

Reconfigurable Cavity Antenna Based on Metallic Pins

Zejiang Lin⁽¹⁾ and Alex M. H. Wong^{(1), (2)}

(1) Department of Electrical Engineering, City University of Hong Kong, Hong Kong SAR, China

(2) State Key Laboratory of Terahertz and Millimeter Waves, City University of Hong Kong, Hong Kong SAR, China

Email: alex.mh.wong@cityu.edu.hk

Abstract—A reconfigurable cavity antenna (RCA) featuring beam steering is developed based on metallic pins. The metallic pins are pluggable, and by adjusting their distribution inside the cavity, we can modulate the antenna's aperture field with a great degree of freedom. Based on the analytical model describing the cavity field distribution, we develop the optimization algorithm to determine the optimal pin distribution for each objective beam pattern. To illustrate the concept, we present examples of the antenna under two distinct pin distributions, yielding two different dual beams respectively. One dual beam is directed towards $\pm 25^\circ$ and the other is directed to 0° and -30° . The proposed antenna is characterized by its remarkable versatility, simplicity and cost-effectiveness, making it highly promising for industrial applications.

I. INTRODUCTION

The rapid development of modern wireless systems is driving an increasingly urgent demand for reconfigurable antennas (RAs). RAs are antennas with variable characteristics (such as radiation patterns) to accommodate various operating scenarios. According to the implementation techniques, RAs generally fall into four types: electronic, mechanical, photoconductive, and tunable material-based [1]. Among these, electronic and mechanical RAs are the most prevalent.

Electronic reconfigurations feature the advantages of a high degree of freedom and high tuning speed. However, they usually rely on numerous active elements such as Positive-Intrinsic-Negative diodes, varactors, or RF MEMS, which involve complex biasing circuits, making the whole system highly intricate, bulky and costly [2]. On the other hand, mechanical reconfigurations eliminate the reliance on the active elements and biasing circuits, making them attractive for RAs that do not require high tuning speed. However, the flexibility and reconfigurability of mechanical RAs are generally quite limited, thus providing rather restricted multifunctionality.

This paper introduces a mechanical RA with high flexibility and reconfigurability, utilizing adjustable metallic pins. The distribution of metallic pins inside the antenna is highly reconfigurable, giving us a high degree of freedom to manipulate the aperture field, and hence endows the antenna with considerable multifunctionality. To validate the concept, we present examples of the antenna (operating at 7.5 GHz) under two distinct pin distributions, one producing the dual beam at $\pm 25^\circ$, and the other generating the dual beam at 0° and -30° . The proposed antenna may achieve additional functionalities by adjusting the pins to other distributions, like generating single-beam radiation in different directions or at various frequencies.

II. METHODS

Due to space constraints, we will summarize the design principles and steps without elaborate details. Fig. 1 shows the sketches of the proposed RCA, which features a perforated top metal plate. The pluggable pins can be inserted through the holes in the top plate into different positions inside the cavity to manipulate the aperture field. To achieve the objective beam pattern (for example, the symmetric dual beam shown in Fig. 1(a), or the asymmetric dual beam shown in Fig. 1(b)), we develop the optimization algorithm to find the optimal pin distributions. The optimization algorithm relies on the forward-problem analytic model which calculates the field of the RCA under a given pin distribution.

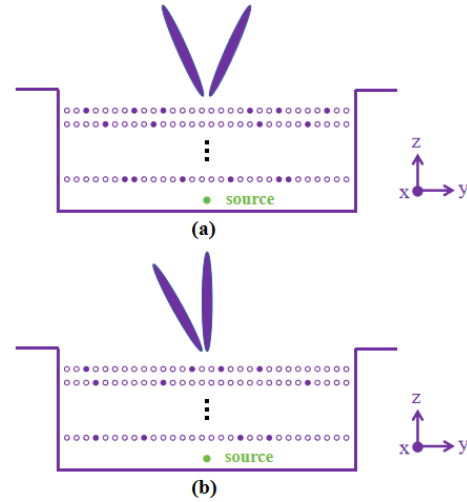


Figure 1. Sketches of the reconfigurable cavity antenna (top views). The distribution of metallic pins can be adjusted to generate different radiation patterns, for example, the symmetric dual beam in (a) and the asymmetric dual beam in (b).

