

## Research Article

# Enhanced Loop Structure of NFC Antenna for Mobile Handset Applications

Byungje Lee,<sup>1</sup> Byeongkwan Kim,<sup>2</sup> and Sunghyun Yang<sup>3</sup>

<sup>1</sup> Department of Wireless Communications Engineering, Kwangwoon University, No. 447-1, Wolgye-Dong, Nowon-Gu, Seoul 139-701, Republic of Korea

<sup>2</sup> Defence R&D Center, Hanwha Corporation, 52-1 Woisam-Dong, Yuseong-Gu, Daejeon 305-156, Republic of Korea

<sup>3</sup> Department of Electronic Engineering, Kwangwoon University, No. 447-1, Wolgye-Dong, Nowon-Gu, Seoul 139-701, Republic of Korea

Correspondence should be addressed to Byungje Lee; [bj\\_lee@kw.ac.kr](mailto:bj_lee@kw.ac.kr)

Received 27 November 2013; Accepted 20 February 2014; Published 8 April 2014

Academic Editor: Yuan Yao

Copyright © 2014 Byungje Lee et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

A new structure of an NFC loop antenna for mobile handset applications is proposed. The proposed antenna consists of conventional loop elements and a parasitic loop embedded capacitor to enhance its performance. Although the sintered ferrite sheets with higher relative permeability ( $\mu_r \approx 200$ ) have been used to reduce the performance deterioration due to the eddy current on the battery pack of a mobile handset, their costs are high, and they are considerably breakable. In this paper, with the proposed structure, we effectively enhance the performance of an NFC loop antenna by employing the ferrite-polymer composite with lower relative permeability ( $\mu_r \approx 55$ ).

## 1. Introduction

A near-field communication (NFC) system has attracted much attention as a short-range wireless communication technology at 13.56 MHz which allows devices to communicate through inductive coupling and provides users with the card mode service and the reader/writer (R/W) mode service. The demand for a mobile NFC service has been increased due to its high security without a complex pairing process [1–4]. Currently, the NFC antenna technology faces several challenges such as reducing the thickness, high manufacturing costs, and performance degradation when it is embedded on the metallic components such as the PCB ground or the battery pack of mobile devices. To prevent performance degradation of an NFC antenna due to an eddy current [5] on the metallic components near the NFC antenna, a ferrite sheet is generally inserted between the NFC antenna and the metallic components. In most cases, NFC antennas are embedded in the battery pack of a mobile phone, so that a sintered ferrite sheet with high relative permeability has been attached between the NFC antenna and the

metal case of a phone battery to avoid an eddy current. Also, a thickness of a ferrite sheet is usually limited in industry because an NFC antenna must be designed within a very small volume. Therefore, a very thin (80  $\mu\text{m}$ ) sintered ferrite sheet has been used with high relative permeability ( $\mu_r \approx 200$ ) to simply avoid performance degradation of an NFC antenna due to an eddy current. However, since the sintered ferrite has higher manufacturing cost and is considerably breakable, ferrite-polymer composites are interesting as an alternative in industry. A ferrite-polymer composite is flexible and durable, and its manufacturing cost is reasonable. But, due to lower relative permeability ( $\mu_r \approx 55$ ) than that of the sintered ferrite, it is difficult to effectively reduce an eddy current and achieve good performance from a conventional structure of an NFC loop antenna with a thin (80  $\mu\text{m}$ ) ferrite-polymer composite, so that a detection range and a load modulation level become deteriorated. So far, studies on enhancing the performance of an NFC antenna with a ferrite-polymer composite have not been investigated yet. Therefore, enhancement of the performance of an NFC antenna with

