Evaluation of HF Band NFC/RFID Antennas for Smart Shelf Applications

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***Abstract* — a mass number of tagged items are predicted to be in use in future applications of HF RFID/NFC systems. One such application, where items such as books or other items contained on a shelf or in a cupboard, can use RFID technology to ascertain the position and logging of such items in addition to identifying their existence on the shelf hence defined as a smart shelf. In the first instance, a new theoretical approach is presented to increase bandwidth of RFID reader antennas operating at HF band to improve the reception of the backscattered RFID response. A prototype antenna is designed and evaluated by measurement for its capability in being used for smart shelf applications. The more bandwidth will support subcarrier frequencies for the all the existing HF RFID standards (ISO/IEC 15693 and ISO/IEC14443) to be detected more easily and thus leads to increased range of identification. Also, it is shown that in the presence of books, the HF RFID technology is capable of identifying the distance of a tag antenna based on the received *H*-field, which could be used in a smart shelf management system.**

Index Terms — Near-field radiation; Radio Frequency Identification Antennas (RFID antennas); Inductive Coupling

I. INTRODUCTION

A wireless system using radio frequency identification (RFID) consists of a reader/interrogator device and one or several transponders/tags. The RFID is a technology that communicates through radio waves to transfer data between the reader and the tag attached to an object for the purpose of identification and tracking. The rapid proliferation of passive RFID tags in the past decade has given rise to various concepts that integrate the physical world with the virtual one. One of the most popular is Internet of Things (IoT), a vision in which the Internet extends into our everyday lives through a wireless network of uniquely identifiable objects i.e. the IoT refers to uniquely identifiable objects (things) and their virtual representations in an Internet-like structure. If all objects of daily life were equipped with the RFID tags, they could be identified and inventoried by computers [1, 2]. In this type of RFID system, each physical object is accompanied by a rich, globally accessible virtual object that contains both current and historical information on that object's physical properties, origin, ownership, and sensory context. Smart RFID reader systems are building blocks for the IoT [3] and recently the RFID smart-shelf system has received much attention because of increasing demands for large scale item-level management such as grocery products in the retail supply chain, large volumes of books in libraries and important documentation in offices [4-7].

Most of the previous works address the RFID application on the performance of ultra high frequency (UHF) band and less have been reported that are relevant to high frequency (HF) applications which use inductive coupling to operate i.e. HF RFID [8]. HF RFID technology has an operation range of up to 1~2 meters and has good performance in a crowded environment when compared with UHF RFID because the magnetic field is not affected by most of the surrounding dielectric materials [9]. In the recent two years renewed interest and rapid progress has been made in the application of HF RFID for the IoT purposes [10].

Numerous predictions are given that we'll have hundreds of billions of RFID-tagged objects at approximately five cents per tag by 2015 [11]. Communications in such a crowded vast group of tags/readers as well as having more data transfer necessitate the need for reliable antenna to create smart RFID stock management, so a new design of HF RFID reader antennas is a critical issue. Bandwidth increment of HF RFID antennas will cause easier detection of subcarrier frequencies and thus increased range of identification.

In this paper an approach to increase the bandwidth of HF RFID antennas is presented and then implemented in a prototype antenna. Better range of receiving subcarrier frequencies for the all of the existing HF RFID standards (ISO/IEC 15693 and ISO/IEC 14443) is obtained. The capability of the antenna to identify position of book is investigated. Good results are obtained for the received *H*-field by the tag and also return loss of the enhanced bandwidth reader antenna. The presented antenna is a suitable candidate to be used in a HF RFID smart shelf system.

II. AN APPROACH TO INCREASE BANDWIDTH OF HF RFID ANTENNAS

Previously, a procedure similar to the design of a bandpass filter is used to synthesize the matching network [12], for example 0.5λ or 0.25λ stubs are used at the input of antennas to increase their bandwidth [12-15]. Because 0.5λ or 0.25λ stubs have big length values at HF band it is nearly impossible to use them in a practical HF RFID antenna input in order to increase bandwidth. For example for a HF RFID antenna operating at 13.56 MHz frequency, the wavelength (λ) is about 22.5 m while the dimension of conventional HF RFID antenna is about 1 meter [16, 17], so with due attention to the volume limitations, using equivalent lumped elements of the stubs as a bandpass filter at input of the HF RFID antenna seems a better choice to achieve bandwidth increment.

