A Study on the Effective Pattern of Magnetic Sheet Considering Their Characteristics Attached on NFC Antenna

Takaho Sekiguchi, Yoshinobu Okano
Department of Information Engineering
Tokyo City University
1-28-1, Tamazutsumi, Setagaya-Ku, Tokyo, Japan
E-mail: g1581510@tcu.ac.jp, y-okano@tcu.ac.jp

Naoki Ohmura, Satoshi Ogino
Microwave Absorbers Inc.
Technology Development
5-4-5, Asakusabashi, Taito-Ku, Tokyo, Japan
E-mail: ohmura@mwa.co.jp,ogino@mwa.co.jp

***Abstract*-In case of payment system with NFC (Near Field Communication)/HF-RFID (Radio Frequency IDentification) installed into the smart-phone, NFC antenna's communication performance at 13.56MHz is deteriorated by the battery case or circuit boards. To solve this problem, the magnetic sheet with high permeability is inserted into the NFC/HF-RFID antenna and metal object. Thin magnetic compound or sintered ferrite has been used as the high permeability sheet. However, these sheet thicknesses could not be suppressed to improve the NFC/HF-RFID antenna's performance. In order to make thickness of these materials thinner, we propose amorphous magnetic sheet. Besides because the loss of amorphous magnetic sheet is large, that loss suppression technique is also proposed.**

Keywords—RFID tags , Impedance matching , Inductance

I. INTRODUCTION

NFC and HF-RFID system are used as the traffic toll collection system or the electric money system (such as SUICA, PASMO or EDY) in Japan [1]. Recently, the situation that these systems are installed into the smart phone is increasing. However, the antenna performances for R/W (Reader/Writer) or tag used with these systems are remarkably deteriorated with adjacent metallic objects [2], [3]. The reason is that actual electric current on NFC/HF-RFID antenna is suppressed by induction electric current generated with metallic objects. When there is 10mm gap between NFC/HF-RFID antennas and metallic objects, its communication performance is recovered. Because it is necessary to suppress the smart phone's thickness, the NFC/HF-RFID antenna's thickness should be also thin. Thus it is difficult to keep 10 mm gap between NFC antennas and metallic objects. Therefore, thin magnetic sheet with high permeability is inserted instead of keeping large gap between them. The magnetic sheet insertion ability are described as below;

(a) Faradic flow on metallic object can be suppressed.
(b) Magnetic flux flows generated by NFC antenna are not intercepted by metallic objects with passing through the magnetic sheet.

As for the insertion magnetic sheet, thin compound magnetic sheet or thin sintered ferrite has been used. However, when the compound magnetic sheet is used, its thickness should be increased to improve the performance of NFC antenna. On the other hand, sintered ferrite sheet is not easy handling because it is expensive and fragile.

In this paper, the use of amorphous sheet that the permeability is higher than compound magnetic or sintered ferrite sheet is proposed. The performance of NFC antenna can be expected to improve even if it is thinner than the compound magnetic or sintered ferrite sheet because amorphous sheet's permeability is high. In contrast, because a magnetic loss of amorphous sheet is larger than that of other sheet, the insertion technique to NFC antenna should be investigated carefully. The results about studying the control of a magnetic loss by the shape of amorphous sheet are also described in this paper.

II. TEST MODEL

The system configuration of communication distance measurement system is indicated in Fig.1. In this paper, two models of the following are assumed as the communication distance measurement situation between the NFC antenna (active antenna) and the Tag antenna (passive antenna);

