URSI AP-RASC, Sydney, Australia, 17 – 22 August 2025

Multiband Reflective Metasurface at X-Band Frequency Using Multi-Square Ring Resonators (SRRs)

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Abstract

A multiband reflective metasurface has been designed using a multi-Square Ring Resonator (SRR) operating at X-band frequencies. Each SRR is designed to resonate at 8, 10, and 12 GHz, respectively. Based on the simulated results, the reflection values are -0.4 dB at 8 GHz, -1.86 dB at 10 GHz, and -1.99 dB at 12 GHz, while the reflection phases are -1.06° at 8 GHz, -9.8° at 10 GHz, and -1.98° at 12 GHz. Overall, all resonance frequencies exhibit more than 60% reflected power, with bandwidths of 0.67 GHz at 8 GHz and 0.2 GHz at 10 and 12 GHz.

1. Introduction

The Smart Radio Environment (SRE) is a promising solution for next-generation wireless communication networks, addressing challenges like coverage gaps in urban areas caused by obstacles in the radio environment [1]. SRE can be implemented using a planar metasurface, which can operate in reflective, transmissive, or hybrid modes (both reflective and transmissive simultaneously) [2]. In reflective mode, the incoming and reflected waves are on the same side due to the ground plane beneath the metasurface.

Previous research on reflective metasurfaces includes a dual-band design at 7.7 GHz and 16.6 GHz, utilizing three metal layers (I-shaped patch, C-shaped ring patch, and ground plane) and two dielectric substrates, allowing independent regulation of amplitude and phase [3]. Additionally, a static metasurface reflector at 30 GHz has been demonstrated using coupled resonator configurations that enable independent control of magnitude and phase [4]. This paper presents the design and simulation of a multiband reflective metasurface operating at X-band frequencies.

2. Multiband Reflective Metasurface Design

The multiband reflective metasurface as shown in Figure 1 is designed for the X-band frequency range, specifically at 8, 10, and 12 GHz. It consists of a metasurface structure with a copper layer on top, a ground plane on the bottom, and a 1.5 mm F4BMX220 substrate (ε_r = 2.2, tan δ = 10^{-3}) as the dielectric substrate located between the top and bottom layers. The metasurface structure utilizes three Square Ring Resonators (SRRs), with each SRR having a resonance frequency at 8, 10, and 12 GHz, respectively. The physical dimensions of the SRRs can be calculated by using the following equations [5]:

$$f_o = \frac{1}{2\pi\sqrt{LC}} \quad (1).$$

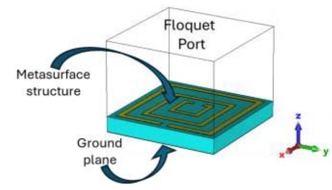
$$L = \mu_0 a_m \left(\ln\frac{8a_m}{h+w} - 0.5\right) \quad (2).$$

$$C_{total} = C_{gap} + C_{surface} \quad (3).$$

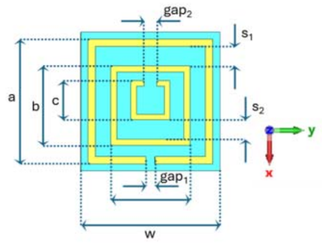
$$C_{gap} = \varepsilon_0 \left[\frac{wh}{g} + \frac{2\pi h}{\ln\frac{2.4h}{w}}\right] \quad (3a).$$

$$C_{surface} = \frac{2\varepsilon_0 h}{\pi}\ln\frac{4a}{g} \quad (3b).$$

where f_o is resonance frequency, L is approximated inductance of the ring, a_m is mean radius of the ring, w is ring width, h is thickness of the ring, g is gap width, and C_{total} is the total capacitance resulting from the parallel combination of the gap (C_{gap}) and surface ($C_{surface}$).



(a)



Parameters	Value (in mm)
w	11.43
a	10.25
b	6.525
c	3.2
gap_1	0.75
gap_2	1.05
s_1, s_2	1.6

(b)

Figure 1. The proposed design of the multiband reflective metasurface: (a) Simulated configuration and (b) Dimensions.

