Study of MACKEY Type H Antenna Miniaturized Using Slits

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***Abstract*—The metasurface inspired antenna chip developed by the KIT EOE Laboratory (MACKEY, RFID 920 MHz) is an electrically small antenna that is sufficiently robust to metal objects. However, there have been demands for miniaturization of the available model, which has a length of 200 mm at 920 MHz. Therefore, a new model called the MACKEY type H (RFID 920 MHz band) is proposed herein and is miniaturized to the size of a card. The type H antenna can extend the current path in a meandered manner through slits cut along the long sides of the grid plate. This paper presents the characteristics of the MACKEY type H antenna and its measurement results.**

***Index Terms*—MACKEY, RFID 920 MHz, metasurface inspired antenna, artificial magnetic conductor substrate, robust.**

I. Introduction

Communication technologies, such as smart phones and tablets, have spread rapidly in recent years, and further developments are expected with advancements in the Internet of Things (IoT). Hence, there is a need to endow domestic appliances, such as televisions and air conditioners, with communication functions for remote operation. The antennas on such devices should be small, thin, and flexible enough for installation regardless of the presence of surrounding metal components. Metasurface technology is a key development that contributes to the miniaturization and thinning of antennas placed on metals. One such example is the artificial magnetic conductor (AMC) substrate, which reflects the incident electric field in the same phase using dielectric and metal plates. There are several reported studies on this AMC substrate [1]–[3]; in the present study, a capacitance grid [4] is used as the AMC substrate.

The metasurface inspired antenna chip developed by the KIT EOE Laboratory (MACKEY) [5] is an antenna design based on the AMC substrate technology; it is an electrically small antenna that has sufficient robustness to metal objects. There are reports that the basic design suffers from very little degradation of the impedance and radiation characteristics not only in free space but also on metals. In addition, the MACKEY II has been proposed as a reduced-thickness model [6] that is designed to operate in the radio frequency identification (RFID) 920 MHz band (below VSWR3). However, the MACKEY II has a reported length of 200 mm; thus, the antenna length must be reduced for placement on devices.

This paper presents a new model called the MACKEY II type H (henceforth referred to as “type H”) in which slits are cut along the long sides of the lattice plate and the current path is meandered and extended to obtain a smaller size than the MACKEY II antenna.

II. Conventional MACKEY II

Fig. 1 illustrates the MACKEY II back-feed-type model designed for the RFID 920 MHz band; as shown in the figure, the antenna plate is placed inside the AMC substrate to thin the structure. Additionally, the MACKEY II is a three-layer structure consisting of an antenna plate, a grid plate, and a metal plate in descending order, with a dielectric material filled in between them. Impedance matching is performed on the basis of the grid length g and antenna length ℓ; thus, the thickness, length, and width of the model are 2 mm, 50 mm, and 196.2 mm, respectively. Feeding is done by two-port measurement using the S-parameter method.

Fig. 2 shows the measured results of the VSWR characteristics in free space and on a metal. To study the behavior on the metal, a 366 mm × 366 mm metal plate shown in Fig. 3 is used to ensure sufficient size. The measured results in Fig. 2 demonstrate that the MACKEY II operates not only in free space but also on metals; the frequency is slightly shifted between that in free space and on the metal, but the VSWR is less than 3 in both cases. However, the model length L of the MACKEY II is 196.2 mm, and the main problem here is that the board is large. Therefore, we studied a new model for the MACKEY II in the 920 MHz band for size reduction.

III. Proposed Miniaturized MACKEY II Antenna

Fig. 4 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 [5]. In the conventional MACKEY, 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 190 mm, which is large, and we reduce the this size by cutting slits along the length of the grid plate to ensure a current path of $\lambda/2$ or more even with a short L.

Fig. 5 shows the miniaturization principle. By cutting slits along the long sides of the grid plate, the current path (blue line in Fig. 5) is extended in a meandered pattern. This ensures electrically securing a current path of $\lambda/2$ or more even for a physically reduced L. The MACKEY II design with this structure is designated as MACKEY II type H.

