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Circular Polarization of MACKEY Q-Type

Koki Iijima
Electrical and Electronic Engineering
Kanazawa Institute of Technology
Nonoichi, Ishikawa, Japan
b1813979@planet.kanazawa-it.ac.jp

Keito Yokoe
Electrical and Electronic Engineering
Kanazawa Institute of Technology
Nonoichi, Ishikawa, Japan
b1995149@planet.kanazawa-it.ac.jp

Michinori Yoneda
Electrical and Electronic Engineering
Kanazawa Institute of Technology
Nonoichi, Ishikawa, Japan
b1812587@planet.kanazawa-it.ac.jp

Hajime Suzuki
Electrical and Electronic Engineering
Kanazawa Institute of Technology
Nonoichi, Ishikawa, Japan
b1845590@planet.kanazawa-it.ac.jp

Shigeru Makino
Electrical and Electronic Engineering
Kanazawa Institute of Technology
Nonoichi, Ishikawa, Japan
makino@neptune.kanazawa-it.ac.jp

Kenji Itoh
Electrical and Electronic Engineering
Kanazawa Institute of Technology
Nonoichi, Ishikawa, Japan
itoh.kenji@neptune.kanazawa-it.ac.jp

***Abstract*—The metasurface-inspired antenna chip developed by KIT EOE Laboratory (MACKEY) is a small antenna that is not affected by metals. The MACKEY Q-type was developed based on MACKEY. It was miniaturized to a square of side λ/4. This study proposes an antenna that can radiate circularly polarization by cutting into the grid plate.**

Keywords—MACKEY, metasurface-inspired antenna, two polarizations, λ/4 squared

I. Introduction

The metasurface-inspired antenna chip developed by the KIT EOE Laboratory (MACKEY) is a small antenna that remains unaffected by surrounding metals [1]. The MACKEY II unbalanced type, which is a thinner version of MACKEY and uses an inverted L-shaped antenna as a feeding element for unbalanced power supply, was also developed [2]. The MACKEY Q-type was developed based on the MACKEY II unbalanced type [3]. It was miniaturized to a square with a side length of λ/4, using two shorting plates.

Fig. 1 shows the model diagram of the MACKEY Q-type designed for Wi-Fi 2-GHz band. The model consists of three layers: metal, antenna, and grid plates, with a dielectric filling the gap between the plates. The grid and metal plates act as artificial magnetic conductor substrates for working on the metal, and the grid and antenna plates act as antenna substrates for radiation. Fig. 2 shows the voltage standing wave ratio (VSWR) characteristics of this model. This model works in both free space and in metal.

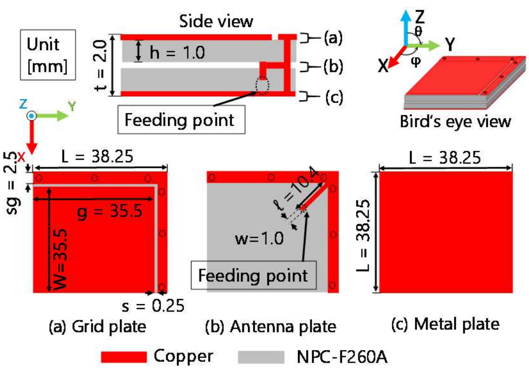

Fig. 1. Model diagram of MACKEY Q-type

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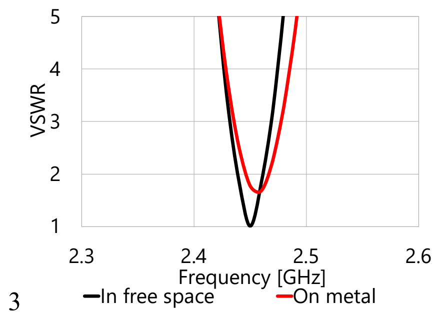

Fig. 2. VSWR characteristics of MACKEY Q-type

II. Proposal of circularly polarized MACKEY Q-type

A. Principle of MACKEY Q-type

The principle of the MACKEY Q-type system is discussed in this sub-section. Power is supplied from the second layer of the antenna plate and the supplied power is transmitted between the shorting and grid plates. Radio waves are radiated at the left and bottom edges of the grid plate. Because the radio waves radiating from each side are orthogonal with equal amplitudes and phases, the combined wave radiates a linearly polarized wave with φ = 135°, and the gain is 3 dB greater than that at φ = 90°, where φ is the angle of rotation along the x-axis.

B. Circularly polarization design method

Fig. 3 shows the amplitude and phase frequency responses of the circularly polarized MACKEY Q-type. Orthogonal modes #1 and #2 are generated on the grid plate. To radiate circularly polarized waves, the relative phases of the two modes should be 90°. By making a cut at the bottom edge of the grid plate, the resonant frequency of mode #1 becomes lower than that of mode #2. Therefore, by varying the depth of the cut d, the relative phases of modes #1 and #2 are designed as 90°.

