Dual-Polarized Phase-Gradient Reflecting Metasurface for 5G mmWave Coverage Improvement

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- The perfect anomalous reflection.
- Design of passive dual-polarized phase-gradient metasurface reflector.
- Metasurface configuration.
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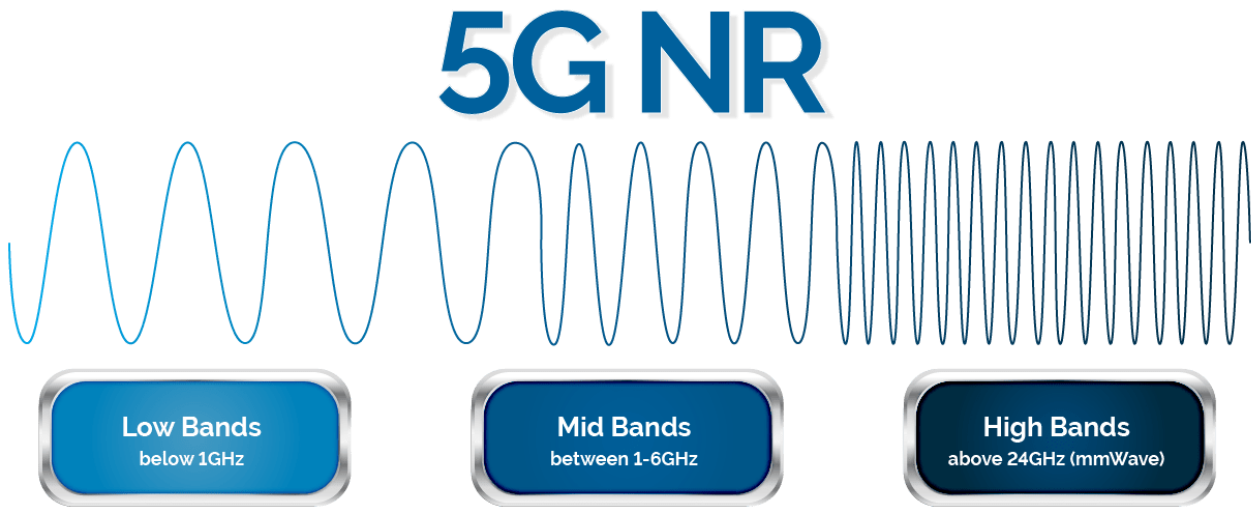
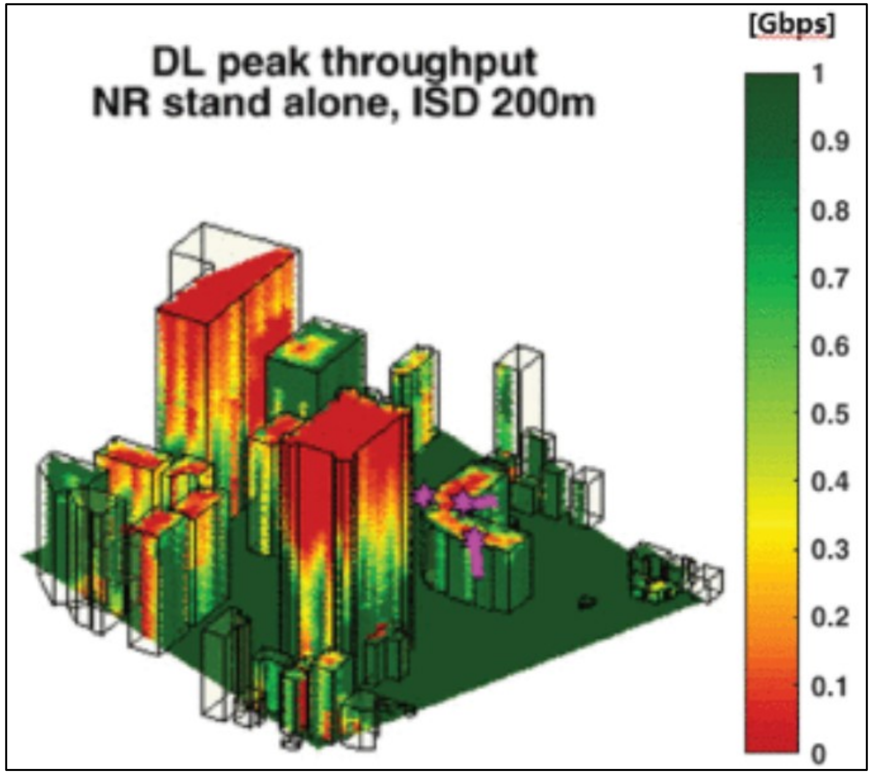
Millimeter wave & 5G NR



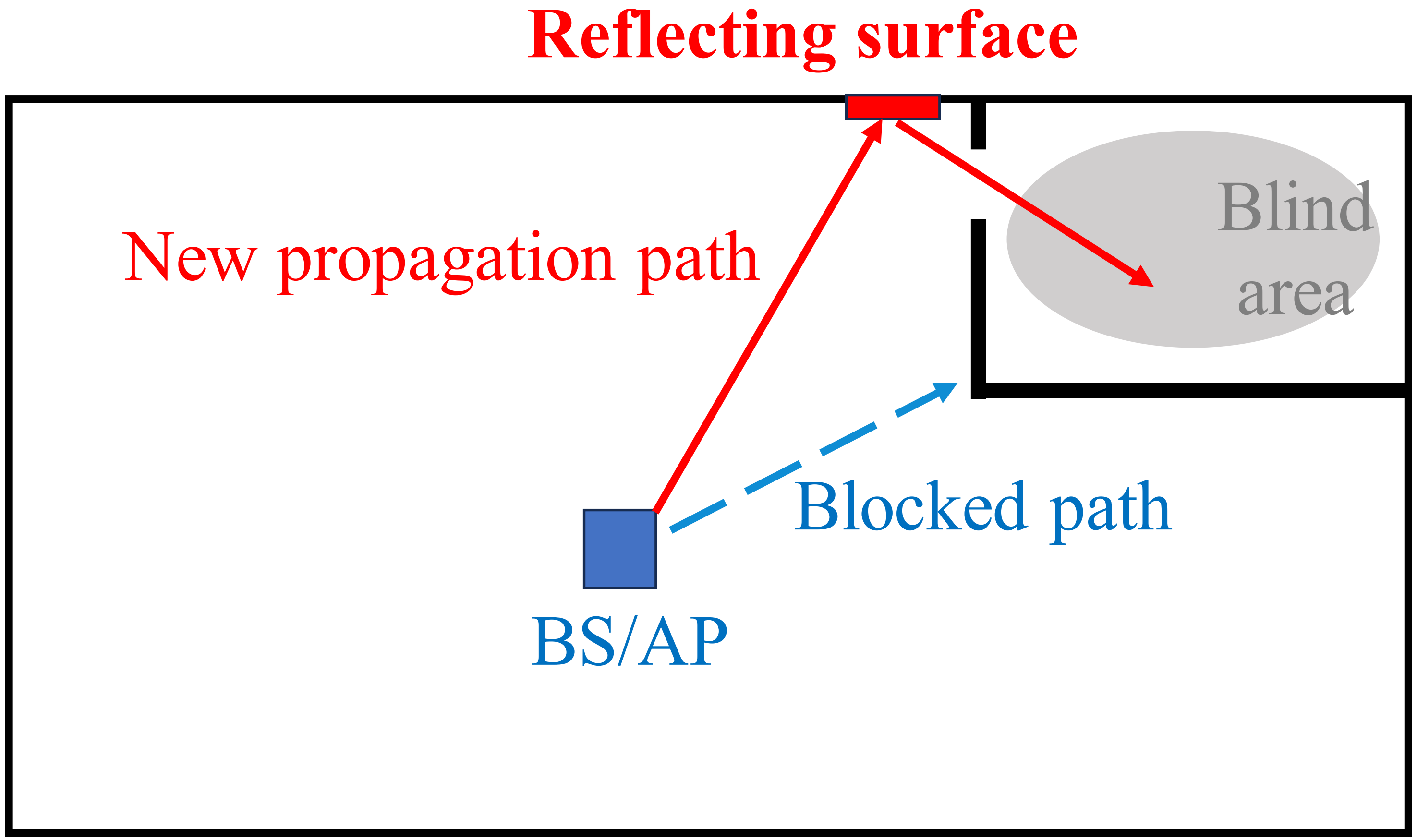
- A millimeter wave (mmWave) band enables
  - Faster data rates.
  - Greater channel capacity.
  - Lower latency.
- The mmWave suffers from severe loss and limited coverage.