An open 0.25λ stub could be approximated by a lumped series LC circuit [18] as shown in Fig. 1 (Circuit A with L and C_S). By adding a small capacitor, C_P, parallel with the inductor L at the circuit A, circuit B is obtained, which is less sensitive to impedance variations and also cause to better controlling of resonance in comparison with circuit A. The calculated input impedance of circuit B is:

$$Z_B = \frac{LS^2(C_s + C_p) + 1}{(LC_pS^2 + 1)C_sS} \quad (1)$$

Where $S = j\omega = j2\pi f$. From (1) zero and pole of Z_B are:

$$\text{Zero of } Z_B: S_z = j/\sqrt{L(C_p + C_s)} \quad (2)$$

$$\text{Pole of } Z_B: S_p = j/\sqrt{LC_p} \quad (3)$$

The characteristic impedance of an open ideal 0.25λ stub, $Z_{0.25\lambda}$, at frequency of f based on transmission line theory is simulated by ADS software and is shown in Fig.2. To obtain a characteristic impedance of circuit B as near as possible to the characteristic impedance of an ideal 0.25λ stub at $f = f_{HF}$, zero and pole of circuit B i.e. (2) and (3), are set equal to zero and pole of an ideal 0.25λ stub (Fig.2), respectively, as:

$$\text{Zero of } Z_B: S_z = j/\sqrt{L(C_p + C_s)} = j2\pi f_{HF} \quad (4)$$

$$\text{Pole of } Z_B: S_p = j/\sqrt{LC_p} = j2\pi * 2f_{HF} \quad (5)$$

It is expected that by choosing proper values for C_P, C_S and L satisfying (4) and (5), bandwidth increment would be achieved based on the above approach.

III. Using the Approach to Increase the Bandwidth of a HF RFID Antenna Operating at 13.56 MHz

A HF RFID loop antenna operating at 13.56 MHz is characterized and is investigated in terms of impedance matching, resonant frequency, magnetic-field intensity/field distribution, quality factor, and detection range in [16,17]. Here, a loop antenna having the same dimensions with the antenna introduced in [16, 17] is considered in order to increase its bandwidth by using the approach introduced in section II. Circuit B in Fig.1 is added to HF input impedance matching circuit as shown in Fig.3. C_P=27pF, C_S=133 (100 || 33) pF and L = 1 uH are chosen as near values to satisfy (4) and (5) when f_{HF}=13.56MHz. An impedance matching circuit [19, 20] with capacitors was designed to match the antenna to a 50 Ω feed line, and to tune the central frequency of the antenna to 13.56 MHz with C_{P1}= 470 pF, C_{P2} = 165 (150 || 15) pF, C_{S1}= 33pF and C_{S2} = 27 pF as shown in Fig. 3. The equivalent circuit of the whole antenna structure containing the loop, matching circuit and circuit B is shown in Fig.4. The loop is modeled as an inductor L_A having a very low resistance $R_A \simeq 0$ [8]. The antenna is fabricated and mounted on the supporting flexible substrate with the dielectric constant of 1.07 and 0.1 mm thickness.

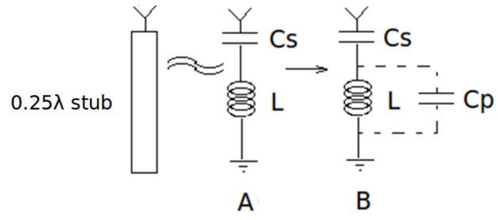

Figure1. (A) Approximated LC circuit for a open 0.25λ stub (B) modified LC circuit of circuit A

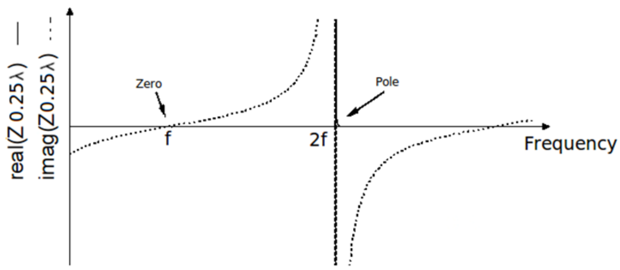

Figure2. Characteristic impedance of an open ideal 0.25 λ stub at frequency of f

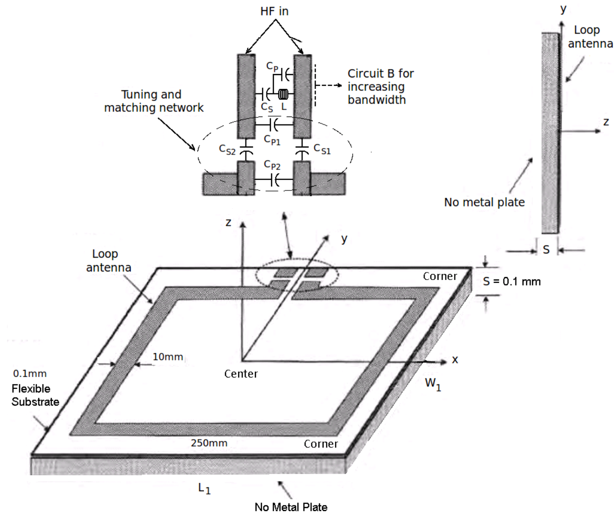

Figure3. Configuration of the enhanced bandwidth HF RFID loop antenna

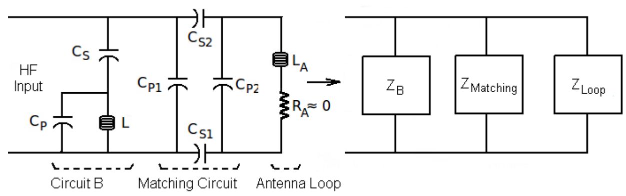

Figure4. Equivalent circuit of the whole enhanced bandwidth HF RFID antenna structure including antenna loop, matching circuit and circuit B