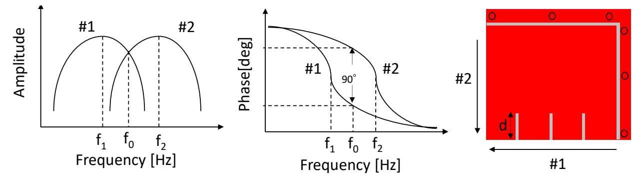

Fig. 3. Amplitude and phase frequency response

III. Analysis Results

The results of the analysis of the circularly polarized MACKEY Q-type are discussed in this section. The analysis was performed using an electromagnetic field simulator (ANSYS HFSS) based on the finite element method. The diagram of the model used for the analysis is shown in Fig. 4. Matching was performed by varying the grid plate height W, grid plate width g, and antenna length ℓ. Fig. 5 shows the VSWR characteristics in free space and on the metal. Fig. 6 shows the amplitude and phase of the far field in the Z-axis direction in free space and on the metal. Fig. 7 shows the axial ratio characteristics in the Z-axis direction in free space and on the metal. Fig. 8 shows the radiation patterns at 2.45 GHz for the cut planes φ = 0° and φ = 90°.

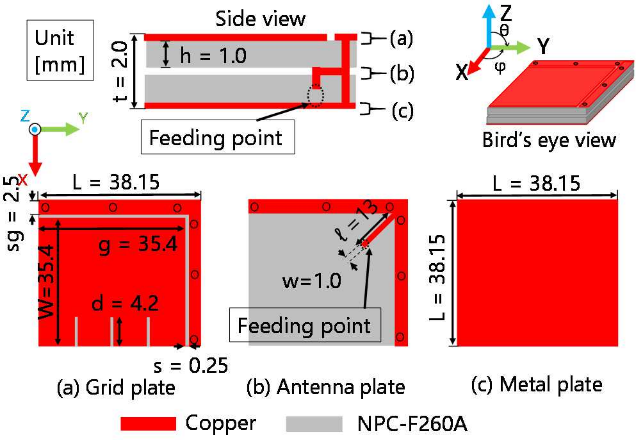

Fig. 4. Model diagram of circularly polarized MACKEY Q-type

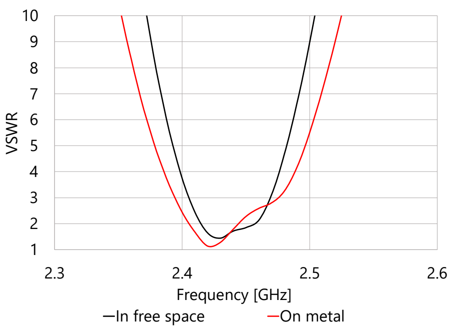

Fig. 5. VSWR characteristics of circularly polarized MACKEY Q

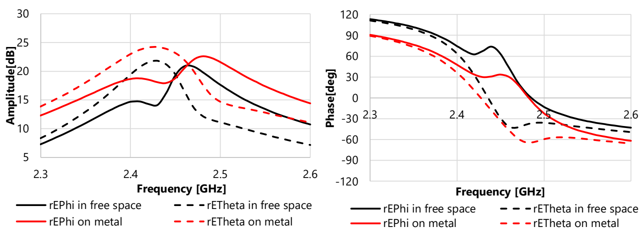

Fig. 6. Amplitude and phase of far field electric field

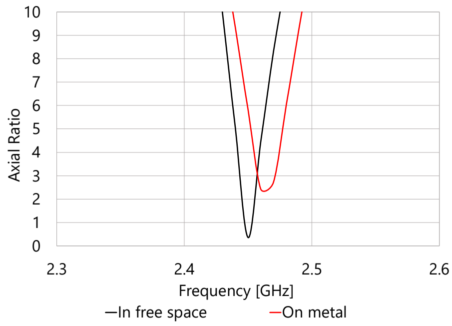

Fig. 7. Axial ratio characteristics of circularly polarized MACKEY Q-type

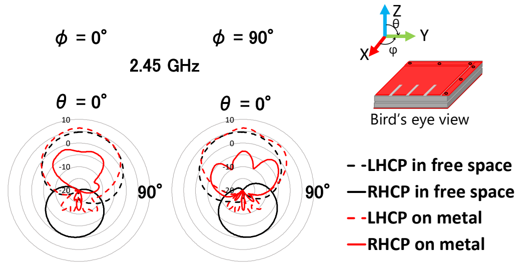

Fig. 8. Radiation pattern of circularly polarized MACKEY Q-type

Fig. 5 shows that, although the circularly polarized MACKEY Q-type has a narrow bandwidth, it operates at 2.45 GHz both in free space and on the metal. Fig. 6 shows that the resonance frequency is shifted at two polarizations, with a 90° phase shift in free space at 2.45 GHz. Fig. 7 shows that the axial ratio is less than 3 dB at 2.45 GHz in free space, but the bandwidth could not be satisfied owing to a slight frequency shift on the metal. Fig. 8 shows that in free space, the main polarization, LHCP was 4.60 dBi in the frontal direction, whereas RHCP, the circularly cross-polarized wave, hardly radiated in the frontal direction. On metal, the frontal gain of the LHCP was 6.31 dBi, which is sufficient to radiate in the frontal direction, but the RHCP was reflected by the metal and radiated in the frontal direction. This results in a larger axial ratio of the metal.

IV. Conclusion

In this study, the principle of operation of the MACKEY Q-type was explained, and a method for cutting a slit in the grid plate to radiate circularly polarized waves was proposed. The depth of cut "d" is an important parameter in designing circularly polarized waves, determining the relative phases of modes #1 and #2. As the proposed antenna radiates circularly polarized waves with a single-point feed, it was confirmed that the antenna radiates circularly polarized waves at 2.45 GHz in free space, despite the narrow bandwidth. However, on the metal, the back lobe was reflected in the frontal direction, resulting in a larger axial ratio. In the future studies, we plan to consider the structures that are less susceptible to metal effects and bandwidth expansions.

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