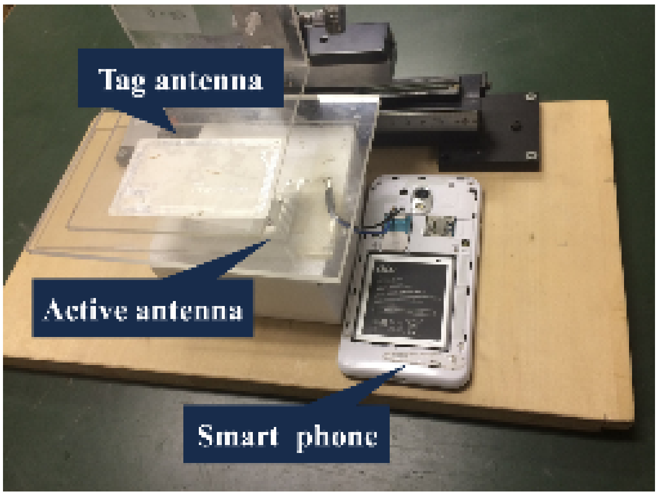
(1) When the communication distance between the Tag antenna and the NFC antenna for smartphone loading is measured, the magnetic sheet is inserted into smartphone's battery cases and NFC antenna.
(2) In the communication distance measurement when a metal plate exists near the Tag antenna, R/W device for NFC is used as an active antenna. Because this model evaluates the influence that the magnetic sheet gives to the Tag antenna, it is inserted into the Tag antenna and a metal plate.

Measurement conditions are indicated in TABLE I.

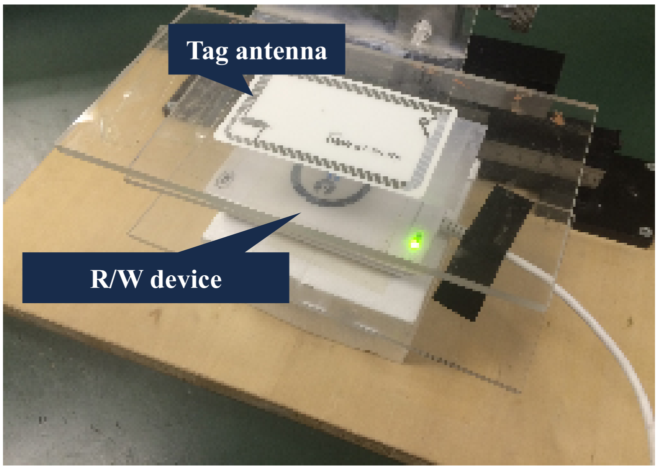
To conjugate match with NFC IC's capacitance in NFC system, the NFC antenna is designed so that the large inductance may rise in 13.56MHz [4]. The amorphous sheet consists of PET cover film, amorphous magnetic sheet and adhesive. The communication distance in “Read model 1" and “Read model 2" is described as *d1* and *d2*, respectively.

TABLE I CONDITIONS OF BOTH TESTS

Frequency	13.56 MHz
Size of Active antenna	30×60 mm
Size of Tag antenna ISO 14443	46×76 mm
Size of metal plate	65×100 mm
Wireless device (R/W)	ACR122 NFC Card R/W
Smartphone(R/W)	GALAXY S II



(1)Read model 1



(2) Read model 2

Fig.1 Communication property evaluation procedure for NFC-Tag.
(a) In case of metal proximity to Active antenna.
(b) In case of metal proximity to Tag antenna.

The characteristic and dimension of magnetic sheet used for this measurement are listed in TABLE II. There are three kinds of magnetic sheet used for the measurement. Those are the compound magnetic sheet A which has low loss factor and, the compound magnetic sheet B which has high loss factor and amorphous sheet. 3 types of sheet size and shape are indicated in TABLE II

TABLE II TYPES OF MAGNETIC SHEET

Composition	Thickness [μm]	Permeability μ' (Real part)	Permeability μ'' (Imaginary part)
Compound A	100	60	1
Compound B	100	110	20
Amorphous	20	250	400

A correlation between the input impedance and the communication distance when the NFC antenna is attached to a metallic object is described in the following chapter. The variation of input impedance and the communication distance when magnetic sheet is inserted between the NFC antenna and a metallic object is also described in next chapter.