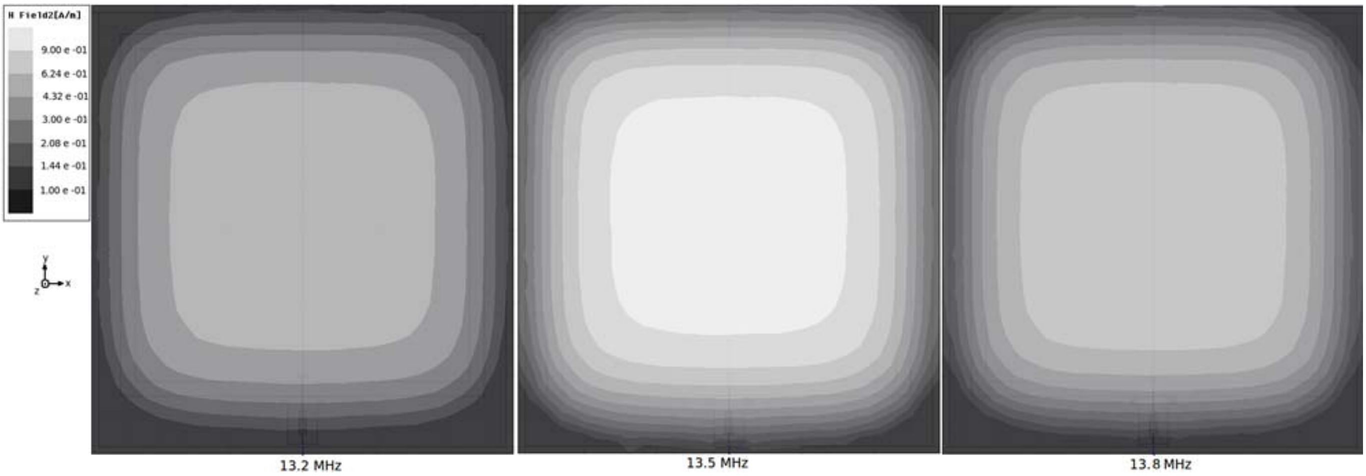

Figure6. The simulated magnetic-field distribution of the enhanced band width loop antenna at 13.2, 13.5 and 13.8MHz, The loop was located in the *x-y* plane at z = 0 mm, and the field distribution was calculated in the *x-y* plane at z = 50 mm.

IV. Simulation And Mesurment Results

The simulated and measured return loss of the antenna presented in section III are shown in Fig.5. It is seen that the S11<-10dB bandwidth, which is 800 KHz, is about 4 times more than the antenna presented in [16, 17]. Return loss of the antenna for different HF RFID standards of 13.56 MHz frequency are compared in Table 1. 13.56 MHz$\pm f_S$ KHz is bandwidth of the standard that f_S is subcarrier frequency. For both ISO/IEC 15693 standard with f_S=212,424 KHz and ISO/IEC14443 standard with f_S = 848 KHz [8], better ranges are obtained to receive subcarriers in comparison with the HF RFID antenna in [16, 17]. Fig. 6 shows the simulated magnetic-field distribution of the enhanced bandwidth loop antenna at three frequencies around the beginning, middle and end of the bandwidth (13.2, 13.5 and 13.8 MHz) using 2 dBm power source. The loop is located in the x-y plane at z = 0 mm and the magnetic-field distribution in the x-y plane at z = 50 mm is shown. Fig. 7 shows the measured magnetic-field intensity of the antennas. The antenna was located in the x-y plane and fixed on a turntable. The magnetic-field probe was positioned in the x-y plane as well, and was moved along the z axis. Also, the effect of paper (books) as a sample material in front of the antenna is shown in Fig. 7. Fig .8 shows the measured *H*-field of the loop antenna, at the center and corner of the antenna shown in Fig.3, versus distance with and without books at 13.56 MHz frequency using 27 dBm power source. Results presented in Fig. 8 show that the designed antenna does have a defined characteristic in how the magnetic *H*-field decays over distance within 80cm and that the effect of the books maintains such a characteristic wherever the tag is positioned on the book. The *H*-filed is dependent on $1/r^3$ at the identification distance as expected for near field of the antenna. The measurement setup is shown in Fig.9.