Forming fields of the RCA with a set number (N) of pins involves three main steps. First, we theoretically express the fields produced by a single current (I) at a general location (y_l, z_l) inside the cavity. In this step, fields inside the cavity are expressed as a modal sum, and the coefficients of each mode are determined based on the boundary conditions at z_l and the aperture ($z_{aperture}$) [3]. The boundary condition at $z_{aperture}$ is analyzed using the mode matching method [4]. Second, we determine the current on each pin under the excitation of the given source (I_{source}). Based on the relationship between the induced current and the acting field (or the total field) on each

pin, N equations can be established to determine the currents on the N pins [5]. Lastly, we compute the total fields of the RCA by superimposing the fields generated by I_{source} and the currents on N pins.

With the analytical model at hand, we build the optimization algorithm to adjust the pin distributions iteratively, minimizing the difference between the achieved and objective aperture fields, to realize the target beam pattern.

III. RESULTS

To validate the feasibility, examples of the RCA under two optimized pin distributions are designed: one for generating a symmetric dual beam directed at $\pm 25^\circ$, and the other for producing an asymmetric dual beam directed at 0° and -30° . We use ANSYS HFSS to simulate the RCA (working at 7.5 GHz). Fig. 2 presents the configuration of the RCA under simulation, in which a flare is installed in front of the aperture to facilitate the launching of the emanating wave to free space.

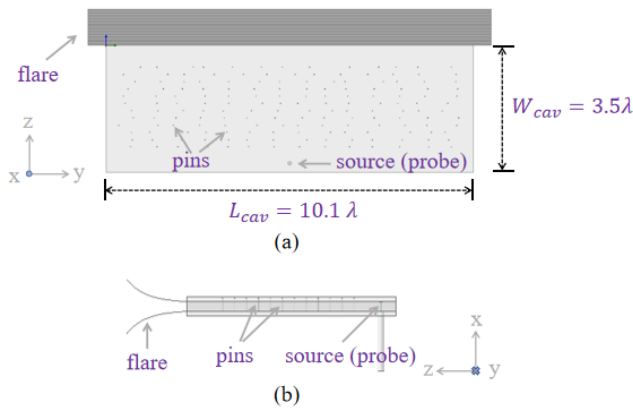


Figure 2. Configuration of the RCA. (a) Top view of the RCA, where the pin distribution is optimized for generating the asymmetric dual beam directed at 0° and -30° . (b) Left view of the RCA.

Figs. 3 (a-b) show the full-wave simulated E-field distributions of the RCAs producing the symmetric dual beam and the asymmetric dual beam. Fig. 4 presents the normalized radiation patterns for both cases, from which we can see that the symmetric dual beams point at $\pm 25^\circ$, and the asymmetric one points at 0° and -30° , aligning excellently with the design objectives. For both cases, the simulated sidelobe levels can reach -10 dB. Additionally, for the asymmetric dual beam, we especially stipulate the objective aperture field to ensure that the two main lobes of the asymmetric dual beam shown in Fig. 4 remain at the same level. Generally, the simulated results in Fig. 4 verify the effectiveness of the design methodology.

IV. CONCLUSION

This paper introduces a methodology for designing a mechanical RA with high reconfigurability, based on adjustable metallic pins. Examples of the antenna under two distinct pin distributions are designed, to generate a symmetric dual beam directed at $\pm 25^\circ$, and an asymmetric dual beam directed at 0° and -30° , respectively. The simulation results match the design targets very well, validating the high tunability and versatility of the antenna. Such a design methodology greatly enhances the flexibility and multifunctionality of mechanical RAs in a cost-

effective and simple manner, making it promising for applications in future wireless systems.

