3^{rd} URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

Design Concept for Multiple-Band Multi-functional Metasurafces with Hybrid Feeding

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Abstract

In this paper, we explore a design concept of multi-functional metasurfaces (MTS) at multiple bands using hybrid feeding. The metasurface is designed in a novel way such that it can perform different functionalities at different frequency bands using different feeding techniques. As a proof of concept, a MTS composed of compact electric–LC (ELC), two-arm spiral resonator and cross structure is designed. The simulated results demonstrate that when the incident field propagates from the top to the bottom in a reflective mode, the MTS acts as polarization converter, and when the incident field propagate from the bottom to the top in a transmissive mode, the MTS acts as impedance matching surface. The proposed concept serves as the first step toward the achievement of fully customized multi-function multi-band MTS with hybrid feeding.

1. Introduction

The next generation of antennas and RF devices will be envisioned as fully customized multi-band, multi-function sensing devices. Due to the ability to alter electromagnetic (EM) properties, MTS is a key in designing a new generation of antennas. To alter electromagnetic properties, one needs to design metallic or dieletric elements, which serve as building blocks in MTS. These elements can be viewed as atoms in the conventional material. Despite its EM tunning capability, designing MTS, which offers multi-functionality and multi-band capability, is a challenging task.

During the last decade, researchers have focused on multi-band MTS designs. Various multi-band MTS designs have been introduced. For instance, by stacking two-layers of metallic L-patterns, three-band polarization converter can be realized as proposed in [1]. However, most of proposed multi-band MTS designs are mainly used to realize multi-band for single functionality, such as polarization converter or beam forming. Multi-functionality and multi-band in MTS design still needs to be explored.

In this paper, we want to tackle the challenge in designing multi-band and multi-functionality MTS. As a proof of concept, both the number of bands and functions are limited to two. Conceptually, by combining different MTS patterns into a single design, multi-functionality can be realized. Furthermore, by carefully adjusting the dimensions of different patterns, multi-band can also be realized. To demonstrate the concept, a MTS composed of two layers of cross structure, and compact electric–LC (ELC) two-arm spiral resonator are designed and simulated. For the direction of incident feeding field (top to bottom or bottom to top), the two layers perform either as polarization converter, or impedance matching surface, respectively.

2. Multi-functional Multi-band Metasurface Configuration

To design the impedance matching surface, we utilize the configuration that had been studied in our previous work [2]. The surface consists of meander line (ML)-loaded ELC and two-arm spiral resonator element. ML-loaded ELC resonator [3] couples strongly to a uniform electric field and two-arm spiral resonator, [4], [5] is a magnetic resonatr. The combination of both configurations into one element creates the magneto-dieletric MTS, which offers impedance matching free space and relatively high refractive index.

To design the polarization converter, we follow the procedure proposed in [6]. Utilizing two orthogonal I-shaped structures placed on the top of a grounded substrate, the two orthogonal reflection phases can be modulated independently by tuning the length of the I-shaped structure. This provides more agility for controlling different polarization states of reflected waves. In this work, we focus on circular polarization conversion.

To demonstrate the multi-functional multi-band MTS concept, we design the element that combines both patterns: for impedance matching function (bottom), and polarization converter (top) into single element, as depicted in Figure 1.

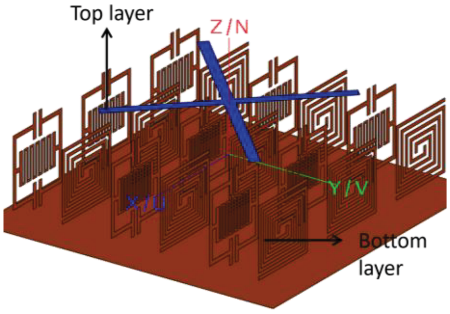

Figure 1. Unit cell of multi-functional multi-band MTS

The unit cell is place at the origin and excite the plane wave traveling along either plus *z* axis or minus *z*, depending on the operating mode of MTS. For the sake of simplicity, we set the host material with permittivity and permeability. For the case of dielectric host material, the resonance shifts to lower frequency proportionally to $\sqrt{\varepsilon_r}$ of the host material.

3. Numerical Modeling in FEKO

To demonstrate the first mode (polarization converter), we assume the plane wave propagates in minus *z* direction (top to bottom). Figure 2 shows the reflected waves and axial ratio for the simulated unit cell as depicted in Figure 1. As depicted in figure 2, the magnitude of the cross-polarized and the co-polarized of the reflection coefficient meet around 27 GHz, which indicate the linear to circular polarization conversion. The axial ratio, around 27 GHz, also re-confirms the linear to circular polarization conversion. As discussion in the previous section, the polarization conversion is due to two orthogonal I-shaped structure, placed on the top. The structure below it doesn't affect the performance of the polarization converter. In other words, there is minimal interaction between the two layers, as expected since the second (bottom) layer is designed to operate at different frequency band, with different functionality. Thus, we verify the first mode of the proposed design at around 27 GHz, assuming the plane wave propagates in minus z direction (top to bottom).

To demonstrate the second mode (free-space impedance matching with relatively high refractive index), we assume the plane wave propagates in plus *z* direction (bottom to top). The reflection and transmission coefficients (amplitude and phase) for the unit cell, as depicted in Figure 1, are computed using FEKO. As we can see in Figure 3, the magnitude of reflection coefficient is close to 0, and transmission coefficient is close to 1 around 15.5 GHz. This indicates that the surface impedance of the material is closely matched to the impedance of free space. Furthermore, phase of reflection and transmission coefficients drops rapidly around 15.5 GHz, which indicates that the material has high refractive index. So, we also successfully verify the second mode of the proposed design at around 15.5 GHz, assuming the plane wave propagates in plus z direction (bottom to top).

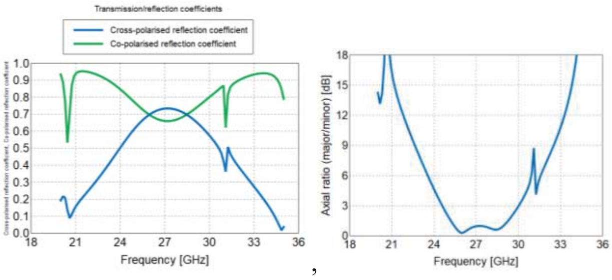

Figure 2. Magnitude of simulated reflection and axial ratio for the unit cell depicted in Figure 1, top-down feeding

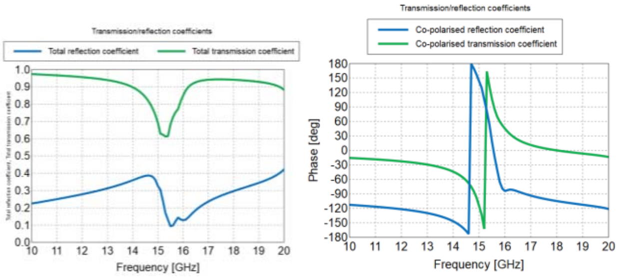

Figure 3. Magnitude and phase of simulated reflection and transmission coefficients for unit cell shown in Figure 1, bottom-up feeding

4. Conclusion

In this work, we propose the concept of multi-functional and multi-band MTS, with hybrid feeding of reflective (top to bottom) and transmissive (bottom to top) feedings. The design idea is based on combining different structures that offer different functionalities at different frequency bands into one unit cell. By carefully arranging them in the novel way to minimize the coupling among layers, we successfully demonstrate the polarization converter function around 27 GHz and the free-space impedance matching with relatively high refractive index function at around 15.5 GHz. This work will establish the pathway to fully realize the customized multi-functionalities multi-band MTS.

References

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