Self-Complementary Metasurface for designing a new kind of Frequency Selective Surface

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Abstract

A self-complementary metasurface is studied in this paper. The unit cell consists of a split ring resonator and its complementary counterpart. Numerical simulations demonstrate that this structure behaves like a very selective band-pass filter for one linear polarization and like a band-stop filter for the orthogonal polarization at the same frequency range.

1. Introduction

Frequency selective surfaces (FSS) – thin screens made with periodically distributed flat metal scatterers – have the property of filtering incident electromagnetic waves. When scatterers are connected metal elements, the FSS behaves as a band-pass filter and when they are unconnected then the FSS is a band-stop filter [1, 2]. Since the proposal of Split Ring Resonator (SRR) by Pendry [3], this and some other resonators used in metamaterial science have also been incorporated to FSS design by some researchers. The newly created devices are often called metasurfaces [4]. Beruete et al. [6] proposed an interesting self-complementary array (using only connected elements), which worked as a polarizer at some frequency in the THz range. That structure had poor frequency selectivity and thus it could not be used as a band-pass filter. Here, we study a structure that can be used as band-pass or band-stop filter depending on the polarization state of the incident radiation.

2. Theory

The unit cell of the self-complementary metasurface is shown in Fig. 1 (left side). One SRR and one Complementary-SRR (C-SRR) are placed together. In the long wavelength limit, the central strips of the SRR act like a capacitor that can be excited by a tangential electric field along the x-axis (E_x, x-polarization). Invoking duality, the C-SRR must exhibit an important response to a magnetic field along the same direction (B_x, y-polarization). Moreover, according to the Babinet's principle, both resonators should have the same resonance frequency provided zero thickness perfect conductors are used.

Far from the resonance frequency, the region filled by SRR resonators should be almost transparent, while the region with C-SRRs should behave like continuous metallic strips without apertures. Under this hypothesis, the metasurface acts like a strip grating which, for wavelengths much larger than the periodicity, rejects plane waves with $\mathbf{E}$ parallel to the strips (y-polarization) while allows the radiation to freely pass through when $\mathbf{E}$ is perpendicular (x-polarization). This provides the correct baselines for

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band-pass and stop-band filtering. The corresponding bands appear close to resonant frequency because x-polarized electromagnetic waves excite the SRRs and y-polarized waves excite the C-SRRs. Following a reasoning similar to the one reported in Ref. [5], it can be seen that, at the resonant frequency, the transmission coefficient should vanish for x-polarization and reach unity for y-polarization. In this way, we obtain a band-stop filter for x-polarization and a band-pass filter for y-polarization (normal incidence is assumed). In fact, a moment of thought allows us to understand that this phenomenon is completely consistent with the Babinet's principle, since the metasurface is self-complementary.

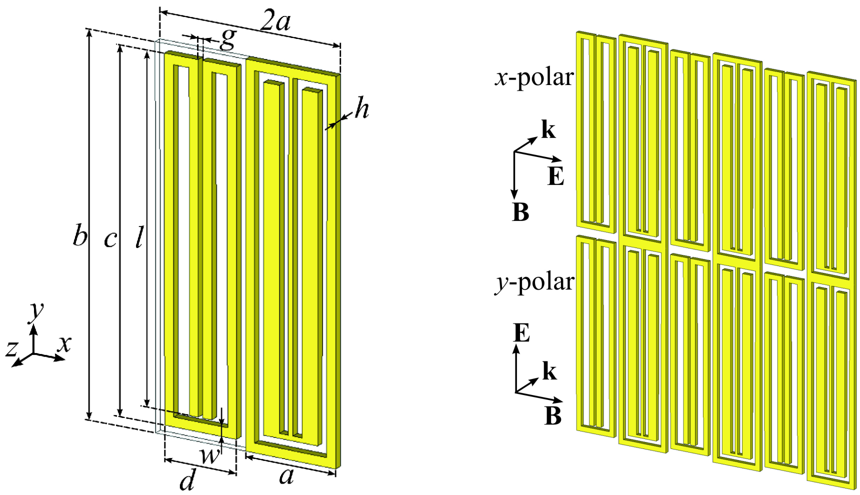

Fig. 1: On the left side, the unit cell made of one SRR and one C-SRR. On the right side, a view of the metasurface iluminated by x- or y-polarized plane waves.