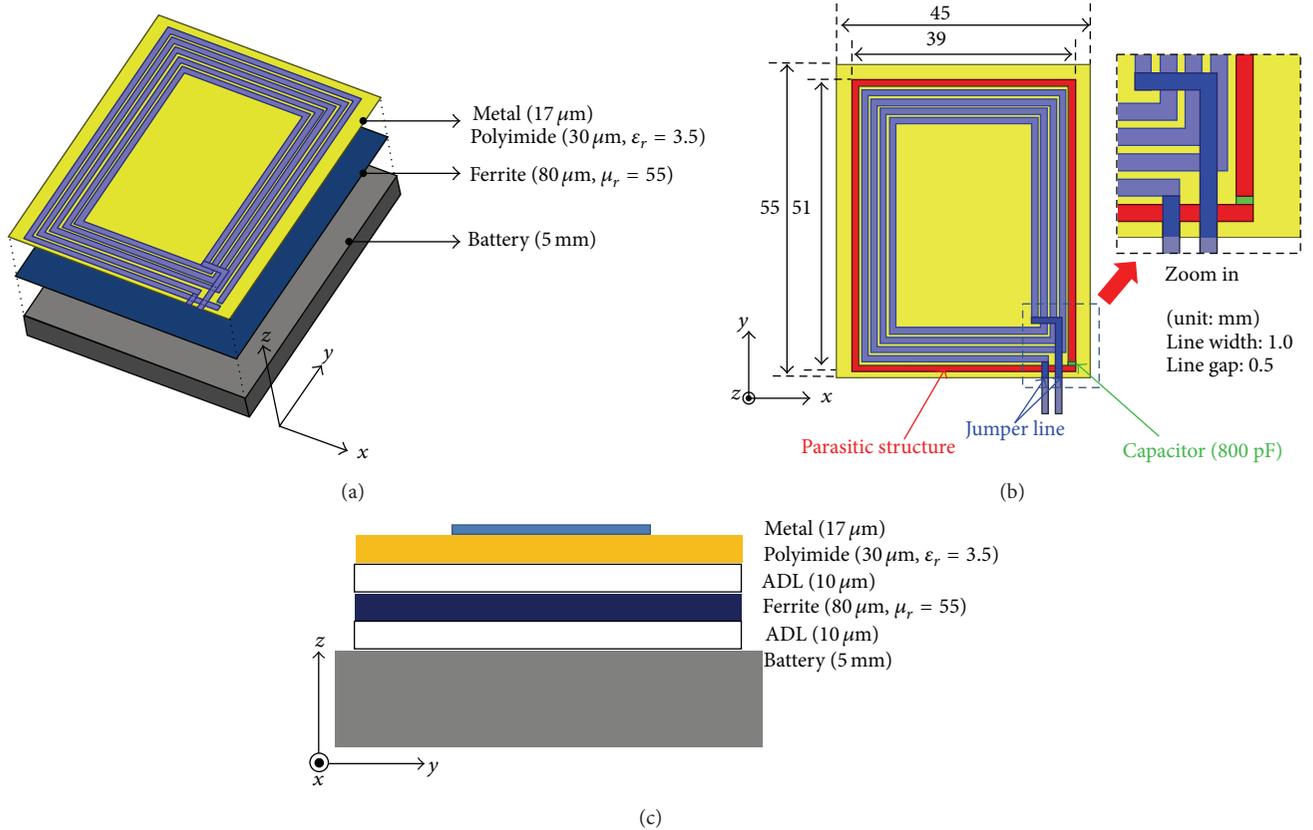


FIGURE 1: Geometry of the proposed NFC loop antenna; (a) overall view, (b) top view printed on FPCB, and (c) side view.

a ferrite-polymer composite challenges and warrants further study.

In this paper, a novel structure of an NFC loop antenna is proposed for mobile handset applications by improving the performance of an NFC loop antenna when a ferrite-polymer composite is attached between the embedded NFC loop antenna and the phone battery. The proposed loop antenna has a parasitic loop structure with a capacitor in order to tune the parasitic loop to be operated at 13.56 MHz. The current direction on the resonated parasitic loop is the same as those of nearby loop antenna elements. This additional current from a parasitic loop induces more intensive  $H$ -field in the near-field region, so that a thin ferrite-polymer composite sheet can be used for the proposed loop antenna, in spite of its lower relative permeability. Therefore, in the Euro pay, MasterCard and Visa (EMV) test for the card mode and in the detection range test for the reader/writer (R/W) mode, the proposed loop antenna gives better performance than that of a conventional NFC loop antenna when both are attached on the same ferrite-polymer composite sheet.