Downlink performance simulation (26 GHz)

Source: K. Zheng, D. Wang, Y. Han, X. Zhao, and D. Wang, "Performance and Measurement Analysis of a Commercial 5G Millimeter-Wave Network," in IEEE Access, vol. 8, pp. 163996-164011, 2020.

⁜ Coverage improvement

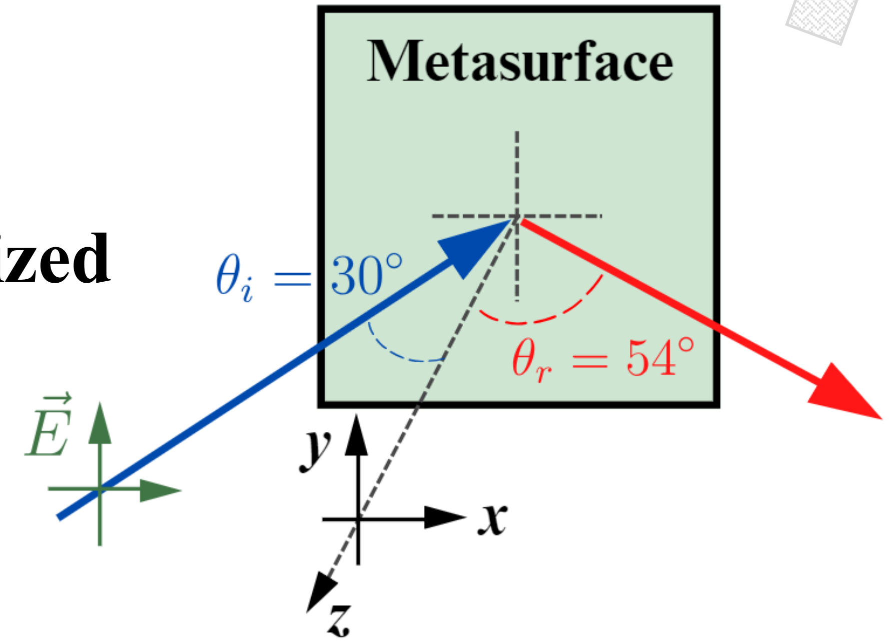


Creating a new propagation path by a reflecting surface.

⁜ Objectives

The main objective of this research is to design a reflecting metasurface that

- Can perform the **anomalous** reflection.
- Supports an operation with **dual-polarized mmWave** signals of **25.8 GHz**.
- Has **low design complexity.**



Perfect anomalous reflection

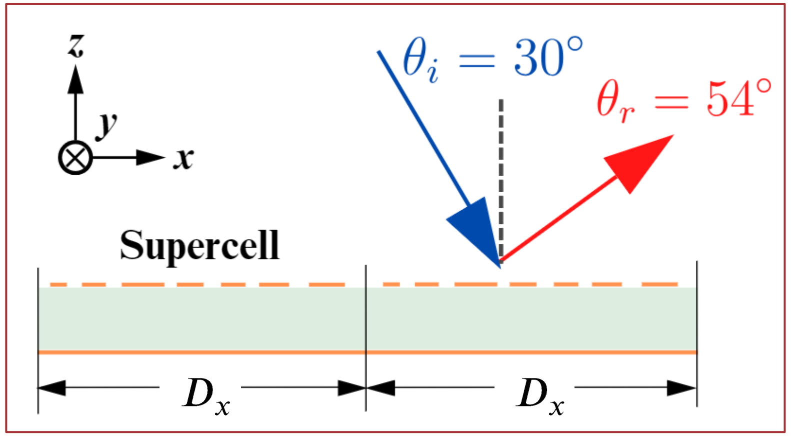
- To achieve the perfect anomalous reflection*, the periodic phase variation of the wave along the *x*-axis is

$$\Phi_{\mathrm{r}}(x) = k_0 x(\sin\theta_i - \sin\theta_r) = \Phi_{\mathrm{r}}(x + D_x).$$

- A spatial periodicity is

$$D_x = \frac{\lambda_0}{|\sin\theta_r - \sin\theta_i|}.$$

- λ_0 is the wavelength at the center frequency.
- $k_0 = 2\pi/\lambda_0$ is the wave constant.
- θ_i and θ_r are the incident and reflecting angles, respectively.



At 25.8 GHz, $\theta_i = 30°$ and $\theta_r = 54°$, we have $D_x = 37.6$ mm.

*A. Díaz-Rubio, V. S. Asadchy, A. Elsakka, and S. A. Tretyakov, "From the Generalized Reflection Law to the Realization of Perfect Anomalous Reflectors," *Science Advances*, vol. 3, No. 8, Aug. 2017

Perfect anomalous reflection

- According to the perfect anomalous reflection principle, the required surface impedance of the metasurface is

$$Z_s(x) = \frac{120\pi}{\sqrt{\cos\theta_i \cos\theta_r}} \frac{\sqrt{\cos\theta_r} + \sqrt{\cos\theta_i} e^{j\Phi_r(x)}}{\sqrt{\cos\theta_r} - \sqrt{\cos\theta_i} e^{j\Phi_r(x)}}.$$