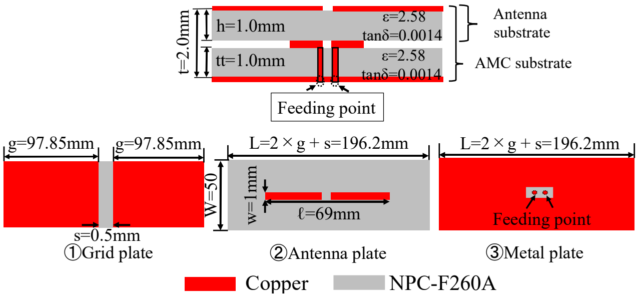

Fig. 1. Model diagram of the MACKEY II antenna.

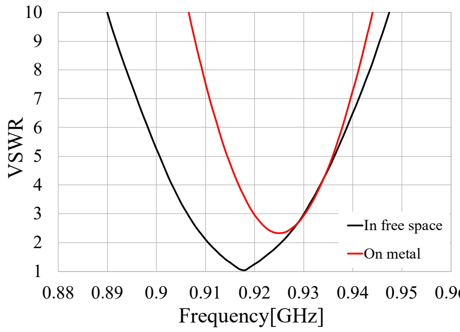

Fig. 2. VSWR characteristics of the MACKEY II antenna.

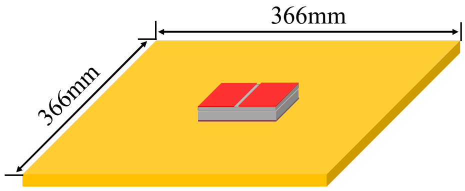

Fig. 3. Model installed on a metal plate.

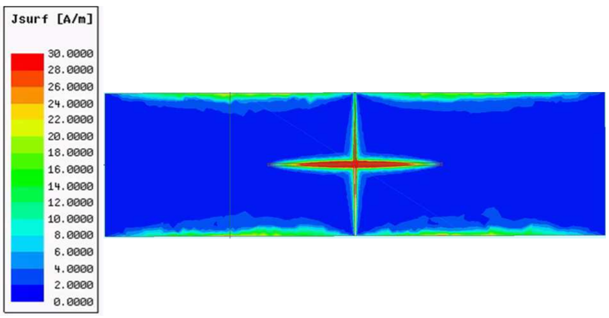

Fig. 4. Current distribution on the grid substrate at 920 MHz.

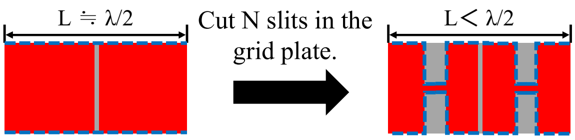

Fig. 5. Miniaturization principle.

IV. CONSIDERATIONS FOR MINIATURIZATION

Fig. 6 shows the model diagram of the type H antenna. In this study, the substrate length L and height W are fixed at 80 mm and 50 mm, respectively, since the expected size is that of a card. The relationship between the base length L and design parameters is shown in (1).

$$L=2*tg+4*g_m+s \tag{1}$$

In (1), L was fixed at 80 mm, and the dielectric length (tg) was obtained by determining the metal length (g_m). Fig. 7 shows the relationship between g_m and resonant frequency. The type H shows a resonant frequency at 920 MHz for $g_m \approx$ 5.8 and $g_m \approx$ 13.9, and the lowest resonant frequency is at $g_m \approx$ 10.0 mm.

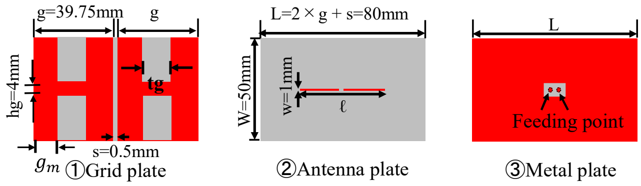

Fig. 6. Model diagram of the MACKEY II type H antenna.