It might be effective to reduce the amount of use of sheet when large magnetic sheet of loss factor is used. As shown in Figure 2, the use of doughnut shape magnetic sheet to remove magnetic sheet right under the antenna center is attempted for the loss factor reduction.

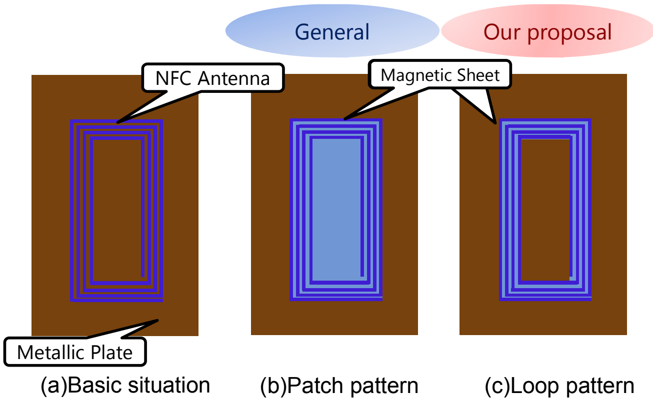


Fig.2 Attaching pattern of magnetic substance sheet.
(a) Basic situation (not magnetic substance sheet loadings).
(b) Patch-shape magnetic substance sheet loadings case.
(c) Loop-shape magnetic substance sheet loadings case.

III. RESULTS AND DISCUS

Fig. 3 shows NFC antenna's inductance Ls and resistance Rs as the function of permeability based on actual measurement data. As results, it is thought that the permeability control of magnetic sheet is indispensable to the impedance matching of the NFC antenna. However, the permeability control by the composition of the magnetic substance is not so easy. Accordingly, it is attempted to control the impedance of the NFC antenna by partially attaching magnetic sheet.

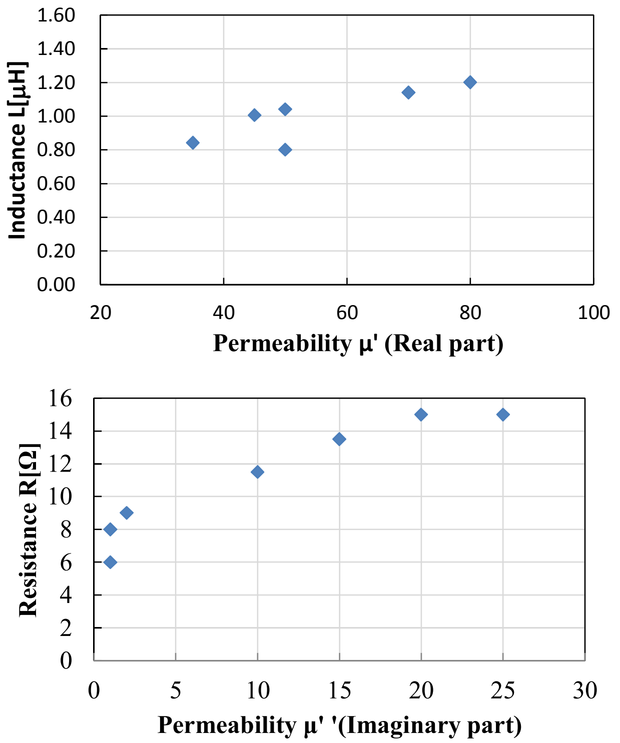
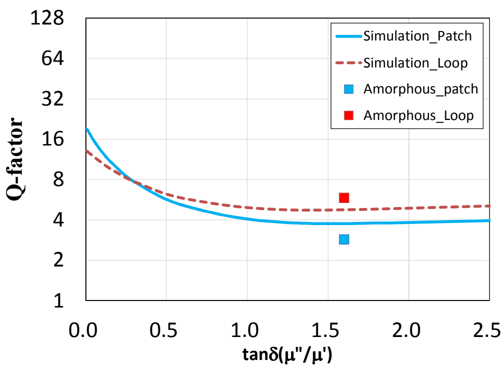