## 2. Antenna Structure and Analysis

Figure 1(a) shows the overall view of the proposed NFC loop antenna structure. It is printed on the polyimide ( $\epsilon_r = 3.5$  and thickness = 30 μm) FPCB (flexible printed circuit board)

whose size is  $45 \times 55 \text{ mm}^2$  as shown in Figure 1(b), and it is mounted on the battery pack ( $50 \times 60 \times 5 \text{ mm}^3$ ) of a mobile phone. The ferrite-polymer composite sheet ( $\mu_r = 55$ ,  $\tan \delta_m = 0.07$ , and thickness = 80 μm) is attached by using an adhesive layer (ADL, thickness = 10 μm) as shown in Figure 1(c). The line width of each loop is 1 mm, and the gap distance between loops is 0.5 mm. The parasitic loop is printed at outermost location. A capacitor (880 pF) is embedded in order to tune this parasitic loop to be operated at 13.56 MHz.

Figure 2 shows the simulated  $H$ -field intensity (RMS value) along with a normal direction ( $z$ -direction) on the center of a conventional loop antenna without a parasitic loop element for different relative permeability of a ferrite sheet (thickness = 80 μm) when a conventional 4-turn loop antenna is assembled as the same layout shown in Figure 1(c) and connected with a matching circuit toward an NFC chip ( $Z_{in} = 80 \Omega$ ) [6]. It is noticed that the relative permeability value of the ferrite sheet mainly affects the intensity of the  $H$ -field. Also, the lower value of relative permeability may disrupt the generation of the  $H$ -field intensity from the loop antenna in the near-field region. Thus, a conventional loop antenna by using a ferrite-polymer composite sheet of lower permeability ( $\mu_r = 55$ ) may not achieve good performance of a NFC loop antenna.

Figure 3 shows the simulated  $H$ -field intensity along with a normal direction ( $z$ -axis) on the center of a conventional

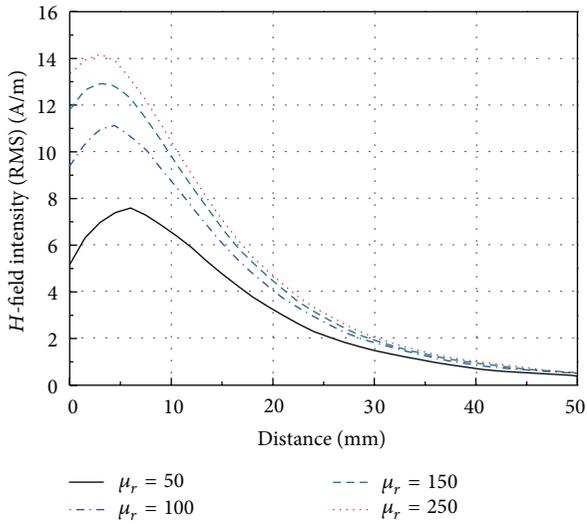


FIGURE 2: Simulated  $H$ -field intensity along with a normal direction ( $z$ -axis) on the center of the 4-turn loop antenna by varying relative permeability of a ferrite sheet (thickness =  $80 \mu\text{m}$ ).

