Spatial Modulating Metasurface with Power Screw for Dynamic Beam Control

Sakobyly Kiv, Ratanak Phon, Junghyeon Kim, Sungjoon Lim*
Chung-Ang University*
Kiv.sakobyly168@gmail.com, ratanakelc@gmail.com, wjdgus6748@naver.com,
*sungjoon@cau.ac.kr

Abstract

Reconfigurable reflective metasurfaces (RRMs) have garnered significant attention due to their capability to control reflection characteristics. This work introduces a novel power screw-assisted reflective metasurface achieving real-time beam steering via spatial modulation. The integrated power screw enables controlled displacement and continuous beam scanning, outperforming designs with complex control systems. Experimental results demonstrate scanning from ±32° to ±15° at 28 GHz.

Ⅰ. Introduction

Metamaterials and metasurfaces offer unprecedented control over electromagnetic waves, enabling diverse functionalities like negative refraction, super-resolution imaging, and beam steering [1]. Conventional beam-steering methods, such as phased array antennas, are expensive and bulky due to complex hardware requirements. Metasurfaces provide a simpler alternative, achieving beam control through tailored unit cell design [2]. However, existing approaches often lack continuous beam scanning capabilities. This work addresses this limitation by introducing a novel power screw-assisted metasurface for continuous beam steering and spatial modulation.

Ⅱ. Method

1. Beam scanning metasurface.

This work explores a passive metasurface design for dual-beam scanning using resonated elements. The metasurface design uses resonating unit cells made of two different-sized metallic patches. As shown in Fig. 1 (a-b), Ideally, these resonators should achieve a reflection magnitude of 1 and a 180-degree phase difference between the two states. Unlike active methods, we achieve beam manipulation by varying the spatial distance (d) between fixed resonators (0-10 mm) within the metastrips. These metastrips, as illustrated in Fig. 1 (c-d), have a width (Δx) of 10 mm and a length (l) of 100 mm.

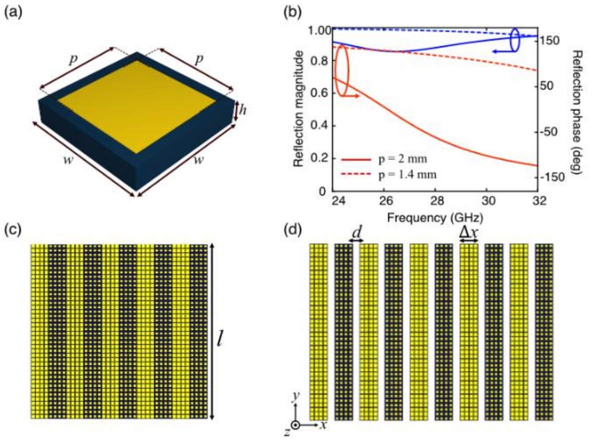

Fig.1. (a) Unit cell geometry. (b) Simulated reflection response. (c) Modulating metasurface with resonating unit cells. (d) Unit cell with 10 metastrips (d = separation distance).

The deflection angle can be expressed as:

$$\theta_r = sin^{-1}\left(a.\frac{\lambda}{\Delta x+d}\right), \tag{1}$$

$a = \frac{2\gamma+1}{2}, \gamma = 0,1,2\ldots.,$ and γ -order of the deflect angle, Δx is each metastrip length, d is the distance between metastrips, and φ is the phase.

Fig. 2(a-b) shows the theoretical prediction. First- and second-order modes are obtained at d = 0 mm and 6 mm, respectively.

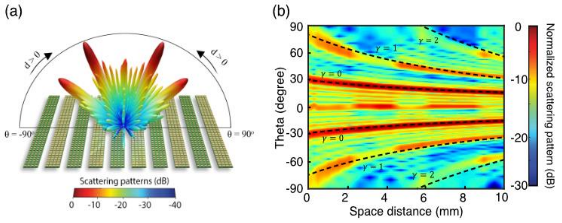

Fig. 2. Beam scanning metasurface: (a) 3D reflection at 28 GHz (b) 2D scattering patterns (d=0-10mm).

2. Power-screw mechanism.

The proposed metasurface leverages a novel power screw mechanism to achieve continuous beam scanning via spatial modulation. This mechanism translates rotational input into precise linear displacement, meticulously controlling the gaps between the metastrips. Bidirectional rotation Fig. 3 (a-b) induces expansion or compression of these gaps, enabling dynamic spatial modulation. By carefully controlling the power screw's rotation, the metasurface dynamically adjusts the gaps, facilitating real-time beam steering.

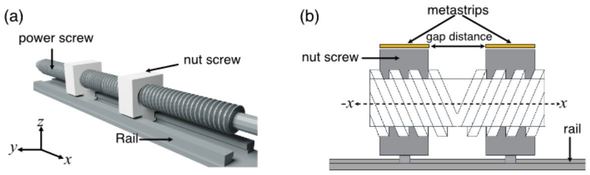

Fig. 3 (a) Bidirectional screw with dual nuts. (b) Bidirectional screw cross-section view with metastrips mounted.

3. Results

The proposed metasurface's performance was validated through bistatic measurements (26.4-40 GHz) using horn antennas and a vector network analyzer. As shown in Fig.4 The power screw mechanism enabled controlled gap variations (0-10 mm) for beam scanning. The metasurface achieved continuous beam steering from ±32° to ±15° by adjusting the screw positions (0-10 mm) at a rate of 1 mm/s.

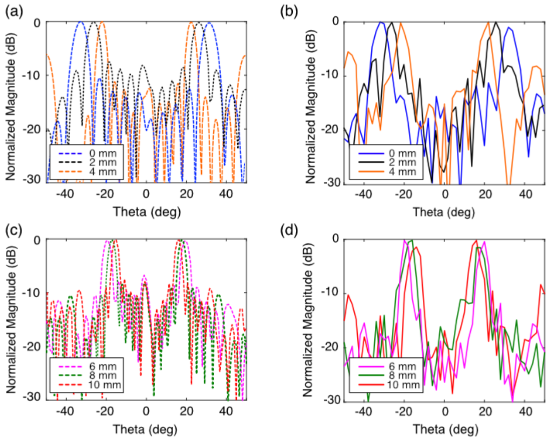

Fig. 5. Experimental Validation: Compressing & Expanding Output Waves (Simulations-dashed, Measurements-solid) (a-b) 0, 2, 4 mm; (c-d) 6, 8, 10 mm.

Ⅲ. Conclusion

The proposed power screw-assisted metasurface offers continuous beam scanning with a simple, 3D-printed design. Power screw technology enables wideband operation and surpasses methods requiring complex control systems. This work highlights a cost-effective approach for dynamic beam steering, with potential applications in radar and communication systems.

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