A Method for Reducing the Size of MACKEY II Antenna Using Slits

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***Abstract*— A metasurface-inspired antenna chip developed by KIT EOE Laboratory (MACKEY), which operates in free space and on a metal plate, was investigated in this study. We proposed a method for reducing the size of MACKEY II in the 920 MHz band to the size of a credit card.**

***Keywords*— MACKEY, RFID 920 MHz, metasurface inspired antenna, artificial magnetic conductor substrate**

I. Introduction

An electrically small antenna, known as MACKEY basic type, which is sufficiently robust to interact with metal objects, has been developed [1]. In addition, a model with reduced thickness, MACKEY II has been proposed [2].

Fig. 1 shows the MACKEY II back feed type model designed for the radio frequency identification (RFID) band of 920 MHz. The model is a three-layer structure consisting of an antenna plate, a grid plate, and a metal plate in descending order, with a dielectric material separating them. Impedance matching was performed based on the grid width g and antenna length ℓ. Fig. 2 shows the measurement results of the voltage standing wave ratio (VSWR) characteristics in a free space and on a metal plate. The measurement results in Fig. 2 demonstrate that the MACKEY II back feed type antenna operates both in free space and on a metal plate.

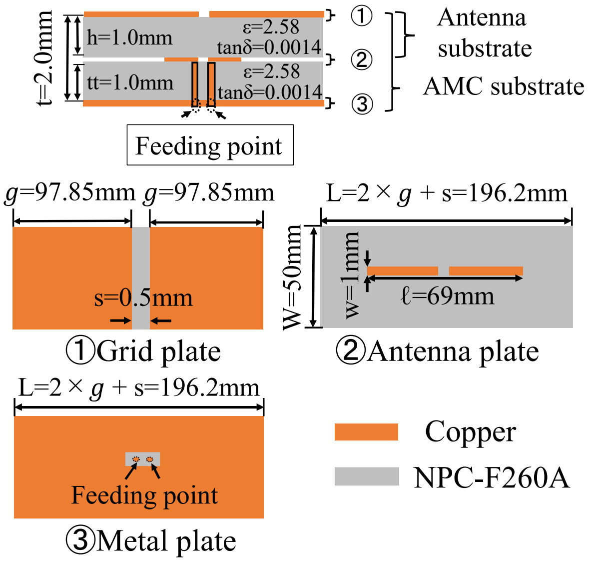

Fig. 1. Model diagram of the MACKEY II antenna

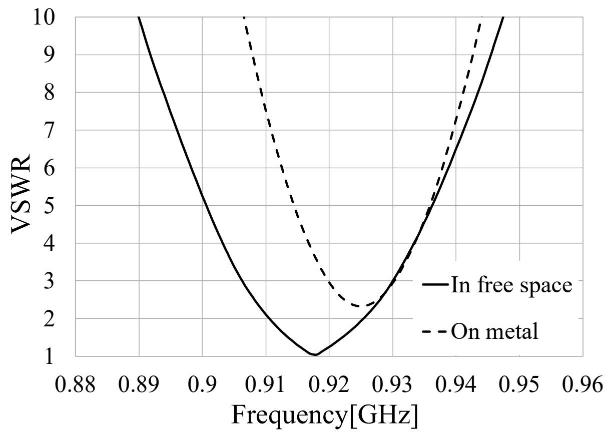

Fig. 2. VSWR characteristics of the MACKEY II antenna.

II. Proposed Miniaturized MACKEY II Antenna

Fig. 3 shows the current distribution on the grid substrate. The MACKEY radiates radio waves from the edge of the lattice plate, where the current flows strongly [1]. In the conventional MACKEY antenna, the length L of the grid plate edge is $\lambda/2$ and depends on the designed frequency. Thus, the base length L of the 920 MHz band MACKEY II is 200 mm, which is large. We reduced this length by introducing slits along the length of the grid plate to ensure a current path of $\lambda/2$ or more, even with a shorter physical length.