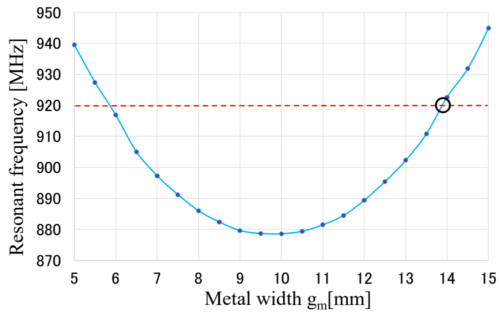

Fig. 7. Relationship between g_m and resonant frequency at L = 80 mm.

V. ANALYTICAL AND MEASURED RESULTS FOR TYPE H

The designed type H and conventional models are compared herein. The type H was designed for the specifications indicated by the black circle in Fig. 7. Fig. 8 shows the designed type H model, with $L \times W$ = 80 mm × 50 mm, and the model volume is reduced to about 40% of that of the MACKEY II. Because the stacking structure of the type H is identical to that of the 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. 9 and Table I, and those on metal are shown in Fig. 10 and Table II, respectively. The black lines represent MACKEY II and red lines represent type H. The solid and dotted lines represent the analytical and measured values, respectively. The type H operates in both free space and on metal, and the measured results for these are observed to be shifted towards lower frequencies compared with the analytical results. The type H characteristics are narrower than those of the MACKEY II both in free space and on metal. The radiation patterns and gains are shown in Fig. 11 and Table III, respectively. The black and red lines represent the MACKEY II and type H, respectively; the solid and dotted lines represent the analyzed and measured values, respectively. The radiation patterns appear at the frequency where the VSWR is lowest; these patterns are observed to be almost identical between the measured and analytical results. The gain is generally consistent between the measured and analytical results; the type H has lower gains in free space and on metals than the MACKEY II. The analysis value of the frequency response of the radiation efficiency is shown in Figure 12. Type H has a lower radiative efficiency than MACKEY II. The lower gain of the type H over the MACKEY II is attributed to its lower radiative efficiency.

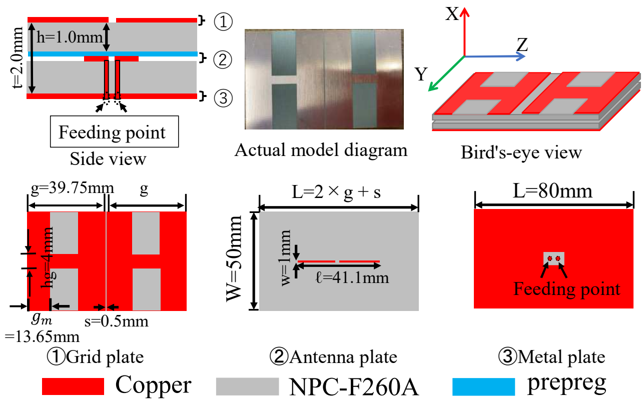

Fig. 8. Type H design model.

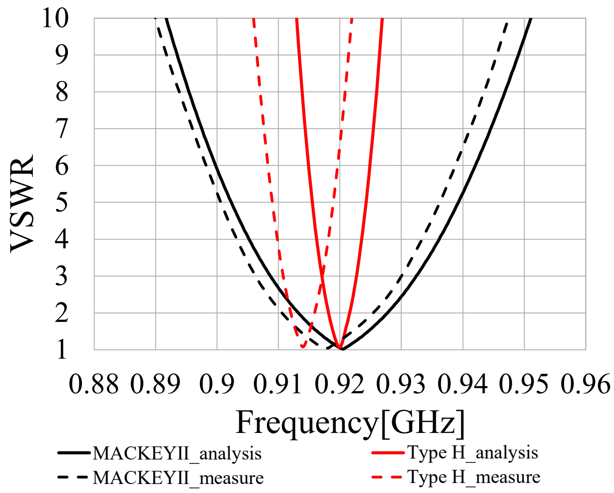

Fig. 9. VSWR characteristics of type H and MACKEY II in free space.

