Broadband Energy Harvesting Metasurface Covering WiFi band with Wide-Angle Incidence

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2023 IEEE International Symposium On Antennas And Propagation (ISAP) | 979-8-3503-4114-0/23/$31.00 ©2023 IEEE | DOI: 10.1109/ISAP57493.2023.10388729

***Abstract*—A broadband energy harvesting electromagnetic energy metasurface with wide-angle incidence characteristic is proposed in this paper. The structure consists of four quarter metal rings plus H-shaped metal patches. The lumped elements are placed on the surface of the metasurface Enables efficient broadband harvesting of energy at 2.45 GHz and 5.8 GHz frequency points. And the bandwidth with an efficiency of more than 90% reaches 2.6 GHz, and the bandwidth with an efficiency of more than 80% reaches 3.43 GHz. The relative bandwidth with an energy harvesting efficiency of more than 80% is 83.67%, and with an energy harvesting efficiency of more than 90% is 65.64%.**

Keywords—metasurface, energy harvesting, broadband, wide-angle, WiFi band

I. Introduction

Wireless energy transfer has always been a key research topic in electromagnetic research. Wireless Power Transfer (WPT) and Wireless Energy harvesting (WEH) technology are the key technologies for the realization of unlimited energy transfer with high expectations. Among them, the receiving and transmitting antennas, which are currently widely used, have certain defects at the technical level, that is, the inverse contradiction of efficiency and caliber. Since the antenna aperture size is limited, the work efficiency will be limited, which is not conducive to the miniaturization of the receiving antenna. In addition, while ensuring efficient collection, the collection of RF signals with scattered spectrum in the environment also needs to meet the characteristics of wide-angle incidence, polarization insensitivity, broadband collection, and multi-frequency collection, so the design of the receiving antenna has received certain challenges. Therefore, the proposal of electromagnetic metasurface provides a good method for solving the above problems. By changing the metasurface unit cell structure, we can achieve high-efficiency broadband and multi-frequency collection of ambient RF energy instead of the receiving antenna, and also realize the characteristics of polarization insensitivity and wide-angle incidence. In addition, the rectifier metasurface formed by connecting the unit cell with the rectifier circuit can also convert the collected energy into direct current, which is used by subsequent circuits.

Due to the great advantages of the controllability and miniaturization of electromagnetic metasurfaces compared with traditional UWB antenna structures[1], the exploration and research of electromagnetic metasurfaces have been ongoing, and are developing in the direction we hope. Reference [2] shows a complementary structure of an H-type metal patch that enables energy harvesting in the 5 GHz to 6 GHz band and subsequent energy conversion through a rectifier circuit. Reference [3] designs a dual-polarization energy-harvesting metasurface consisting of a cross-patch and a coaxial port loaded with a combination of matched resistors to simulate the input impedance of a load or rectifier. It captures efficiency at the normal incident frequency of 7.11 GHz. Reference [4] proposes a multi-band energy harvesting metasurface that consists of a loop with branches and square with two lumped elements to connect the middle arm. There are also some papers in the field of broadband energy harvesting. Reference [5] and [6] respectively give a novel resonator comprising metallic mirrored split rings and hollow cylinders and a concentric split-ring resonators to maximize the harvesting bandwidth and make the energy harvesting more efficient. In reference [7], a wide-coverage suspended metasueface electromagnetic energy harvester for ISM（Industrial Scientific Medical）band application is proposed, achieving more than 90% energy harvesting efficiency from 2.13 GHz to 2.64 GHz.

In this paper, a structure with wide-angle incidence characteristic consisting of four quarter metal rings plus H-shaped metal patches is proposed. Its energy harvesting efficiency at both 2.45 GHz and 5.8 GHz frequency points exceeds 80%, and the bandwidth with an efficiency of more than 90% reaches 2.6 GHz, and the bandwidth with an efficiency of more than 80% reaches 3.43 GHz. This structure aims to collect the electromagnetic wave energy of the WiFi band in the complex RF signal in the environment for the utilization of specific band energy with practical application significance. The subsequent connection of the rectifier structure to convert the collected AC energy into DC will further give the structure significance in industrial applications.

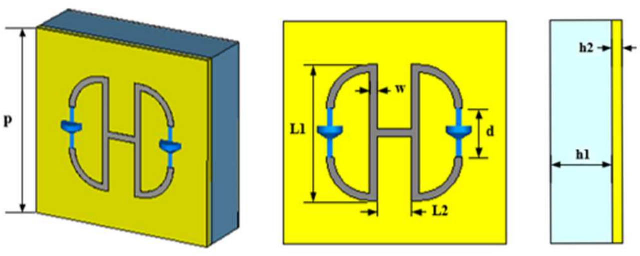

Figure 1. Geometry of the metasurface: (a) perspective view (b) top view (c) side view.

II. Metasurface Unit Cell Design

Figure 1 shows the metasurface element structure with four quarter metal arcs distributed over four corners on the top layer, connected by an H-shaped metal patch in the middle, and collecting resistors connected between the upper and lower arcs with 8 mm lumped elements. The air layer connects the media substrate layer to the metal ground. The dielectric constant ε_r and dielectric loss angle δ of FR-4 are set to 4.3 and 0.027. And the thickness of the metal patch and metal ground of the dielectric substrate is set to 0.035 mm. After numerous simulation optimizations and a comparative analysis of the results, the parameters of the metasurface are set to P = 36 mm, $L1$ = 24.20 mm, $L2$ = 6.05 mm, w = 1.38 mm, d = 8 mm, $h1$ = 10 mm and $h2$ = 1.6 mm. After a series of trial and optimization choices the lumped elements value on the upper surface is set to 500Ω.