Fig. 4 shows the principle of miniaturization. By introducing slits along the long sides of the grid plate, the current path (blue lines in Fig. 4) was extended in a meandering pattern. This ensured electrical securing of the current path of $\lambda/2$ or more, even with a reduced physical length. The MACKEY II design with the proposed structure is designated as MACKEY II type H.

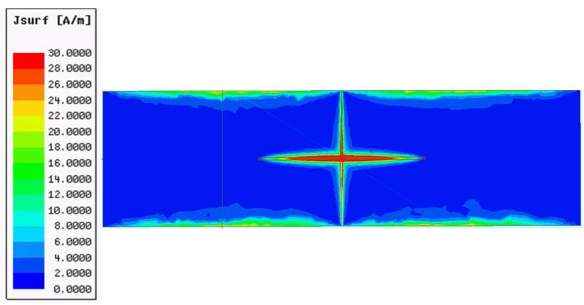

Fig. 3. Current distribution on the grid substrate at 920 MHz.

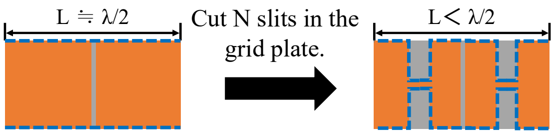

Fig. 4. Miniaturization principle

III. Considerations for Miniaturization

Fig. 5 shows the model diagram of the MACKEY II type H antenna. In this study, the substrate length L and height W were fixed at 80 mm and 50 mm, respectively, as the expected size is that of a card. The relationship between the base length L and the design parameters is expressed in (1).

$$L = 2*tg + 4*g_m + s \quad (1)$$

In Eq. (1), L was fixed at 80 mm, and the dielectric length (tg) was obtained by determining the metal length (g_m) and slit width (s). The lowest resonant frequency for the conventional type H was 880 MHz for $g_m \approx 10$mm [3]. However, since the antenna design is done at 920 MHz, we thought it would be possible to design the antenna with a larger slit width s and slit spacing width hg. Therefore, we analyzed two patterns from the conventional type H, one in which only s is increased and the other in which only hg is increased.

Fig. 6 shows the relationship between g_m and the resonant frequency. The black lines represent the conventional type H (hg=4.0mm and s=0.5mm), the red lines represent the case where only s is increased from the conventional type H (hg=4.0mm and s=1.8mm) and the green lines represent the case where only hg is increased from the conventional type H (hg=4.7mm and s=0.5mm). As expected, increasing s and hg shifted the resonance frequency toward the high-frequency side. Also, the lowest resonant frequency is at $g_m \approx 10$mm for all three models.