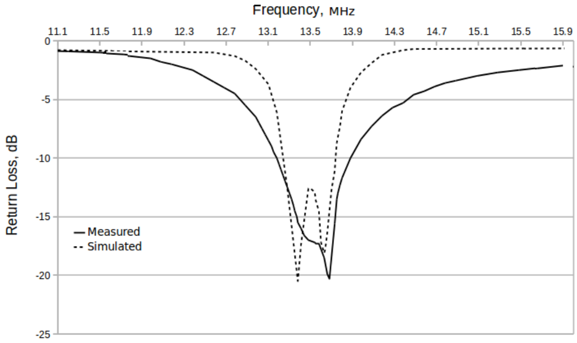

Figure5. The measured and simulated return loss of the enhanced bandwidth loop antenna.

TABLE1. MAXIMUM RETURN LOSS (Fig 5) OF THE ENHANCED BANDWIDTH ANTENNA FOR 13.56 MHz HF RFID STANDARDS

Standard	f_S	Maximum return loss at 13.56 MHz $\pm f_S$ KHz bandwidth
ISO/IEC 15693	212 KHz	-15 dB
	424 KHz	-9.5 dB
ISO/IEC 14443	848 KHz	-6 dB

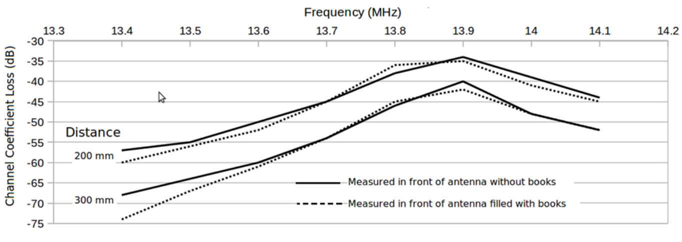

Figure7. The measured magnetic-field distributions of the loop antenna by network analyzer with and without book

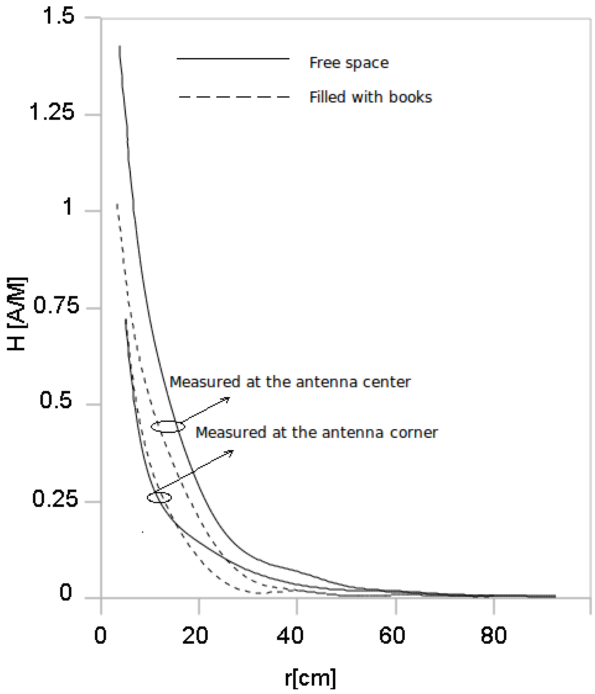

Figure8. The measured *H*-field of the loop antenna versus distance with and without books at 13.56 MHz using 27 dBm power source

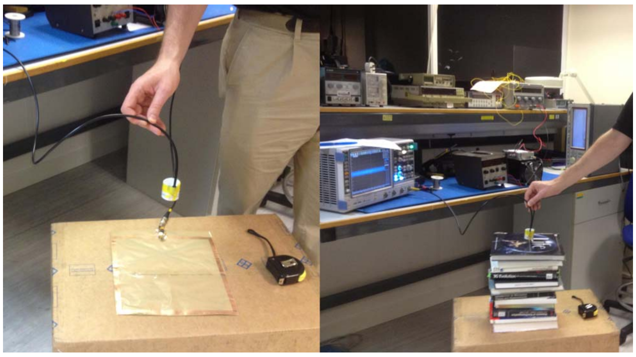

Figure9. The measurement setup of the enhanced bandwidth antenna with and without books

V. CONCLUSION

A method to increase the band width of HF RFID antennas was presented in this paper and then was used to increase band width of a conventional HF RFID antenna. Results presented in this paper show that the smart shelf antenna designed with increased bandwidth to accommodate the ISO/IEC standards for NFC/RFID at the HF band does have a defined characteristic in how the magnetic *H*-field decays over distance within 1m and that the effect of the books maintains such a characteristic wherever the tag is positioned on the book. This therefore verifies the feasibility of the antenna to be used in an intelligent HF RFID system.

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