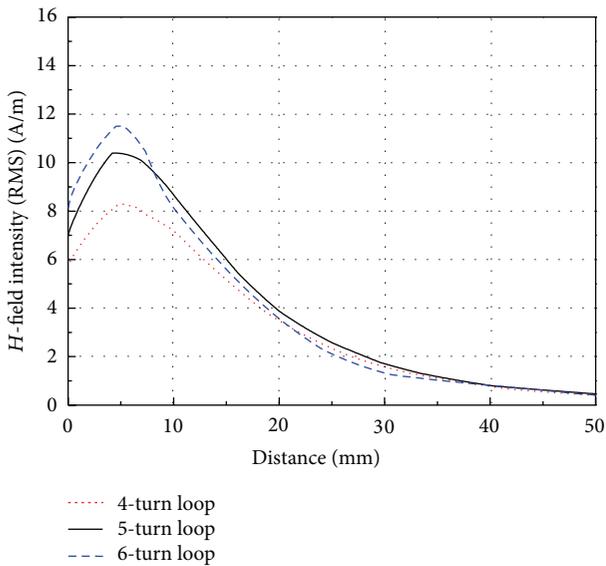


FIGURE 3: Simulated  $H$ -field intensity along with a normal direction ( $z$ -axis) on the center of the loop antenna with varying number of the loop turns.

loop antenna with varying number of the loop turns when the ferrite-polymer composite sheet ( $\mu_r = 55$  and thickness =  $80 \mu\text{m}$ ) is employed. Even though the number of loop turns increases, the  $H$ -field intensity does not be significantly enhanced. This is due to the rapid increment of an electrical resistance, which is a meaningful loss mechanism especially in the near-field loop antenna, as the number of loop turns increases [7, 8]. Thus, in general, the number of loop turns for an NFC antenna is restricted by 4 or 5 because the electrical resistance of a conventional loop antenna wound from the

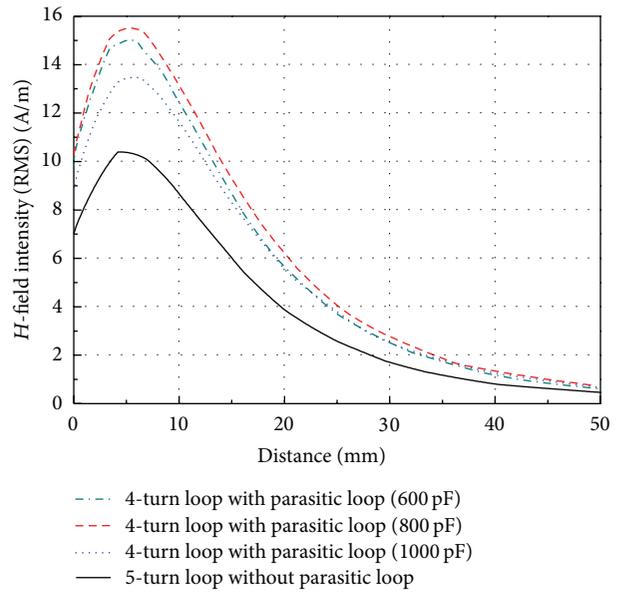


FIGURE 4:  $H$ -field intensity along with a normal direction ( $z$ -axis) on the center of the loop antenna with varying capacitance of a capacitor embedded in the parasitic loop.

outermost line into the innermost line is exponentially increased due to proximity effect among the closely located loop elements as the number of loop turns increases.

To improve the  $H$ -field intensity when the lower relative permeability of a ferrite material is used, a novel structure of an NFC loop antenna is increasingly demanded. The proposed loop antenna shown in Figure 1 has an additional parasitic loop structure embedded with a capacitor. When this parasitic loop structure is coupled by the nearby loop antenna and resonated at the operating frequency (13.56 MHz), the  $H$ -field intensity of the proposed loop antenna is significantly improved. Figure 4 shows the  $H$ -field intensity with varying capacitance of a capacitor embedded in the parasitic loop. It is noticed that the proposed antenna (4-turn loop with a parasitic loop embedded capacitor) gives more intensive  $H$ -field than that of a conventional 5-turn loop antenna only.