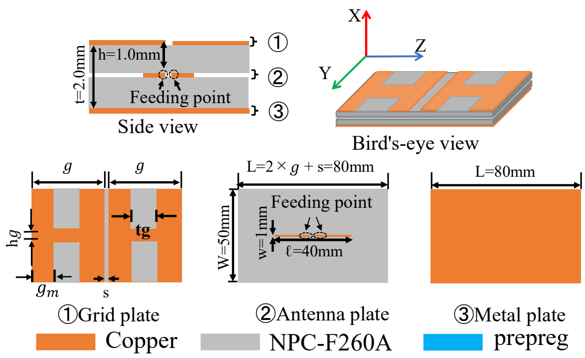

Fig. 5. Model diagram of the type H antenna

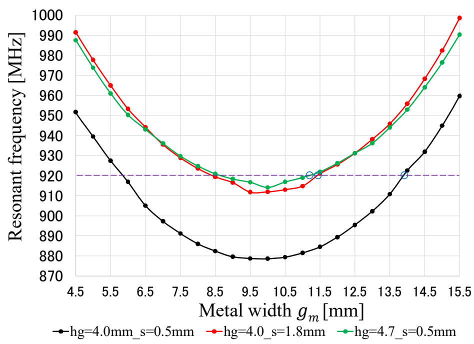

Fig. 6. Relationship between gm and resonant frequency at L = 80 m

IV. Analysis Results and Discussions

The analyzed MACKEY II type H with larger s or hg and conventional MACKEY II type H are compared in this section. Type H is analyzed according to the specifications indicated by the blue circle in Fig. 6. Fig. 7 shows the designed type H model with $L \times W = 80 \times 50$ mm, and the model volume is reduced to approximately 40% of that of the MACKEY II. Table I shows the parameters for g_m, ℓ and g. The sum of the current paths of the grid plate is approximately 170 mm, which is almost equal to that of the length of MACKEY II, as shown in Fig. 1. Since the stacking structure of type H is identical to that of MACKEY II, the feed is supplied at the back of the model via mounted holes. The VSWR characteristics and specific bandwidth in free space are shown in Fig. 8 and Table II, and those on metal are shown in Fig. 9 and Table III, respectively. The black lines represent the conventional type H (hg=4.0mm and s=0.5mm), the red lines represent the case where only s is increased from the conventional type H (hg=4.0mm and s=1.8mm) and the green lines represent the case where only hg is increased from the conventional type H (hg=4.7mm and s=0.5mm). Bandwidths for all three models were generally consistent. However, the shift on the metal was slightly smaller only when s was increased. The radiation patterns and gains are shown in Fig. 10 and Table IV, respectively. The black lines represent the conventional type H (hg=4.0mm and s=0.5mm), the red lines represent the case where only s is increased from the conventional type H (hg=4.0mm and s=1.8mm) and the green lines represent the case where only hg is increased from the conventional type H (hg=4.7mm and s=0.5mm). The radiation patterns appear at the frequency where the VSWR is the lowest. The type H with a larger s or hg has a higher gain than the conventional type H. The frequency response of the radiation efficiency is shown in Fig. 11. The black lines represent the conventional type H (hg=4.0mm and s=0.5mm), the red lines represent the case where only s is increased from the conventional type H (hg=4.0mm and s=1.8mm) and the green lines represent the case where only hg is increased from the conventional type H (hg=4.7mm and s=0.5mm). The type H with a larger s or hg has a higher radiation efficiency than the conventional type H. Based on this result, s and hg must be further increased to obtain high gain with the type H. In other words, MACKEY needs to be made even larger.

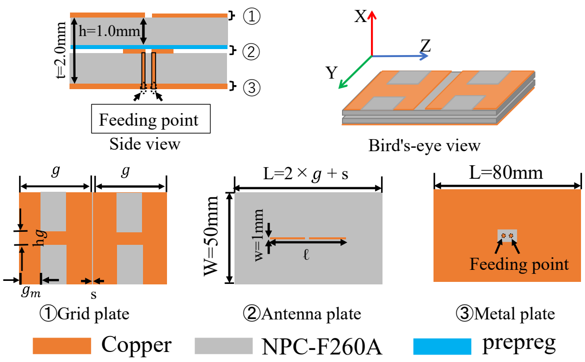

Fig. 7. Type H analysis model

TABLE I. Design Parameters

	hg=4.0mm s=0.5mm	hg=4.0mm s=1.8mm	hg=4.7mm s=0.5mm
g_m [mm]	13.65	9.50	9.90
ℓ [mm]	41.1	39.3	39.7
g [mm]	39.75	39.10	39.75

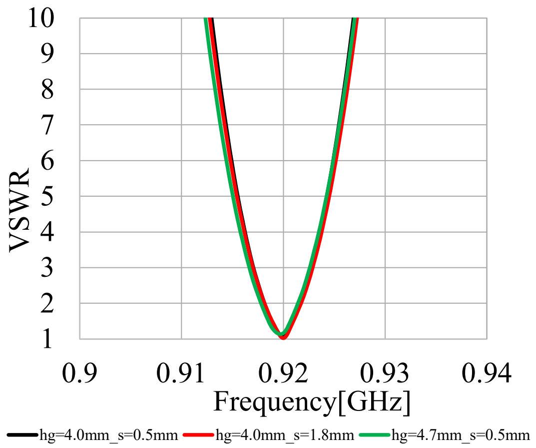

Fig. 8. VSWR characteristics of type H in free space

TABLE II. BANDWIDTHS OF TYPE H IN FREE SPACE

Fractional bandwidth [%] (VSWR≦3)	hg=4.0mm s=0.5mm	hg=4.0mm s=1.8mm	hg=4.7mm s=0.5mm
Analysis	0.613	0.637	0.646