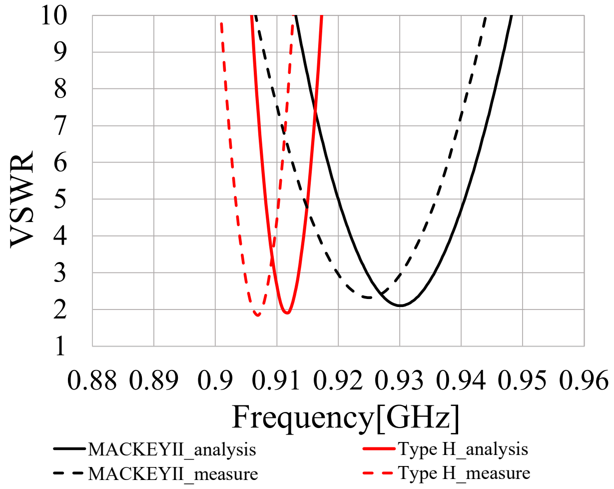

Fig. 10. VSWR characteristics of type H and MACKEY II on metals.

TABLE I. Relative Bandwidths of Type H and MACKEY II in Free Space.

Bandwidth	Type H	MACKEY II
Analysis[%]	0.613	2.58
Measure[%]	0.696	2.59

TABLE II. Relative Bandwidths of Type H and MACKEY II on Metals.

Bandwidth	Type H	MACKEY II
Analysis[%]	0.432	1.18
Measure[%]	0.450	1.12

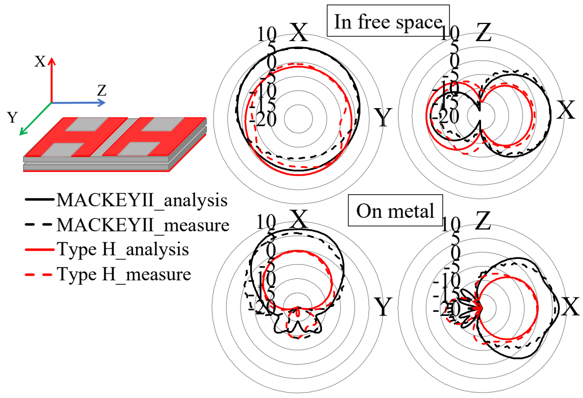

Fig. 11. Radiation Patterns of Type H and MACKEY II.

TABLE III. . Comparison of Gains

Gain	Type H		MACKEY II	
	In free space	On metal	In free space	On metal
Analysis[dBi]	-1.58	-0.23	5.18	7.29
Measure[dBi]	-0.63	-0.48	4.99	5.96

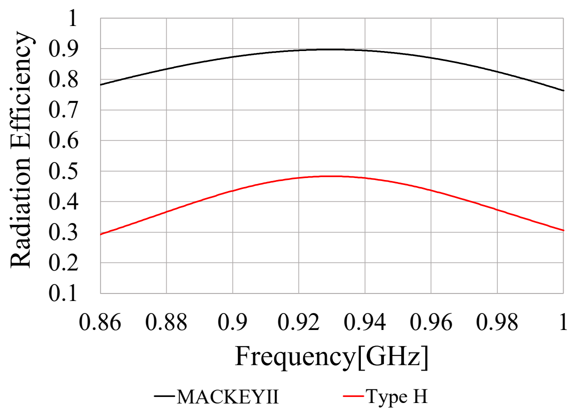

Fig. 12. Frequency characteristics of the radiative efficiency of Type H and MACKEY II (Analysis result)

VI. Conclusion

In this work, the novel MACKEY II type H antenna is proposed to reduce the length of the MACKEY II. In the type H, the current path is extended and reduced by cutting slits on the grid substrate, which is the radiating element. From evaluation of the type H structure, the resonance points at 920 MHz were found by fixing L = 80 mm. Based on the results, the type H model was designed with a size smaller than the MACKEY II, i.e., 80 mm × 50 mm. The type H is about 40% of the size of the MACKEY II but has a narrower bandwidth and lower gain owing to lower radiation efficiency. The measured results in free space and on metal are observed to be shifted towards lower frequencies compared with the analytical results. The radiation patterns between the measured and analytical results are observed to be almost identical, while the gain is generally consistent.

ACKNOWLEDGMENT

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