A Switchable Filter Based On A Deformable Array

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***Abstract*—We introduce a geometrically reconfigurable metasurface whose structure will reorient within unit cells. It can alternate between two contrasting behaviors and serve as a switchable filter that allows the incident energy to be selectively transmitted or reflected with in excess of 10dB isolation at the certain frequencies for both polarizations in the microwave spectrum.**

***Keywords*—filters; metamaterials; resonance; transmission**

I. Introduction

A kind of single layer metamaterial which consists of flat periodic or quasi-periodic array, called metasurface, could create various possibilities to manipulate the propagation behavior of electromagnetic waves meanwhile maintain the ultrathin thickness smaller than the wavelength of interest [1–7]. In this present work, we provide a feasible method to realize a switchable metasurface with superior performance and convenience in practical application. We design the geometrically reconfigurable array which converts between the two kinds of arrays and realizes the working mode of transmission or reflection at the frequencies of interest. We use the equivalent circuit models to predict the electromagnetic behavior of the surface and the function of switching is demonstrated by full-wave analysis, which makes the dynamically transformable array a practicable method for greatly improving the flexibility and simplicity in the design process of a reconfigurable metasurface in different electromagnetic spectrums with alternative resonant structures.

II. Design and Analysis

When the configuration of the unit cell is circular loop aperture element as shown in Fig. 1(a), the long bars in the vertical direction will lead to the inductance L_1 across an equivalent transmission line for TE polarization and the horizontal gaps will act like capacitance C_1 primarily in parallel with L_1, the paralleled LC resonator becomes a classic pass-band filter with a transmission peak in the spectrum of interest. If we take away the dish in the middle of the element as shown in Fig. 1(b), the unit cell becomes the circular aperture element that the wider gaps bring about a smaller capacitance C_0 which cannot produce a valid resonance with high quality factor of the parallel circuit. The transmission characteristics of the two elements will not change for TM polarization due to the symmetry of the structures. When the dish connects to the right edge of the aperture with a cantilever, the equivalent circuit model can be thought of as two different transmission line circuits corresponding to TE and TM polarization respectively as shown in Fig. 1(c) and Fig. 1(d). For TE polarization the equivalent circuit model is the same to Fig. 1(a), but for TM polarization the cantilever converts the region of existing capacitance C_1 to approximate inductance L_2 and out of the connection still remain capacitors with smaller capacitance C_2. The two paralleled LC resonators will generate two resonant peaks in the transmission spectrum contrary to the case of TE polarization, the lower resonant frequency is mostly determined by L_1 and C_1 which own the larger values, whereas the higher resonant frequency mainly depends on the smaller inductance L_2 and capacitance C_2.

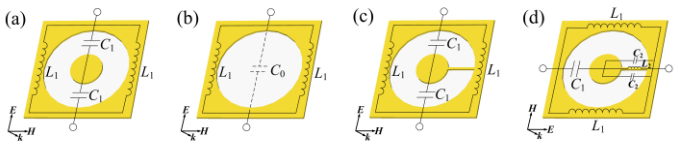

Fig. 1. Equivalent circuit model for TE polarization of (a) circular loop aperture element, (b) circular aperture element, (c) shorted circular loop aperture element and for TM polarization of (d) shorted circular loop aperture element.

Qualitative analysis from the equivalent circuit models imply that we could modify the transmission characteristic of the surface by moving the dish and then switching the morphology of the unit cell between two different geometrical shapes corresponding to the transmissive mode and the reflective mode respectively at the certain frequency. One possible method is connecting the dish and the bar with a cantilever which could bend out of the aperture as shown in Fig. 2. If the dish is bent out of the surface for TE polarization, the morphology of the unit cell will convert from the transmissive structure of resonant element to the reflective structure of approximately inductive element, which leads to a great change in transmission characteristic of the surface; when switching in the same way for TM polarization, it will have a huge influence on the lower resonant frequency because the large distance bring about a small capacitance paralleled with the horizontal bars as previously mentioned, meanwhile the values of C_2 and L_2 will also change due to the variation of spatial relationship between the dish and the vertical bar on the right side, which results in the drift of the higher resonant frequency accordingly.

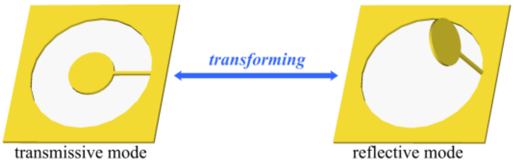

Fig. 2. Operational principle of the model: morphology transforming between two different elements.

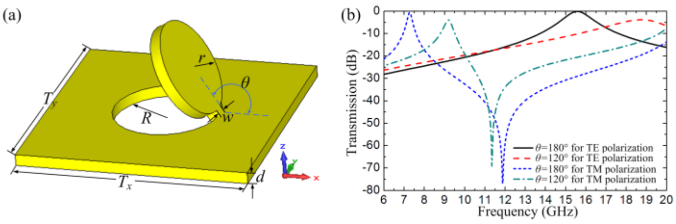

Fig. 3. (a) 3D schematic of the unit cell, where T_x =T_y=15mm, R=3.5mm, r=3.1mm and w=d=0.5mm, the plane wave propagates along Z direction. (b) Frequency response obtained from full-wave simulation with different values of θ for both polarizations.

For getting a vivid illustration of the behavior of the equivalent circuit models, full-wave analysis of the metasurface is performed. A three-dimensional view of the unit cell structure is shown in Fig. 3(a) including the design parameters. Fig. 3(b) shows that the transmission characteristic of the metasurface highly depends on the morphology of the unit cell under normal incidence for both polarizations, demonstrating the consequences predicted by the equivalent circuit models. When the cantilever stays in the aperture of the surface and θ=180° for TE polarization, the unit cell becomes a resonant structure composed of the shorted circular loop aperture element that could transmit the energy impinging on it at 15.5GHz and exhibit a small transmission loss of less than 0.1dB; when the cantilever bends out of the aperture and θ=120°, we obtain an embossed reflector with a good isolation of more than 12dB from transmissive mode at the original resonant frequency, certifying the signal rejection in the mentioned frequency band. For TM polarization we verify that the surface has the ability of switching at 7.3GHz but suffers a failure at 20GHz where we see the grating lobe. Thus take no account of the invalid dual-band switchable filter, we develop a freestanding switchable band-pass filter using a thin self-supporting and air-spaced metasurface composed of the transmutable array, in which the transmittance can be switched at 15.5GHz for TE polarization and at 7.3GHz for TM polarization.

III. Conclusion

In this article, we propose a geometrically reconfigurable metasurface as a flexible platform for realizing the switchable spatial filter in the microwave part of the spectrum. This is accomplished by designing a transformable array whose unit cells could convert their structure from one geometrical shape to the other spontaneously and repeatedly. The simulations have been carried out to validate its performance, demonstrating a switchable attenuation of more than 12dB will occur at disparate frequencies for different polarizations. The design methodology in this paper can be applied to other diverse functions, such as high-sensitivity sensing, tunable filtering, frequency-selective detection, multi-spectral imaging, etc.

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