Figure 5 shows that the current on the resonated parasitic loop has the same direction as those on the nearby 4-turn loop antenna. This additional current helps to induce more intensive  $H$ -field in the near-field region. Thus, although it has lower relative permeability ( $\mu_r = 55$ ), the thin ( $80 \mu\text{m}$ ) ferrite-polymer composite sheet with this proposed structure of an NFC loop antenna can be applied to reduce performance degradation of an NFC antenna due to an eddy current. As mentioned, it is more flexible and durable, and has much lower manufacturing cost than a sintered ferrite sheet ( $\mu_r \approx 200$ ). Figure 6 presents the  $H$ -field distribution of the proposed loop antenna with the parasitic loop embedded capacitor (800 pF) in the near-field region. The proposed antenna generates the  $H$ -field toward the positive  $z$ -axis direction, but it prevents generating the  $H$ -field toward the negative  $z$ -axis direction.

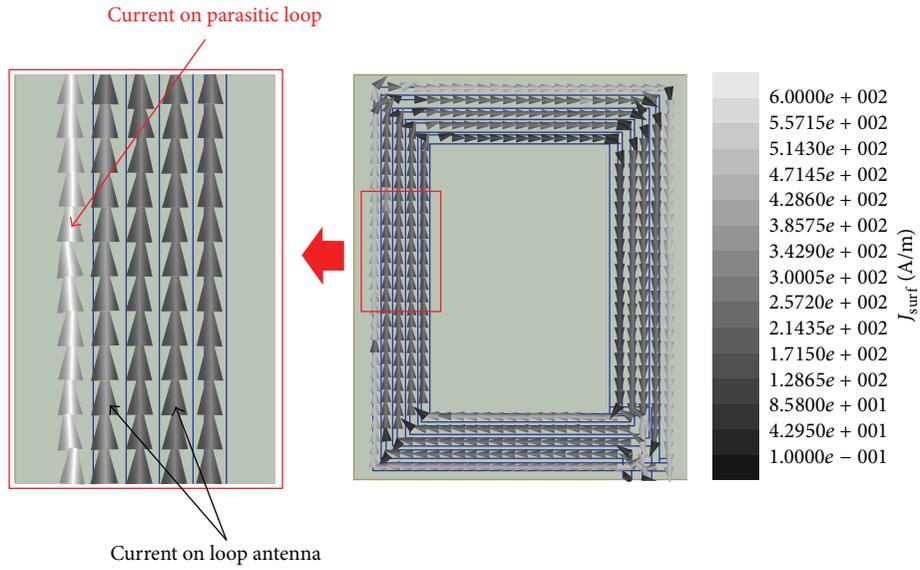


FIGURE 5: Current direction on the proposed loop antenna with the parasitic loop embedded capacitor (800 pF).