The proposed design is simulated using a Floquet port to observe the unit cell characteristics, as shown in Figure 1a. Due to the ground plane at the bottom of the proposed design, the simulation results are presented only with the reflection response, where the transmission value is zero.

Figure 1b shows the optimized dimensions of the proposed design, where the widths of the outer, mid, and inner rings are 0.6 mm, 0.5 mm, and 0.45 mm, respectively. The middle ring has no gap compared to the other rings, resulting in the best overall simulated performance. The overall size of the proposed design is 11.43 x 11.43 mm², or $0.46\lambda_o$ x $0.46\lambda_o$ at 12 GHz.

3. Results and Discussion

The simulated results of the proposed design are presented in the reflection magnitude and reflection phase graphs shown in Figure 2. The reflection magnitude is represented by S_{11} in dB, while the reflection phase is represented by the S_{11} phase in degrees. The S_{11} values indicate three resonance frequencies: -0.4 dB at 8 GHz, -1.86 dB at 10 GHz, and -1.99 dB at 12 GHz. The corresponding S_{11} phase values are -1.06° at 8 GHz, -9.8° at 10 GHz, and -1.98° at 12 GHz.

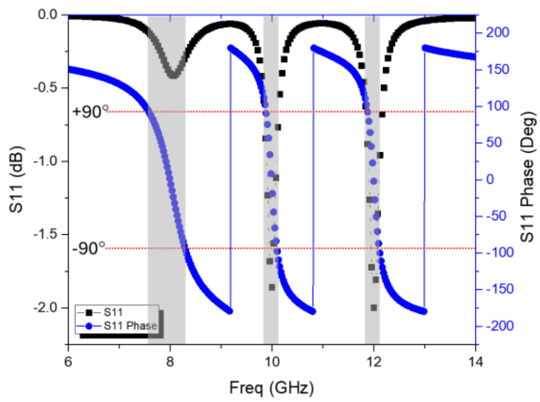


Figure 2. Simulated results of the multiband reflective metasurface.

Table 1. Bandwidth of the proposed design.

Resonance Frequency (GHz)	Bandwidth (GHz)
8	0.67
10	0.2
12	0.22

The simulated results show that the reflection magnitude at 8 GHz is higher than at 10 and 12 GHz due to the coupling effect, which is most prominent at each SRR gap. Reflection values for all resonance frequencies remain above 50% (i.e., above -3 dB). The bandwidths for each resonance frequency, calculated from the reflection phase between +90° and -90° (Table 1), are 0.67 GHz at 8 GHz, 0.2 GHz at 10 GHz, and 0.22 GHz at 12 GHz. The 8 GHz frequency exhibits a wider bandwidth than the higher frequencies at 10 and 12 GHz. This is likely due to stronger coupling at higher frequencies, which reduces the bandwidth compared to the lower frequency.

4. Conclusion

The multiband reflective metasurface was designed and simulated using three Square Ring Resonators (SRRs) operating at 8, 10, and 12 GHz. The overall reflected power exceeded 60%, with the highest reflection observed at 8 GHz due to the coupling effect. The bandwidth at 8 GHz is wider compared to the bandwidths at 10 and 12 GHz, with differences of approximately 0.4 GHz and 0.45 GHz, respectively.

5. Acknowledgements

The authors thank the Ministry of Higher Education (MOHE) for supporting the research work under grant no FRGS/1/2021/STG04/UTM/01/1, Research Management Center (RMC), Universiti Teknologi Malaysia (UTM), Faculty of Electrical Engineering for the support of the research under grant no. Q.J130000.5423.00L90. The authors also would like to thank the National Research and Innovation Agency (BRIN) for supporting our research with the funding of Rumah Program Prototype of IoT Telecommunications System Innovation Research for fiscal year 2025 and KMITL Bangkok Thailand.

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