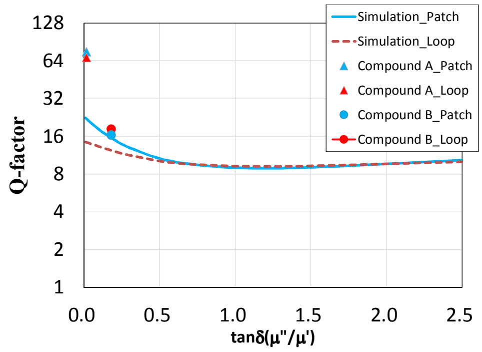
Fig 3 Relation with impedance and permeability.

The numerical analysis result of antenna's Q-factor as the function of tanδ when magnetic sheets (Patch pattern and Loop pattern) are inserted in the active antenna is shown in Figure 4 with the measured ones. In Fig.4 (a), the amorphous sheet (20μm in thickness) is used and in Fig.4 (b), the compound sheet (100μm in thickness) is used respectively. FEM (Finite Element Method) is used for the numerical analysis. Moreover, Q-factor and tanδ are calculated by the following expressions (1) and (2) (μ' is fixed) based on those results. In the case of sweeping tan δ which is described as a value that represents the loss factor by equation (2) and fixing the permeability μ'(Real part)

$$(1)Q = \frac{\omega L}{R} \qquad (2)\tan\delta = \frac{\mu''}{\mu'}$$



(a) Sheet thickness of 20μm (Amorphous)



(b) Sheet thickness of 100μm (Compound A , B)

Fig.4 Measurement result of the Q-factor in case of metal proximity to Active antennaplotted on the simulation results

TABLE III, IV shows the input impedance measurement results about the smart phone loaded NFC antenna and Tag antenna for the different magnetic sheet insertion technique.

TABLE III TEST RESULT OF Active Antenna IMPEDUNCE

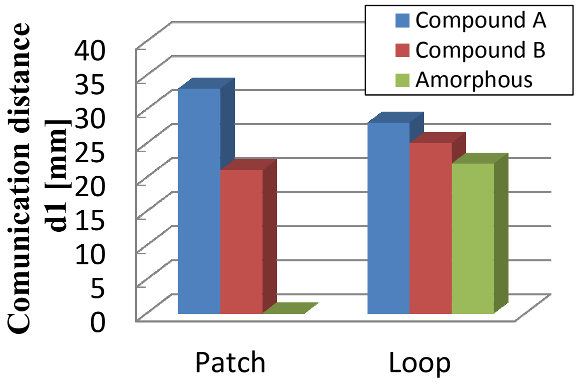
Loading material	Pattern	R[Ω]	L[μH]
Cf.free space	-	0.21	1.28
Without magnetic sheet	-	0.19(-0.02)	0.49(-0.79)
Compound A	Patch	1.31(+1.1)	1.16(-0.12)
Compound A	Loop	1.28(+1.07)	1.02(-0.26)
Compound B	Patch	6.50(+6.29)	1.25(-0.03)
Compound B	Loop	5.50(+5.29)	1.18(-0.1)
Amorphous	Patch	45.00(+44.79)	1.50(+0.22)
Amorphous	Loop	18.00(+17.79)	1.07(-0.21)