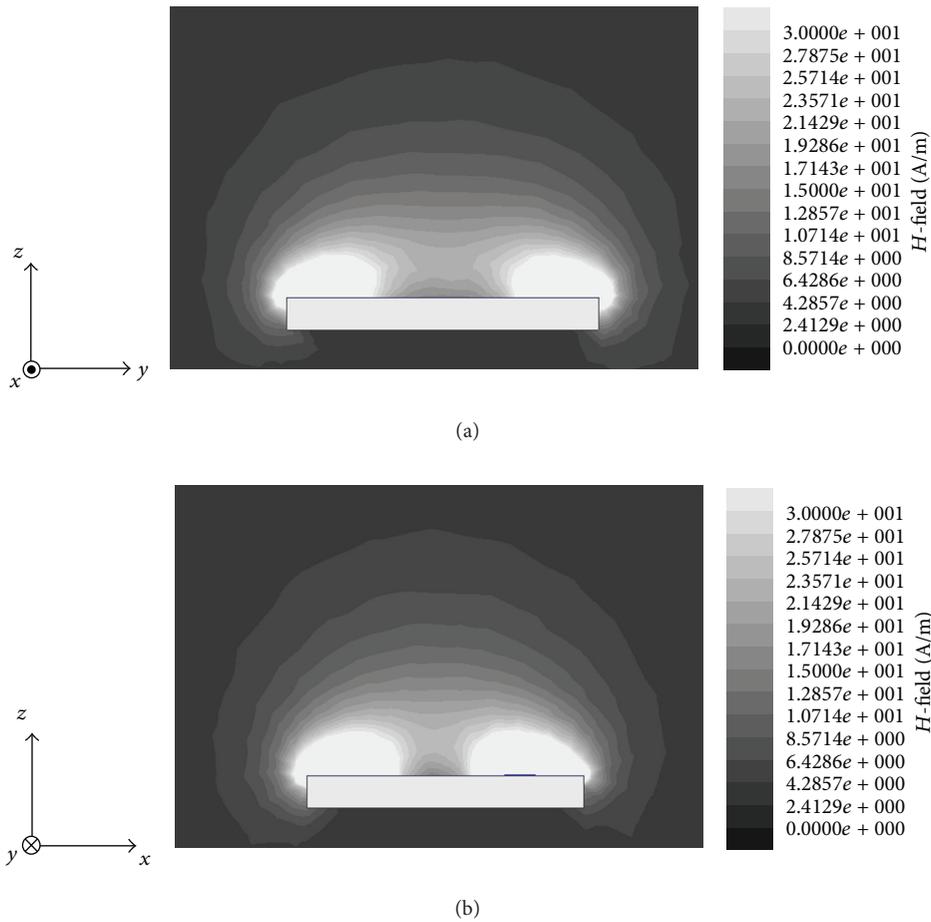


FIGURE 6: Near-field ( $H$ -field) distribution of the proposed loop antenna with the parasitic loop embedded capacitor (800 pF); (a)  $yz$ -plane and (b)  $zx$ -plane.

TABLE 1: Measured inductance and resistance of the proposed antenna.

	Inductance, $L_a$ [nH]	Resistance, $R_a$ [ $\Omega$ ]
Conventional 5-turn loop only	1970	13
4-turn loop with a parasitic loop	1350	7

TABLE 2: Measured results in the card mode and in the R/W mode tests.

	Card mode				R/W mode
	Load modulation Level [mV <sub>pp</sub> ]				Detection range [cm]
	Min. spec. at ( $r, \phi, z$ )				
	<b>8.8</b>	<b>7.2</b>	<b>4.0</b>	<b>2.4</b>	
	(0, 0, 0)	(0, 0, 1)	(0, 0, 2)	(0, 0, 3)	
Conventional 5-turn loop only	27	12	4.4	1.6	46
4-turn loop with a parasitic loop	50	25	11	4.3	56

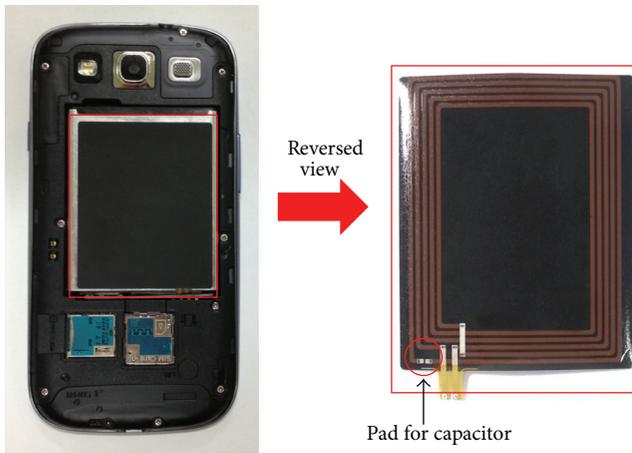


FIGURE 7: Prototype NFC antenna mounted on a mobile handset.