3. Numerical validation

In order to check the hypotheses above, we have simulated the surface shown in Fig. 1 with the following geometrical parameteres: periodicity along the x-axis $a = 4$ mm, periodicity along the y-axis $b = 16$ mm, $c = 15.2$ mm, $d = 3.2$ mm, $g = 0.2$ mm, $l = 14.6$, and $w = 0.4$ mm. In order to fulfill the conditions for the Babinet's principle, the metal thickness is $h = 0$ when PEC is used. It was also simulated with copper using a typical thickness of $h = 0.035$ mm. We have used the frequency domain solver of *CST Microwave Studio*. The results for the magnitude of transmission and reflection coefficients are shown in Fig. 2. There appears a very selective stopband for x-polarization and passband for y-polarization. This clearly demonstrates the theory. Certain numerical inaccuracy prevents the coincidence between the frequencies of the peak and the dip for PEC. For the case of copper, the difference between these frequencies is larger because it is a lossy conductor and it has a finite thickness. Of course, the ohmic losses also makes the curves to do not reach the extreme values of 0 and 1, but it is worth to note that the phenomenon is still obvious for copper.

Fig. 3 shows the surface electric currents over the PEC sample for x- and y-polarization states. Since only one of the resonators in the unit cell is strongly excited at each state, these sketches suggest that the SRRs and C-SRRs subarrays are not interacting. It can be easily understood by realizing that a surface electric current lying on a surface cannot create a tangential magnetic field on the same surface, so SRRs cannot excite neighbouring C-SRRs and, by duality, SRRs cannot excite neighbouring C-SRRs.

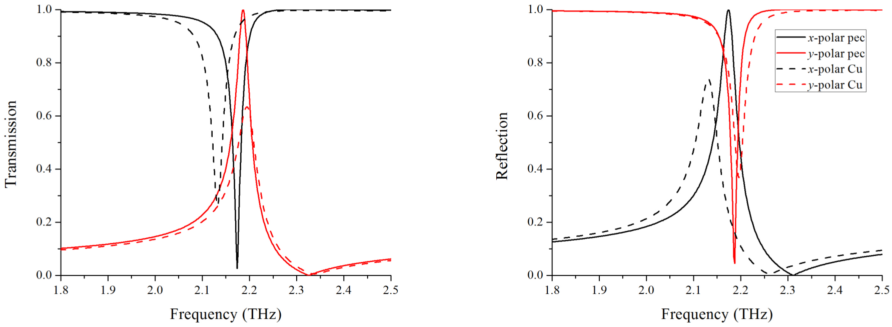

Fig. 2: Transmission and reflection coefficients for metasurfaces of PEC (solid lines) and Cu (dashed lines).

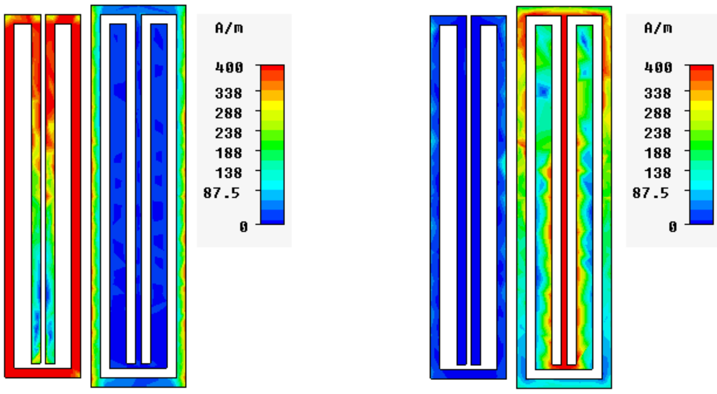

Fig. 3: Electric currents for x-polarization (left side) and y-polarization (right side) at 2.18 GHz for PEC.

4. Conclusions

The self-complementary metasurface proposed in this contribution behaves as a band-pass filter for certain linear polarization and, simultaneously, as a band-stop filter for the orthogonal polarization. The metasurface made with PEC exhibits the expected results. Although the sample of lossy metal shows worse transmission or reflection spectra, the properties of band-pass and band-stop filters still remain for their respective polarizations. Up to now, this kind of response has not yet been reported in the literature of frequency selective surface. Therefore, this self-complementary metasurface could open the way for designing a new type of FSS made of connected and unconnected elements at once.

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