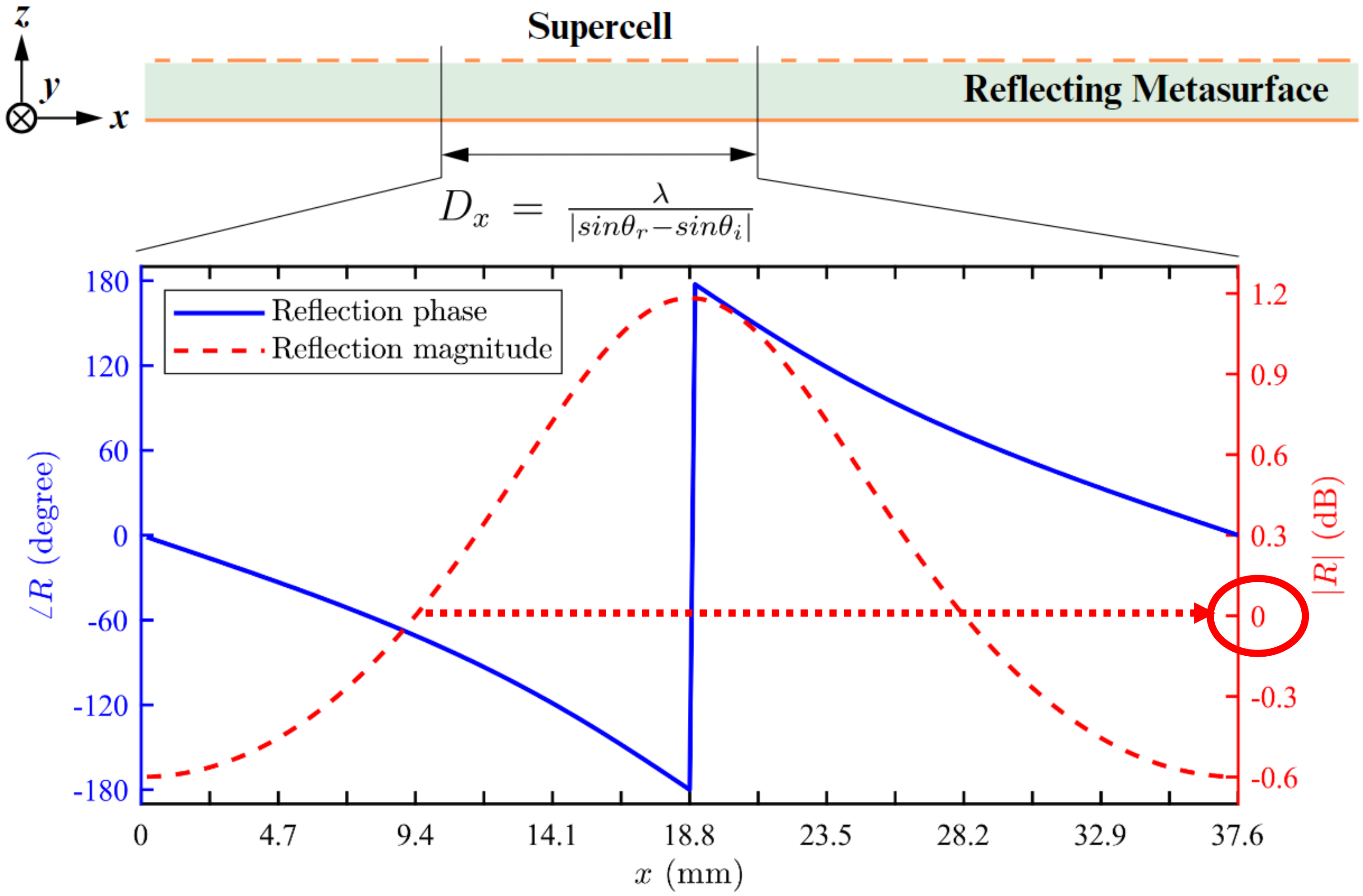
- The corresponding reflection coefficient of the metasurface is

$$R(x) = \frac{Z_s(x) - \eta_0}{Z_s(x) + \eta_0} = \frac{E_{reflected}}{E_{incident}},$$

where $\eta_0 = 120\pi\ \Omega$ is the intrinsic impedance of free space.

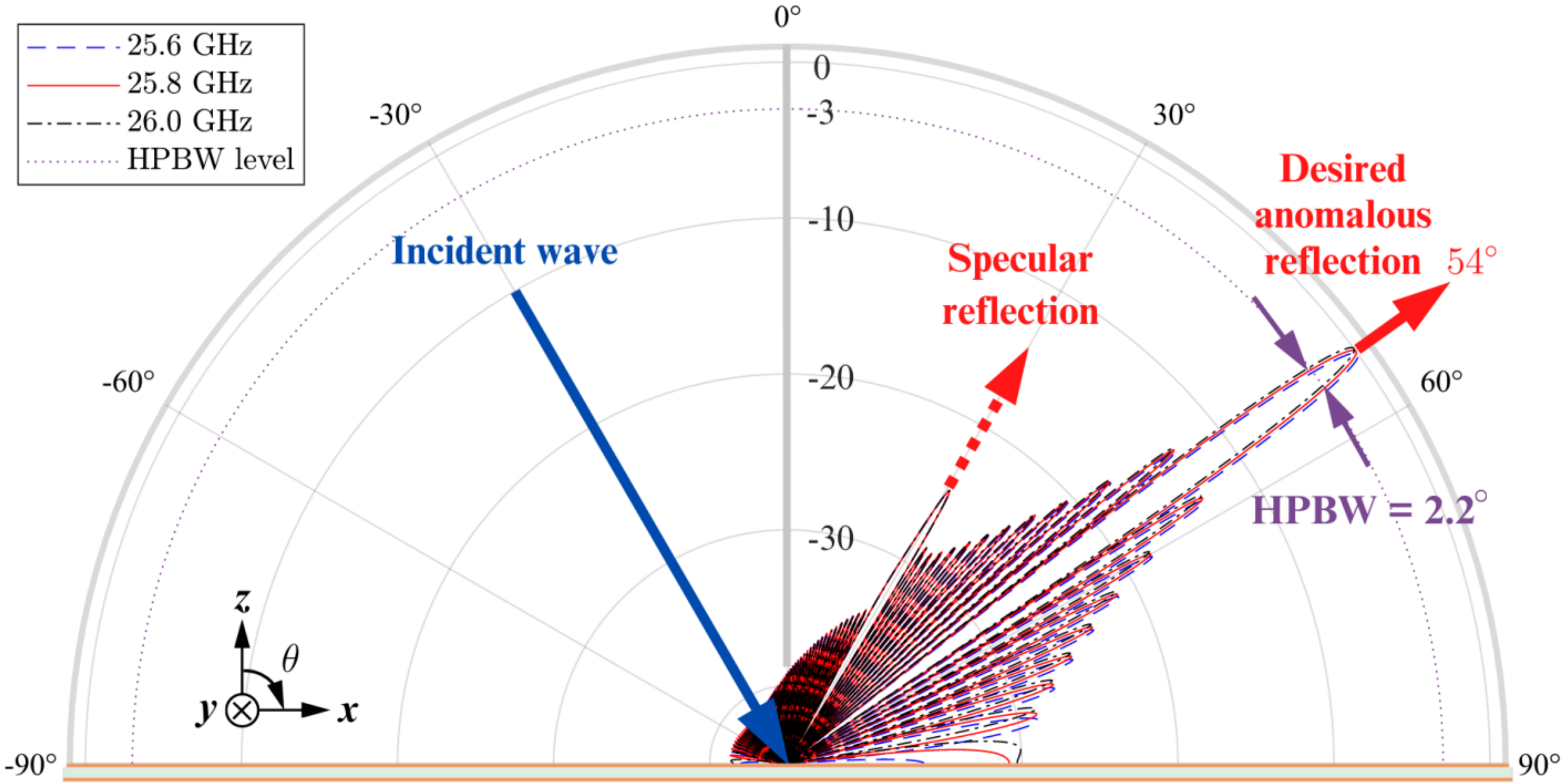
*A. Díaz-Rubio, V. S. Asadchy, A. Elsakka, and S. A. Tretyakov, “From the Generalized Reflection Law to the Realization of Perfect Anomalous Reflectors,” *Science Advances*, vol. 3, No. 8, Aug. 2017