III. Results and Discussion

As shown in Fig. 2, it is observed that the collected energy is distributed to the various structures on the metasurface, including lumped elements, dielectric substrate (FR-4) and metal patch. The energy dissipated on FR-4 is small, and even zero on metal, and almost all the energy is collected by lumped elements.

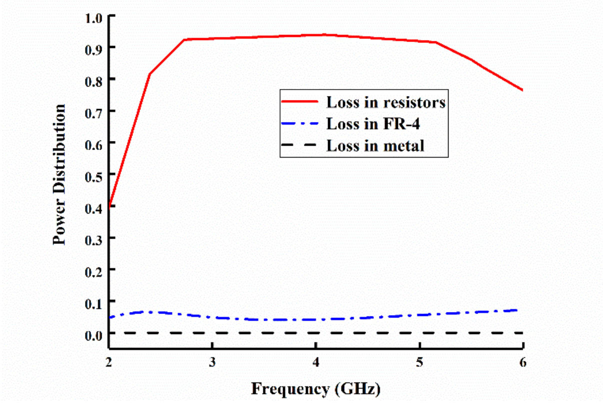

Figure 2. Power distribution into the metasurface unit cell structure.

In order to explore the influence of metasurface unit cell side length on its energy harvesting efficiency, a large number of simulation analyses are carried out using CST software under different side length conditions, and the results are shown in Fig. 3. Finally, the 36mm side length parameter value that is optimal for bandwidth and efficiency is selected. Under this parameter condition, the bandwidth of energy harvesting efficiency reaches 2.6 GHz above 90%, and the bandwidth reaches 3.43 GHz above 80%, of which the efficiency at 2.45 GHz and 5.8 GHz frequency points reaches more than 80%. The relative bandwidths of 83.67% for energy harvesting efficiencies greater than 80% and 65.64% for energy harvesting efficiencies greater than 90% demonstrate the efficacy of the metasurface structural elements for broadband energy harvesting.

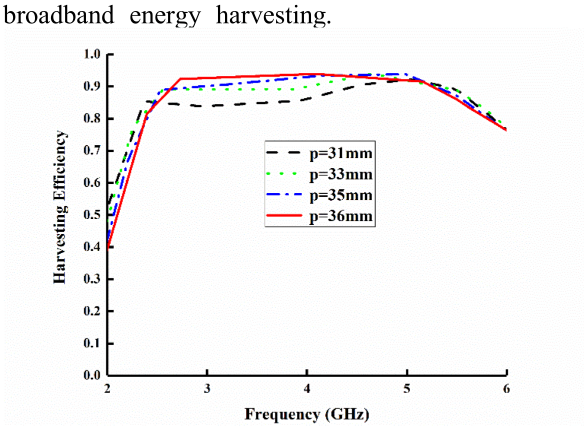

Figure 3. Harvesting efficiency at different unit cell side lengths

In Fig. 4, a large number of simulations are performed on the effect of varying the angle of incidence on the energy harvesting efficiency. It can be observed from the figure that the collection efficiency has not been greatly reduced at an angle of incidence of 0° to 45° (except for a certain fluctuation at 15°), the highest harvesting efficiency reaches more than 90% and it has good performance at 2.45 GHz and 5.8 GHz with the bandwidth still meeting the broadband collection range. It is only at 60° that there is a certain significant decrease. In general, the metasurface unit cell structure satisfies the characteristics of wide-angle incidence.

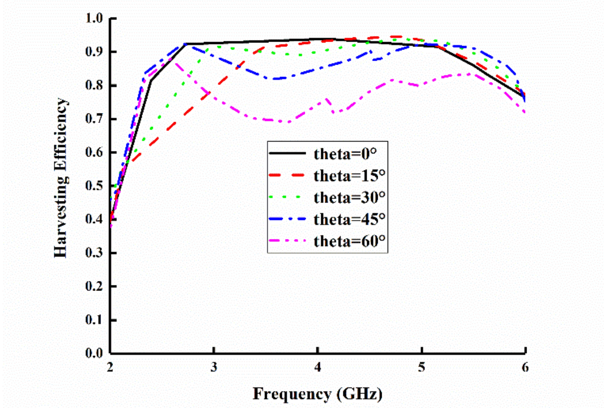

Figure 4. Energy harvesting efficiency at different incident angles.

IV. Conclusion

In this paper, an electromagnetic metasurface structure with good energy harvesting efficiency (greater than 80%) and wide angle of incidence characteristics in the frequency range of 2.45 GHz to 5.8 GHz is proposed. This electromagnetic metasurface structure successfully realizes broadband harvesting of electromagnetic energy in the environment. Among them, the band width of more than 90% of the collection efficiency reaches 2.6 GHz, and the band width of more than 80% of the collection efficiency reaches 3.43 GHz, and the structure has good energy harvesting performance at the frequency points of 2.45 GHz and 5.8 GHz with a wide range of practical applications. In addition, at an incidence angle of 0° to 45°, the metasurface still ensures that the energy harvesting efficiency does not decrease significantly, and has a wide angle of incidence characteristics.

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