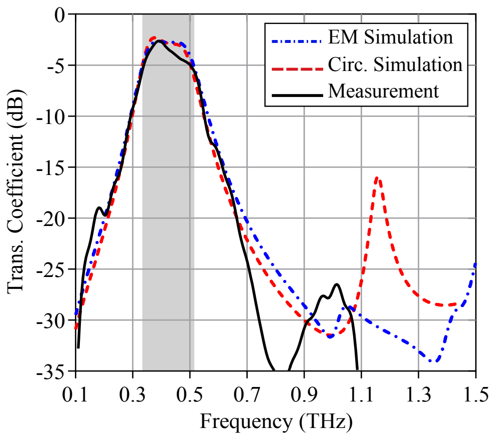


Fig. 4. Comparison between the simulated and measured transmission responses of the designed FSS. The −3 dB fractional bandwidth is shaded with gray.

This loss can be significantly reduced by using a spacer with a lower loss such as cyclo-olefin copolymer (COC). An important metric in an FSS design is the dependence of the transmission response to the oblique angles of incidence. The measured transmission responses of the FSS under oblique incidence are presented in Fig. 5 for both of the TE and TM polarizations. The results in Fig. 5 demonstrate a good stability of the FSS response for oblique incident angles. However, the fractional bandwidth of the FSS is slightly changed for oblique incidences. This is mainly because of a change in wave impedance, which increases by increasing the incident angle in the TE mode resulting in a higher quality factors in the front and back resonators and a narrower fractional bandwidth. Conversely, in the TM mode the wave impedance decreases with an increase in the incidence angle. As a result, the quality factors of the front and back resonators reduce and the fractional bandwidth becomes wider.

## III. Conclusion

A second-order bandpass FSS has been designed and experimentally demonstrated with a center frequency of 0.42 THz.

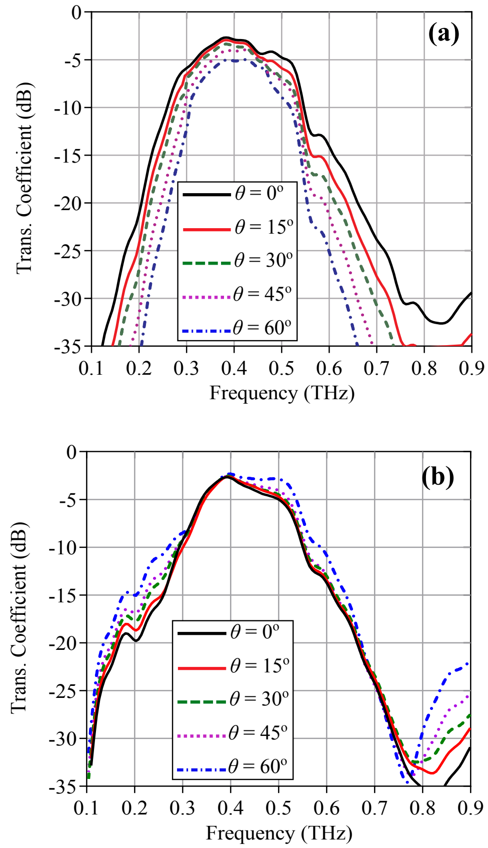


Fig. 5. The measured transmission responses of the FSS under oblique incident angles of the electromagnetic wave for (a) TE polarization and (b) TM polarization.

The FSS is composed of a double layer structure. By introducing a complementary resonator in the back layer, a harmonic-free transmission response is acheived up to 1.4 THz.

## References


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