⁜ Perfect anomalous reflection



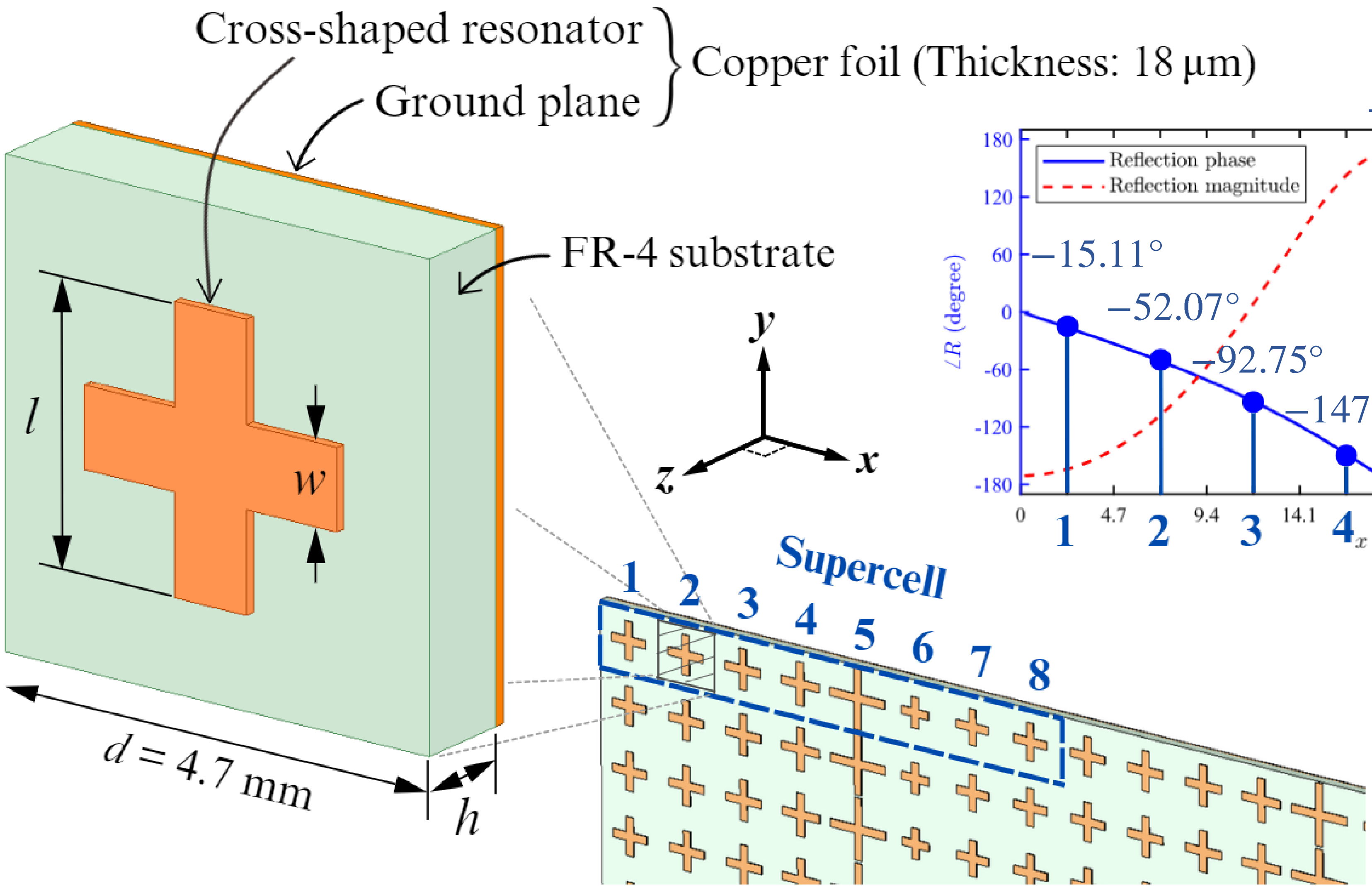
The obtained phase and amplitude of the reflection coefficient of a single supercell.

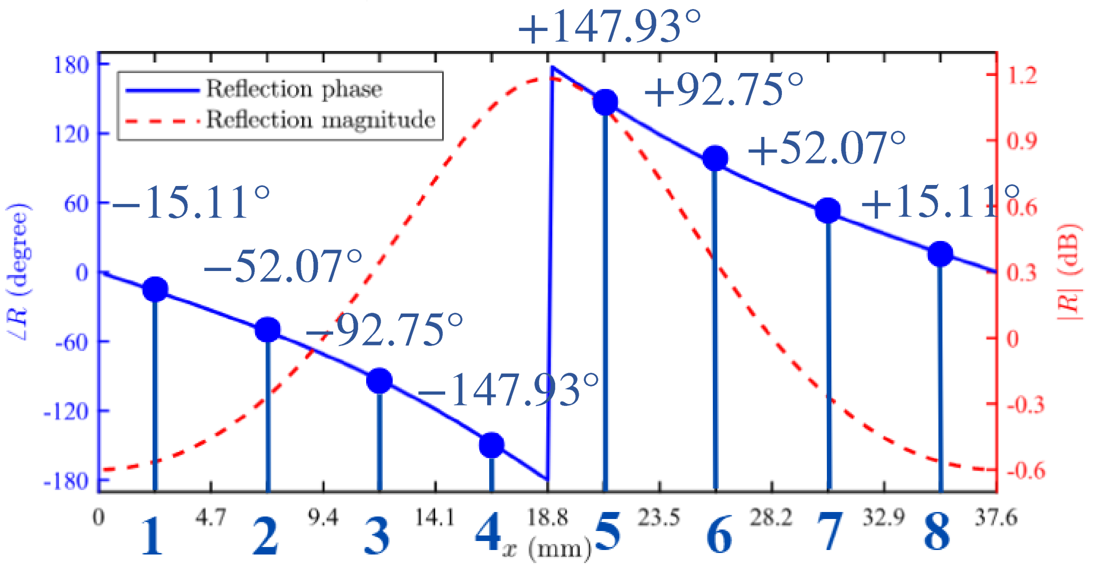
Perfect anomalous reflection



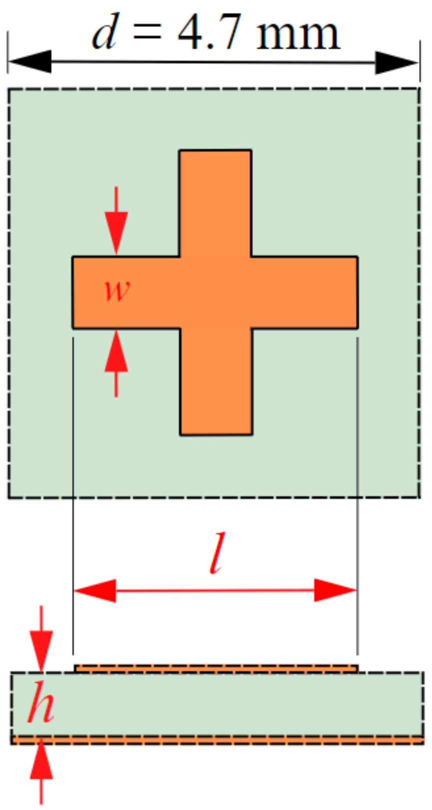
The calculated ideal scattering patterns corresponding to the perfect anomalous reflection conditions at the frequency of 25.6 GHz, 25.8 GHz and 26.0 GHz.

