

# A Low-Cost Arbitrary Electromagnetic Wave Polarization Detection Approach Based on Energy Harvesting Metasurface

Runze Huang, *Student member, IEEE*, and Yan Zhang, *Member, IEEE*

**Abstract**—To fill the gap in the polarization sensing of 6G, this project proposes and develops an arbitrary polarization detection system based on an energy harvesting metasurface (EHM). The system employs a pair of orthogonal polarization-sensitive EHM to independently collect the two orthogonal polarization components of the incident wave, and then converts them into a DC voltage through the respective rectifiers. By deriving the analytical relationship between the output voltage and the polarization angle of the incident wave, the voltage polarization discrimination ratio is established. A line polarization wave discrimination method is established, and an experimental system is developed for verification. The measurement indicates that at 5.8 GHz, the polarization-sensitive EHM achieves an energy harvesting efficiency of 82.1%. The DC output voltage is 0.927 V when the input power is 5 dBm. The developed linear polarization detection demonstration system has a polarization angle detection error of less than  $2.3^\circ$  for linearly polarized incident waves without the requirement of calibration. When the circular polarization axis ratio is less than 3 dB, the axis ratio linear value detection error can be maintained within  $\pm 0.1$ .

**Index Terms**—Polarization detection, energy harvesting, metasurface, rectifier.

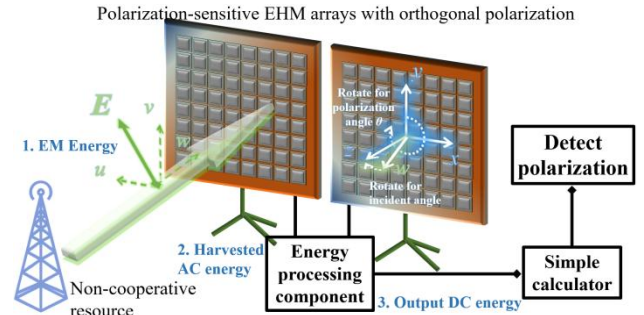
## I. INTRODUCTION

In the sixth-generation (6G) mobile communication system, the integration of communication and sensing is one of the key research focuses in the industry. Metasurfaces are considered an important part for deploying 6G due to their flexibility and powerful electromagnetic wave control capabilities. Polarization matching is crucial for the electromagnetic wave transmission between the transmitter and the receiver [1]. In wireless communication systems such as satellite communication, long-distance microwave links, and radar, polarization adaptation has a significant impact on signal quality and reception efficiency. Especially when receiving electromagnetic waves from unknown or non-cooperative sources, it is necessary to pre-detect or estimate the polarization state and polarization angle of the incident wave to ensure polarization matching. In the field of polarization sensing, traditional polarization detection or tracking systems mainly rely on active components and circuits, which are costly and have complex structures,

contrary to the low-power consumption and low-cost goals in 6G [2]. EHM has flexible electromagnetic wave control and capture capabilities, as well as low power consumption and low-cost features, and is expected to achieve important applications in the 6G sensing field [3][4].

## II. DESIGN AND MEASUREMENT OF POLARIZATION DETECTION SYSTEM

The proposed polarization detection approach is illustrated in Fig. 1(a). Two identical polarization-sensitive EHMs are placed on the  $xy$ -plane orthogonally to harvest either the  $x$ -polarized or  $y$ -polarized component of the normal incident impinging EM wave from a non-cooperative source, respectively. In order to detect arbitrary polarization, the energy processing is divided into amplitude detection and phase detection. The amplitude detection identifies the ratio of the  $x$  and  $y$  components by using two simple rectifiers, while the phase detection identifies the phase difference between the  $x$  and  $y$  components using a directional coupler, a power combiner, and a rectifier. Finally, after a simple calculation, arbitrary polarization can be detected, including linear polarization angle, circular (elliptic) polarization handedness, and axis ratio.

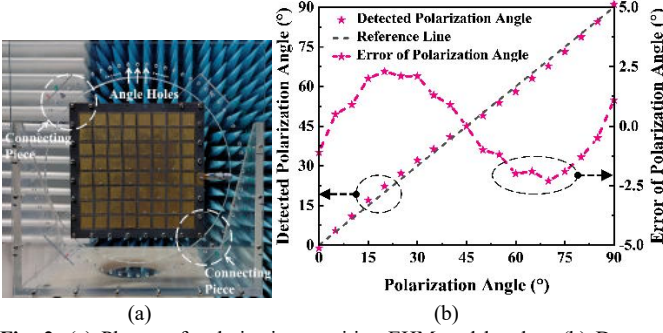


**Fig. 1.** Diagram of the proposed polarization detection approach based on two EHMs with orthogonal-polarization sensitivity.