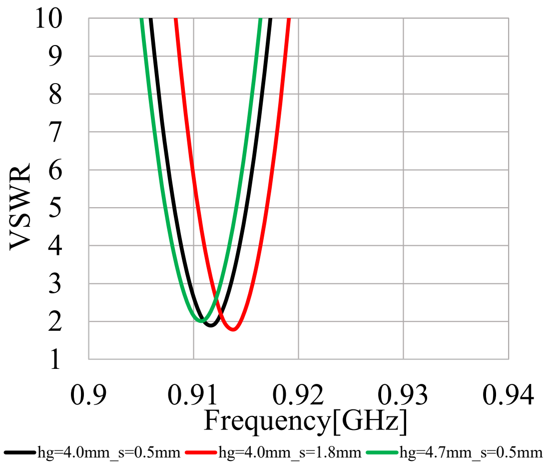

Fig. 9. VSWR characteristics of type H on metal

TABLE III. BANDWIDTHS OF TYPE H ON METAL

Fractional bandwidth [%] (VSWR≦3)	hg=4.0mm s=0.5mm	hg=4.0mm s=1.8mm	hg=4.7mm s=0.5mm
Analysis	0.432	0.423	0.411

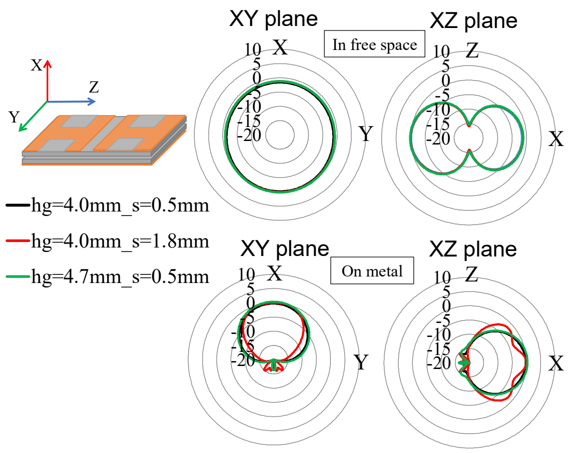

Fig. 10. Radiation Patterns of Type H

TABLE IV. COMPARISON OF GAINS

Analysis	hg=4.0mm s=0.5mm		hg=4.0mm s=1.8mm		hg=4.7mm s=0.5mm	
	In free space	On metal	In free space	On metal	In free space	On metal
Gain [dBi]	-1.58	-0.23	-1.25	-0.05	-1.20	0.37

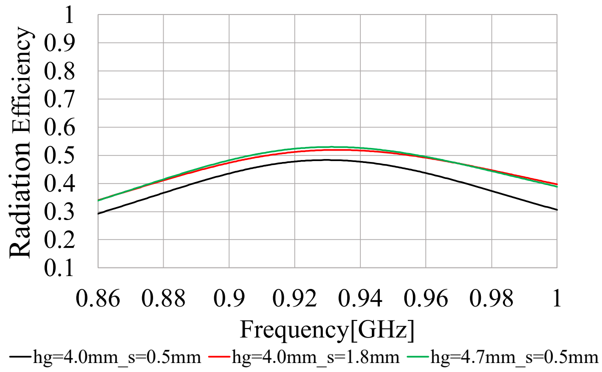

Fig. 11. Frequency characteristics of the radiative efficiency of Type H

V. CONCLUSION

In this study, a MACKEY II type H antenna was proposed to reduce the length of MACKEY II. In type H, the current path was extended by introducing slits on the grid substrate, which is the radiating element. From the evaluation of the MACKEY II type H structure, two models with larger slit width *s* or slit spacing width *hg* from the conventional MACKEY II H model were examined. Type H with larger spacing width *hg* and slit width *s* has a higher gain than the conventional type H, although the bandwidth is not much different. Furthermore, to make MACKEY wideband and high-gain, the antenna size must be increased.

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