Design of phase-gradient metasurface

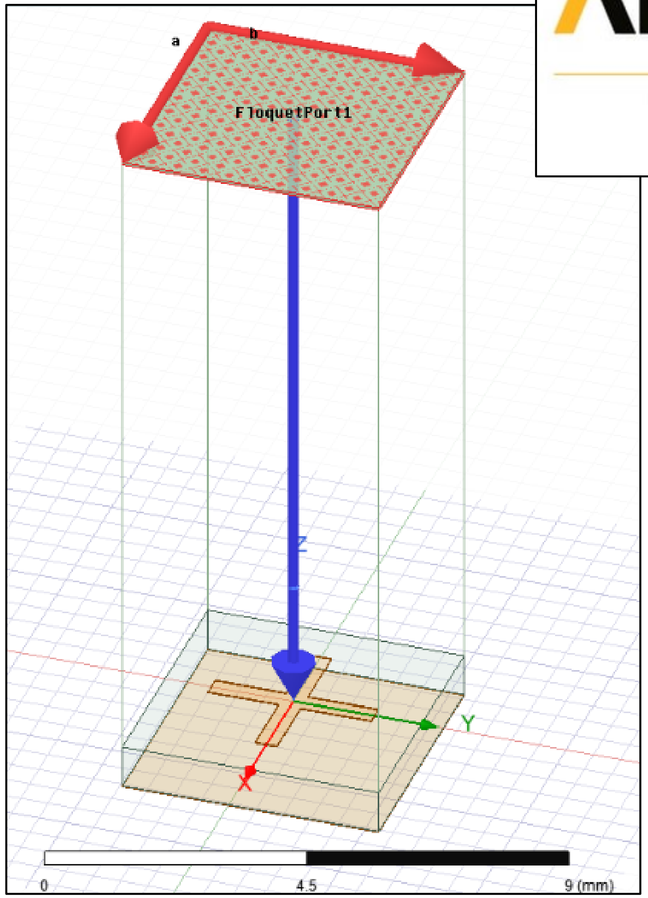




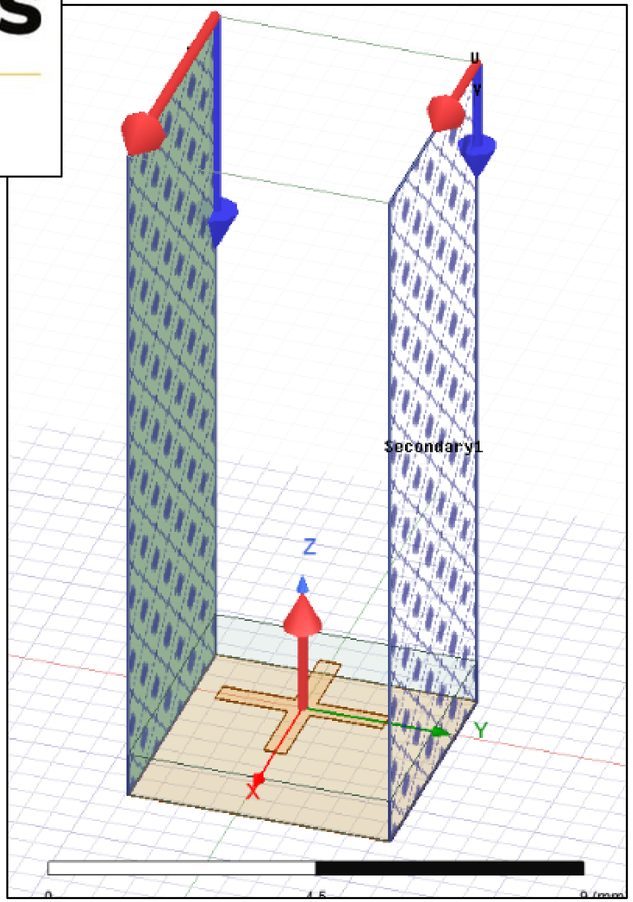
Unit cell investigation



A unit cell.