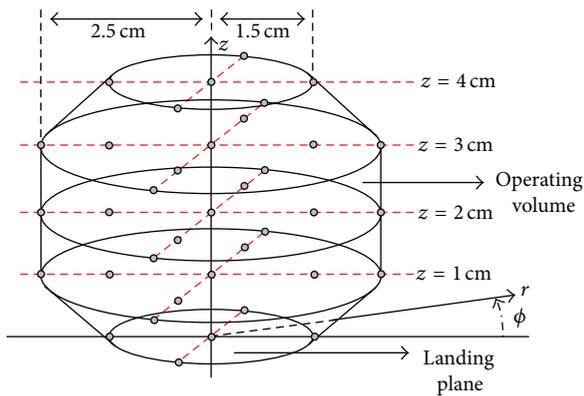


FIGURE 8: Operating volume for the EMV test.

### 3. Measured Result

To verify the performance of the proposed NFC loop antenna, the prototype antenna is mounted on the battery pack of a commercial mobile handset embedded NFC chip (PN544, NXP Semiconductor corp.) [5], as shown in Figure 7. When the proposed antenna embedded on the phone battery is

mounted on a mobile handset, its inductance and resistance are measured first as shown in Table 1. With these measured values, the matching circuit between the NFC chip and the antenna is designed [6]. After that, the card mode and the R/W mode tests are conducted. The card mode test is accomplished by the EMV test which measures a load modulation level ( $V_{pp}$ ) within a specific operating volume ( $r, \phi, z$ ) as shown in Figure 8. The specification of the EMV test applied is a global standard based on the ISO14443 for the contactless card payment [7, 8]. In addition, the R/W mode test is conducted by measuring the detection range responding to a reference tag (Mifare 1k). Table 2 shows the measured detection ranges (R/W mode test) and some of the measured load modulation levels (card mode test). When a mobile handset is in the R/W mode, the detection range of the proposed antenna is 56 mm. In the card mode, all of the measured load modulation levels within the specific operating volume ( $r, \phi, z$ ) meet the criteria values of an NFC system when the reader supplies the power of 600 mW.

### 4. Conclusion

A new structure of a compact NFC loop antenna is proposed for mobile handset applications by adding the parasitic loop on the outer side of a conventional loop antenna in order to improve its performance. The proposed antenna is designed with the ferrite-polymer composite sheet. Although this sheet has a low relative permeability ( $\mu_r \approx 55$ ), it is more durable and has lower cost than the sintered ferrite sheet ( $\mu_r \approx 200$ ). With the same size, the performance of the proposed NFC loop antenna in a load modulation level for the card mode test and in a detection range for the R/W mode test is better than that of a conventional NFC antenna.

### Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

## Acknowledgments

This work (Grant no. C0015229) was supported by Business for Cooperative R&D between Industry, Academy, and Research Institute funded by Korea Small and Medium Business Administration in 2012, the National R&D Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning (no. 2013M1A7A1A02043817), and a research grant from Kwangwoon University in 2014.

## References

- [1] J. Fischer, "NFC in cell phones: the new paradigm for an interactive world," *IEEE Communications Magazine*, vol. 47, no. 6, pp. 22–28, 2009.
- [2] R. Want, "Near field communication," *IEEE Pervasive Computing*, vol. 10, no. 3, pp. 4–7, 2011.
- [3] P. E. Ross, "Phone-y money," *IEEE Spectrum*, vol. 49, no. 6, pp. 60–63, 2012.
- [4] NFC Forum, <http://nfc-forum.org/>.
- [5] K. Finkenzeller, *RFID Handbook: Radio-Frequency Identification Fundamentals and Applications*, John Wiley & Sons, London, UK, 2003.
- [6] NXP Semiconductors, "AN 190810: PN544 C2 antenna design guide," Application Note, Rev. 1.0, April 2010.
- [7] EMVco, "EMV contactless specification for payment systems: Book D," EMV Contactless Communication Protocol Specification, Rev. 2.2, June 2012.
- [8] B. Lee, B. Kim, F. J. Harackiewicz, B. Mun, and H. Lee, "NFC antenna design for low-permeability ferromagnetic material," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 59–62, 2014.