TABLE IV TEST RESULT OF Tag Antenna IMPEDUNCE

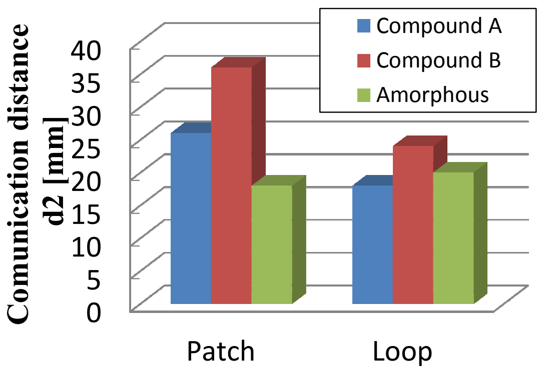
Loading material	Pattern	R[Ω]	L[μH]
Cf.free space	-	3	2.60
Without magnetic sheet	-	2.3(-0.8)	0.87(-1.73)
Compound A	Patch	12.70(+9.7)	2.14(-0.36)
Compound A	Loop	11.90(+8.9)	1.85(-0.75)
Compound B	Patch	15.00(+12)	2.60(±0)
Compound B	Loop	14.00(+11)	2.28(-0.32)
Amorphous	Patch	51.00(+48)	2.40(-0.2)
Amorphous	Loop	25.00(+22)	2.14(-0.26)

If the high loss sheet like amorphous sheet is used, both the analysis and the measurement result predict that Q-facter with Loop pattern sheet is higher than with Patch pattern sheet. In contrast, if low loss factor sheet like 'Compound A' is used, it can be concluded that Patch pattern sheet will demonstrate higher Q-facter.

Fig. 5 shows the comparison measurement results of the NFC communication distance about three magnetic sheet insertion techniques between the NFC antenna and metallic object. The comparison measurement results by two types read model are also shown in Fig. 5.



(a)



(b)

Fig.5 Communication distance transition for location procedure of magnetic substance sheet. (a) In case of read model 1. (b) In case of read model 2.

In case of magnetic sheet attached on the smart phone loaded antenna, the recovery of communication distance with the amorphous patch sheet failed unlike the loop pattern sheet use case. Oppositely, it is thought that the recovery of communication distance with the loop-pattern amorphous sheet is extremely effective.

The communication distance recovery ability of the patch pattern sheet with compound material surpasses it of the loop pattern sheet. However, the difference of the communication distance recovery ability with the compound material and the amorphous reduces.

The Table II indicates that amorphous sheet has higher loss property though it has higher permeability than the compound magnetic sheet. Therefore when amorphous sheet used, the sheet area should be reduced as much as possible. However it becomes a contrary effect for the inductance reinforcement. Considering the amorphous sheet's shape becomes an important task to recover the performance for NFC antenna near metal objects.

IV. CONCLUSION

In this paper, by simulation and measurement it showed the following. If the sheet is thin, when using a magnetic sheet of high loss, like as amorphous, Loop pattern can be achieved a high Q-factor than the Patch pattern. In addition, this great improvement was also observed in the communication distance measurement (Fig.5).

Reducing the impedance mismatch when using amorphous is important task in improving the communication distance. Because of impedance matching and communication distance of NFC system was mainly measured with respecting for the permeability and shape of on-metal magnetic sheet. In addition to improving the Q- factor. It was confirmed that the amorphous sheet, even if it had not been used because of its higher permeability at 13.56 MHz, was applicable for NFC antenna with near-by metal by shaping different size of this sheet. The distance of it is as long as theirs of existing compound sheet. The longer the communication distance is the wider this sheet is. As their imaginary part of permeability is very low, the resistance is hardly be changed. On the other hands amorphous sheet with higher permeability indicates higher loss property. Therefore it is necessary that with downsizing sheet and suppressing its resistance intrinsic impedance of sheet match to the preferable impedance of this sheet.

Attaching compound magnetic sheets for Tag antenna was found to be better using the Patch pattern because Tag antenna is a high-resistance (3Ω) than the active antenna's one(0.21Ω). On the other hand attaching amorphous sheets for Tag antenna was found to be better using the Loop pattern as well as active antenna.

Before this amorphous sheet is used, it is inevitable to evaluate the impedance of this sheet.

Finally, this amorphous sheet is useful for downsizing and cost down for smartphone because even smaller size and thinner thickness is applicable for NFC/HF-RFID on-metal communication. From now on, we will get more data of test and simulation at the same time to optimize the amorphous sheet size and thickness according to NFC/HF-RFID antenna of smartphone.

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