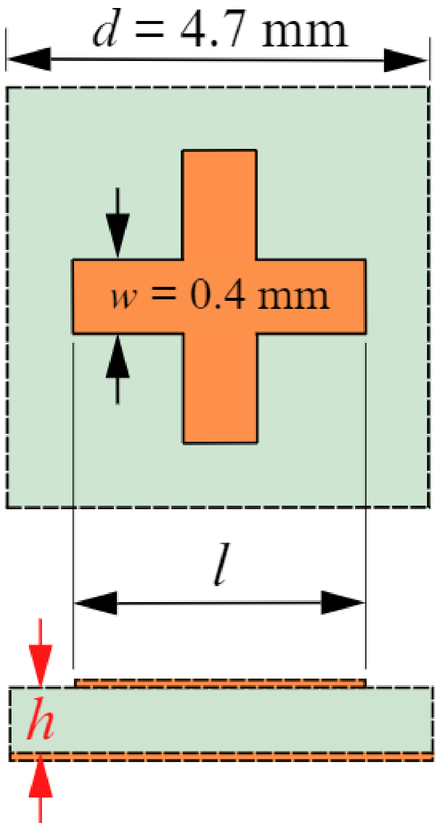


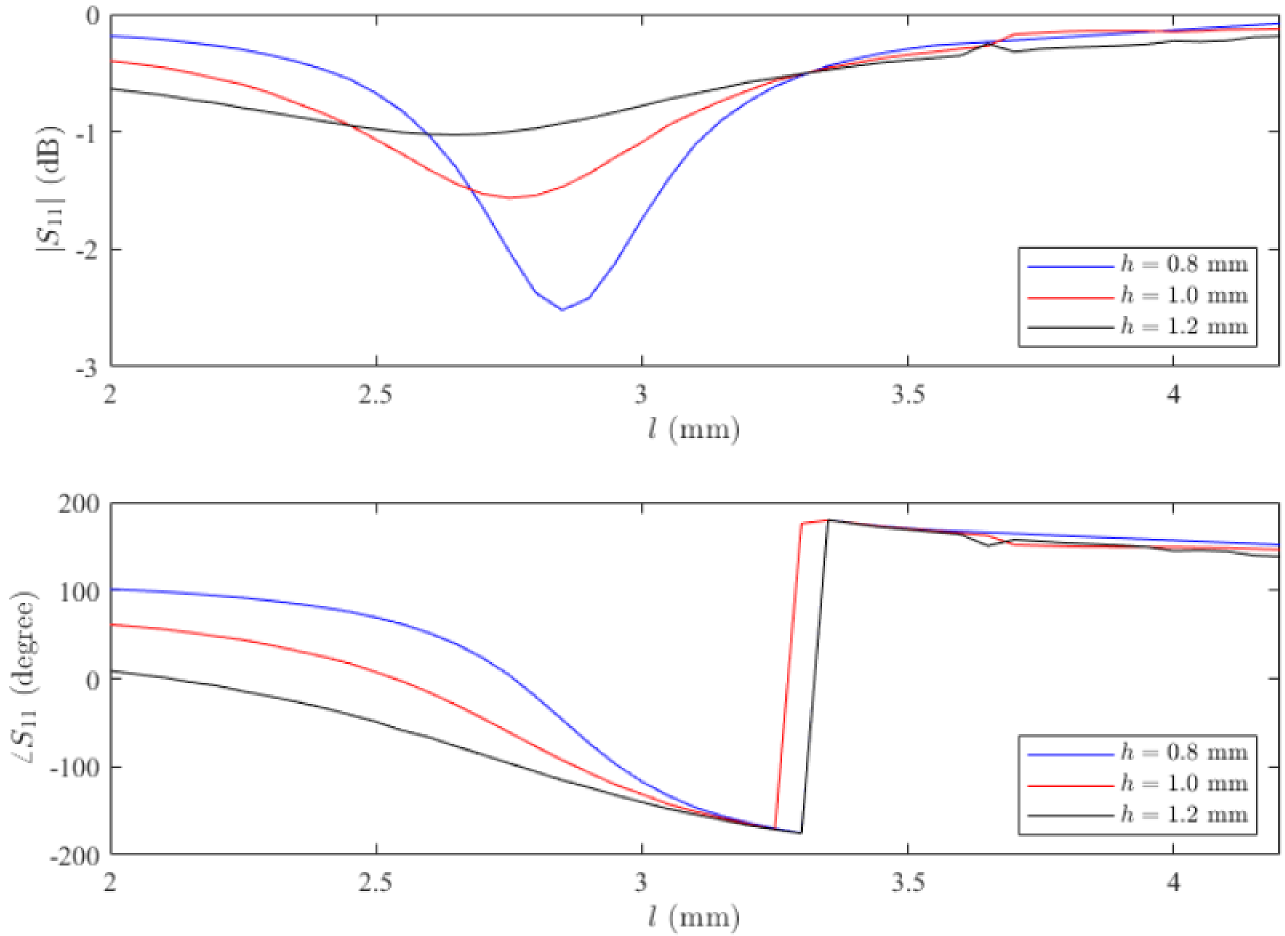
Floquet port excitation.



Periodic boundary condition.

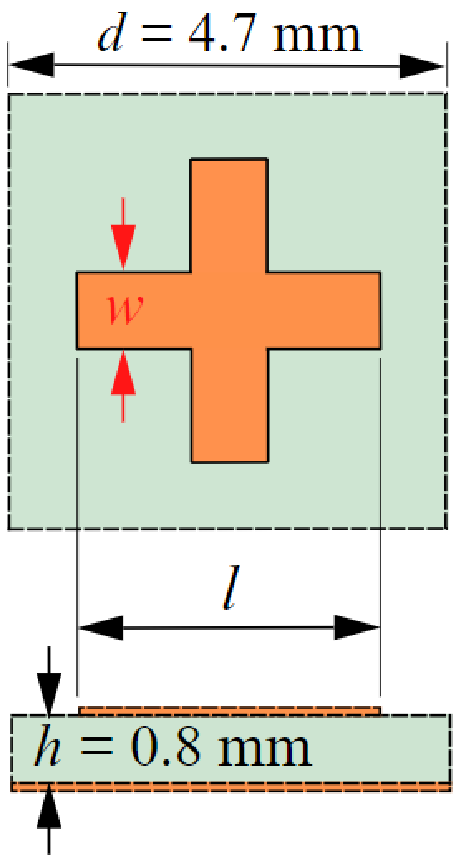
Substrate thickness variation

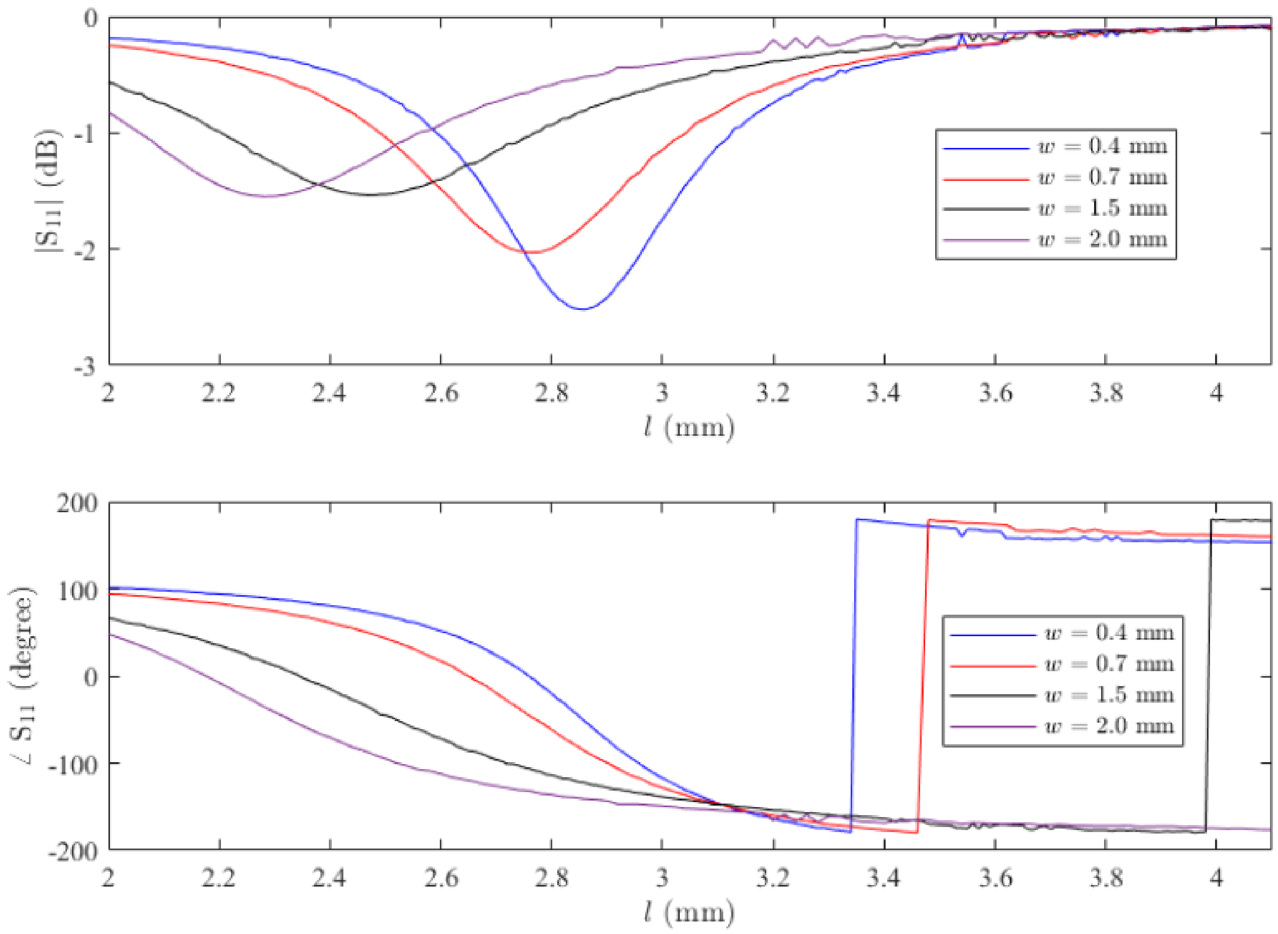




Effect of substrate thickness variation given w = 0.4 mm at 25.8 GHz.