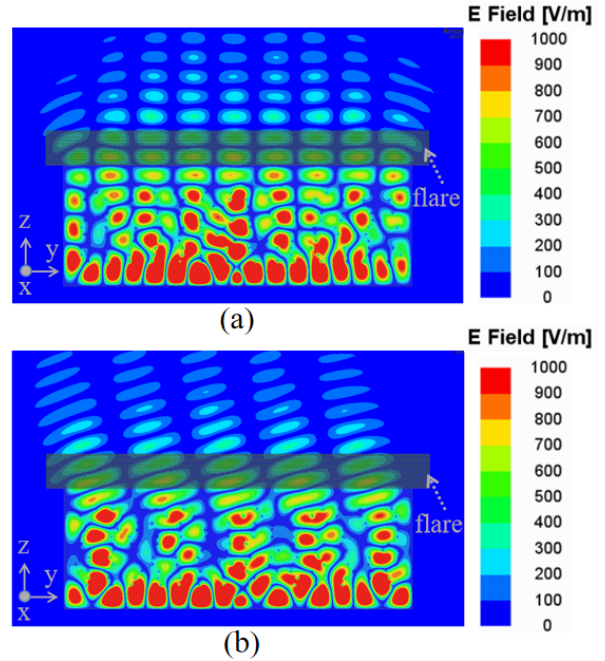


Figure 3. Full-wave simulated E-field distributions of the RCA under different pin distributions: (a) for the symmetric dual beam; (b) for the asymmetric dual beam.

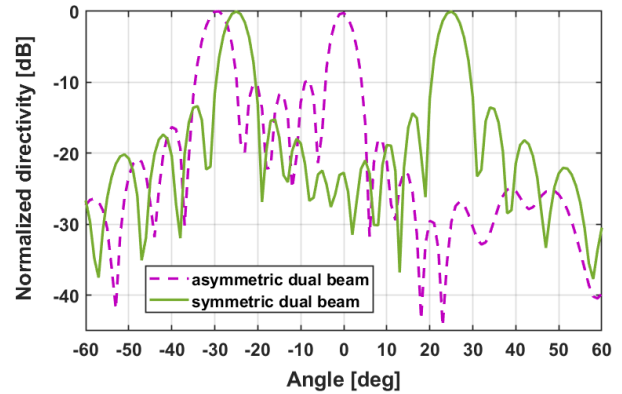


Figure 4. Normalized radiation patterns of the RCA under two distinct pin distributions for generating the symmetric and asymmetric dual beams respectively.

REFERENCES

- [1] N. O. Parchin, H. J. Basherlou, Y. I. A. Al-Yasir, A. M. Abdulkhaleq, and R. A. Abd-Alhameed, "Reconfigurable Antennas: Switching Techniques-A Survey," *Electronics*, vol. 9, no. 2, Art no. 336, Feb 2020.
- [2] H. L. Zhu, S. W. Cheung, X. H. Liu, and T. I. Yuk, "Design of Polarization Reconfigurable Antenna Using Metasurface," *IEEE Trans. Antennas Propag.*, vol. 62, no. 6, pp. 2891-2898, 2014.
- [3] F. Hu and A. Epstein, "Cavity-Excited Switched-Beam Metagrating Antennas," in *Proc. European Conference on Antennas and Propagation (EuCAP)*, Florence, ITALY, Mar 2023.
- [4] J. D. Heeb, M. Ettorre, and A. Grbic, "Wireless Links in the Radiative Near Field via Bessel Beams," *Physical Review Applied*, vol. 6, no. 3, Art no. 034018, Sep 2016.
- [5] F. M. Hu and A. Epstein, "Large-Aperture Cavity-Excited Metagrating Antennas for Dynamic Beam Switching," in *Proc. International Workshop on Antenna Technology (iWAT)*, Aalborg, DENMARK, May 2023.