### A. Linear polarization detection

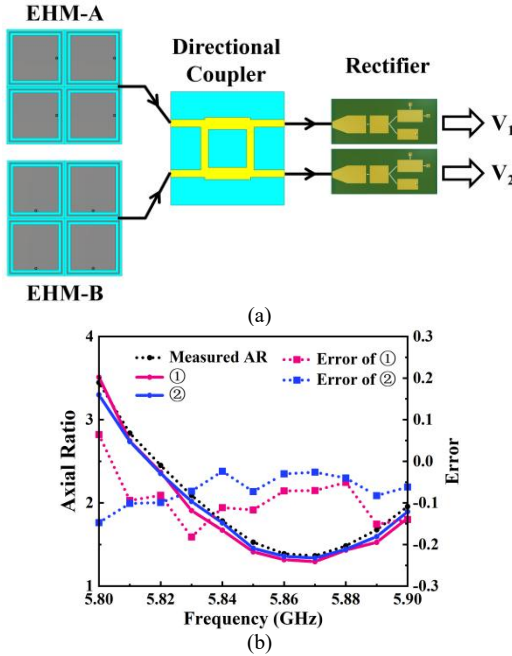
For the EHM, the fabricated PCB of  $8 \times 8$  unit cells and the PCB of the power combiner are installed together through screws, shown in Figs. 2(a). A plexiglass bracket is fabricated to mount the polarization-sensitive EHM through nylon screws, and a rotation with a  $5^\circ$  stepwise is supported by fixing the EHM to the holes distributed continuously along a circle on the bracket. The polarization detection result is plotted in Fig. 2(b). The black dashed line plots the true value of the polarization angle, and the estimated polarization angles are

marked with stars. To clearly show the error between the real value and estimations, the error of the polarization angle is computed and shown in Fig. 2(b) as well. It can be seen that the error is less than  $2.3^\circ$  in the conceptual experiment. Note that if the compound polarization detection voltage ratio (PDVR) is used in the estimation, the error can be greatly reduced. Hence, a calibration is highly recommended with the compound PDVR in practice before performing the polarization detection.



**Fig. 2.** (a) Photos of polarization-sensitive EHM and bracket. (b) Detected polarization angle and corresponding error.

### B. Circular polarization detection



**Fig. 3.** (a) Diagram of circular polarization detection. (b) Comparison of measured axial ratio with simulation results.

Based on the linear polarization detection, the axial ratio (AR) of circular polarization can be calculated by adding a directional coupler, and thus, the circular polarization detection can be completed as shown in Fig.3(a). Fig. 3(a) shows the error between the simulated AR and the measured AR. Here, "①" represents the AR obtained by the simulation of the directional coupler, and "②" represents the AR obtained by the rectifier circuit simulation. The measured error of AR is basically controlled within the range of  $\pm 0.2$ . When the axis is less than 3 dB, the error is within  $\pm 0.1$ .

When using this system to detect AR of circular polarization in practice, if a certain degree of error is acceptable, it is sufficient

to only test the performance of the EHM and directional coupler, and then combine the simulation results of the rectifier circuit for calibration. This can also reduce the system calibration time and complexity, and improve the measurement accuracy.

### III. CONCLUSION AND FUTURE WORK

This project has achieved a low-cost and low-power method for detecting linearly polarized incident waves based on polarization-sensitive EHM, as well as a detection method for arbitrary polarized incident waves. A prototype of the polarization-sensitive EHM with a rectifier is fabricated and measured for conceptual demonstration. It is observed that a polarization angle detection error of less than  $2.3^\circ$  and an AR error within  $\pm 0.1$  is achieved, which shows that the proposed approach has a high accuracy. The proposed polarization detection approach does not require any RF components or a network, and it has the advantages of low cost and simple structure. The proposed approach can be further developed as a sensor, which is promising for polarization detection and polarization tracking of anonymous or non-cooperative radiation sources with slow-time variation properties.

In the future, the project will integrate motors, high-precision turntables, and an FPGA to achieve the integration and automation of linear polarization and circular polarization detection, and improve system efficiency while reducing losses.

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