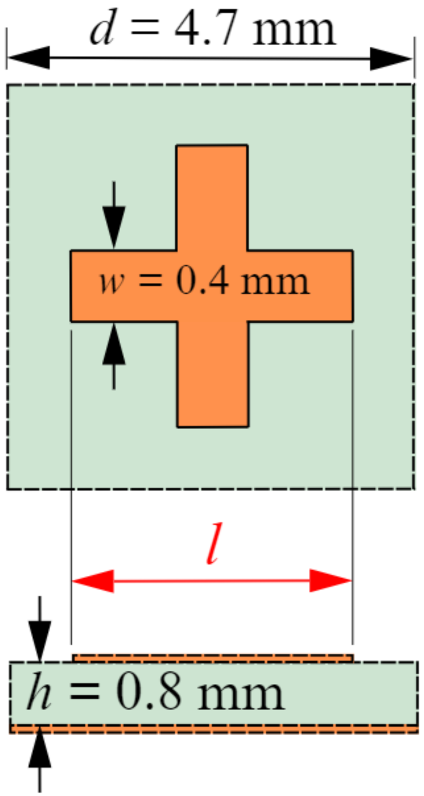
Resonator width variation





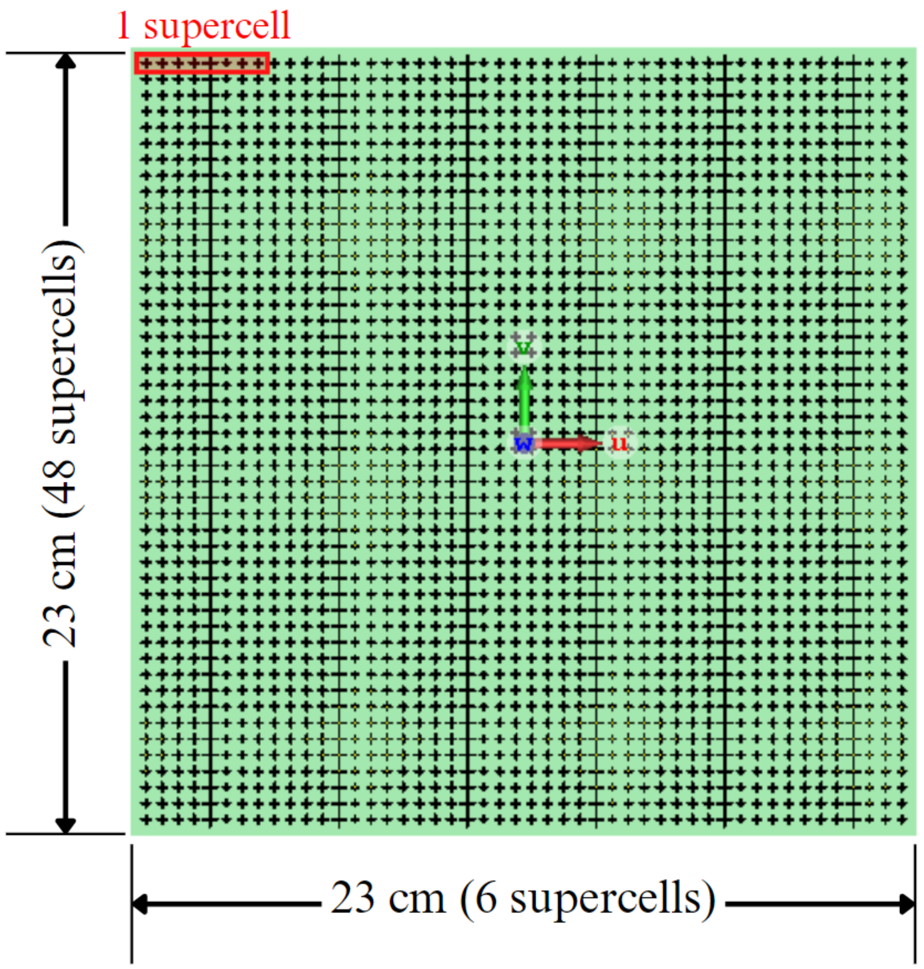
Effect of resonator thickness variation given h = 0.8 mm at 25.8 GHz.

Metasurface configuration

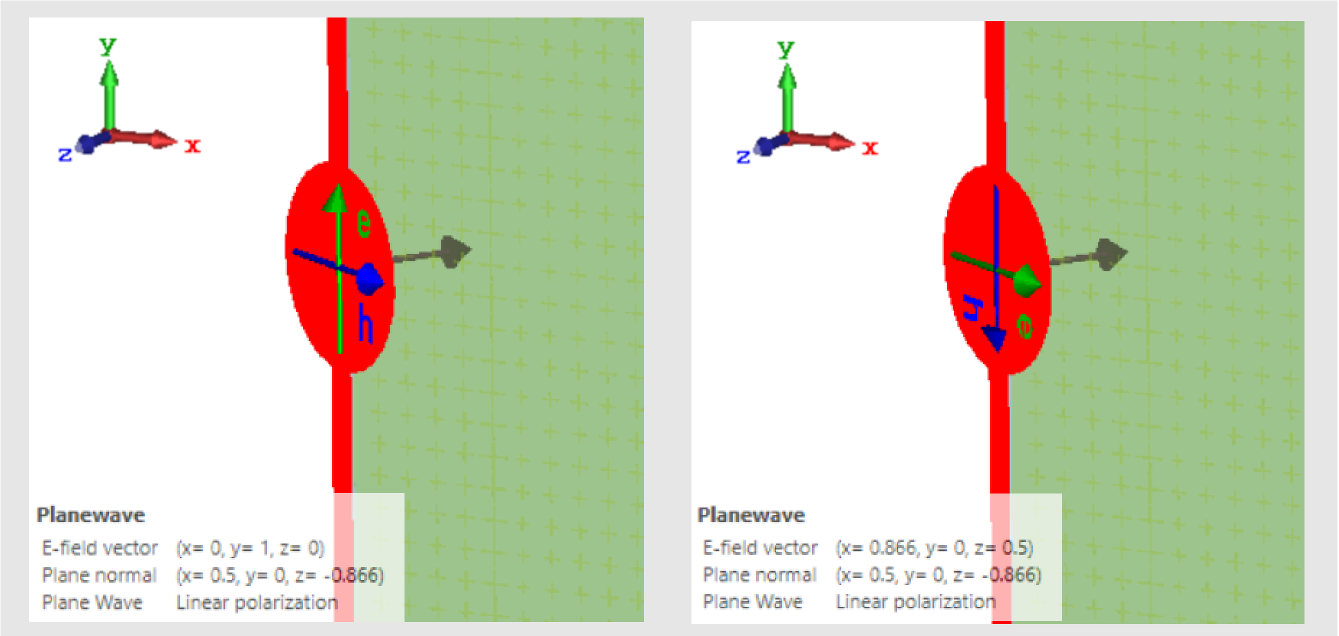


Unit cell no.	Length l (mm)	Reflection coefficient			
		Phase $\angle R$ (Degree)		Magnitude $\|R\|$ (dB)	
		Obtained	Required	Obtained	Required
1	2.79	−15.11	−16.37	−2.13	−0.56
2	2.86	−52.07	−51.26	−2.52	−0.27
3	2.94	−92.75	−93.29	−2.18	+0.34
4	3.11	−147.93	−148.10	−1.08	+1.05
5	4.50	+148.17	+148.10	−0.06	+1.05
6	2.22	+93.39	+93.29	−0.28	+0.34
7	2.60	+51.63	+51.26	−1.04	−0.27
8	2.72	+16.74	+16.37	−1.79	−0.56

Full-wave simulation



The proposed metasurface.

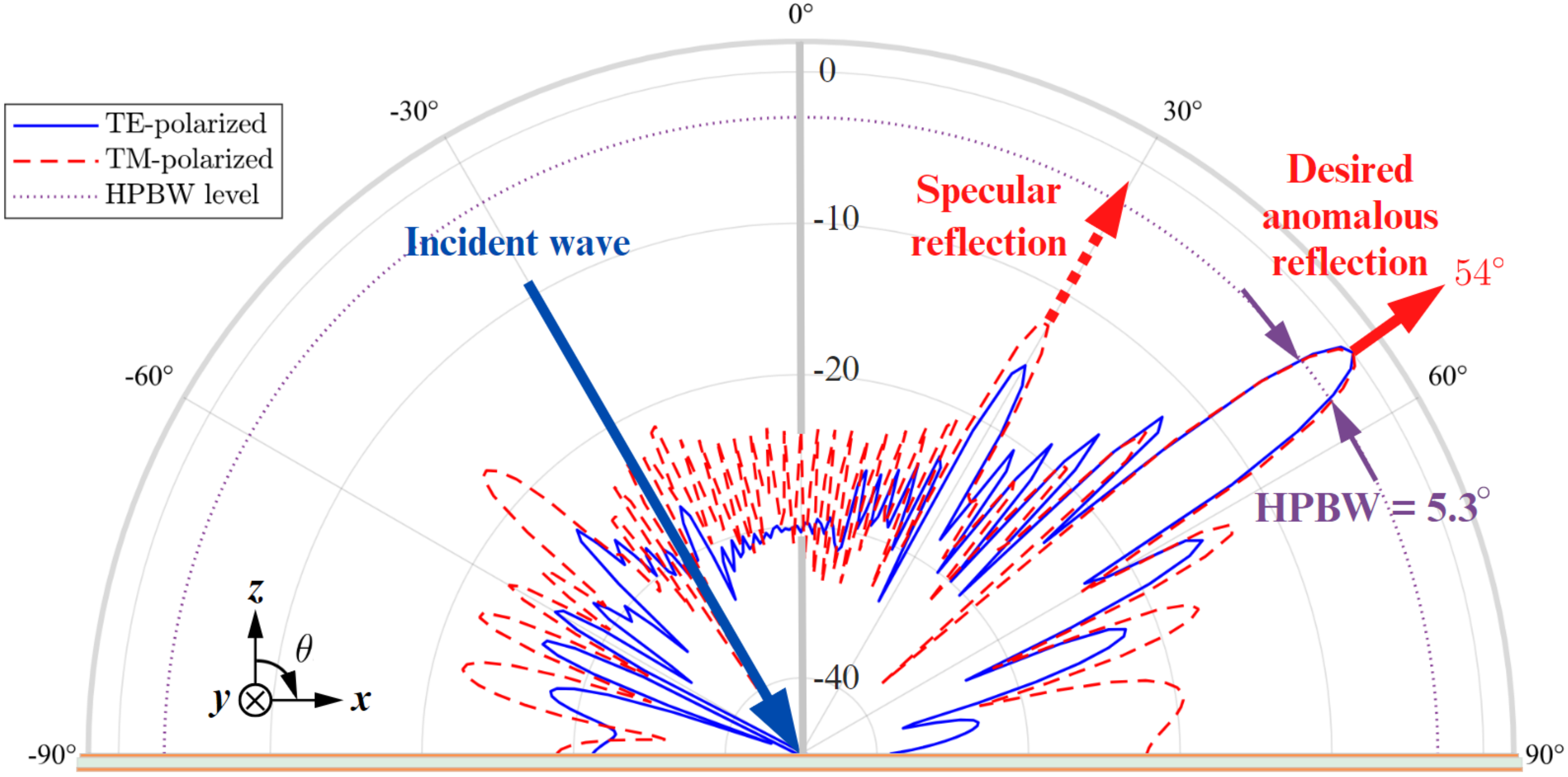


TE-polarized.

TM-polarized.

Dual-polarized incident waves.

Simulation results and discussion



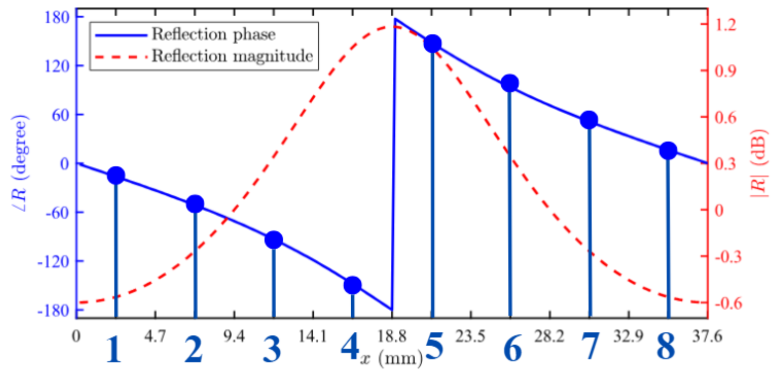
Normalized bistatic RCS patterns.

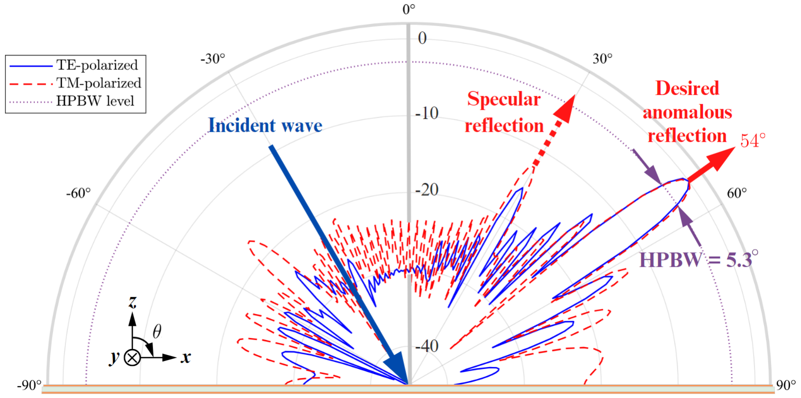
Interesting questions for future works

- How to efficiently manipulate the perpendicular electric-field component?
- Is it possible to create unit cells with positive reflection coefficients? If yes, how?
- How to integrate the anomalous reflection principle to reconfigurable metasurfaces?

Conclusion

- The phase-gradient reflecting metasurface was designed by using the perfect anomalous reflection principle.
- With a proper selection of dimension parameters, a simple cross-shaped resonator can give the reflection phase needed for a periodic arrangement of the metasurface.





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Thank you

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