Influence of substrate types and reflector proximities over a NDTC antenna

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***Abstract*—The influence of dissimilar substrates and reflector proximities over a newly developed Non-uniformly Distributed-Turns Coil (NDTC) antenna for High-Frequency (HF) Radio Frequency IDentification (RFID) applications is presented. In the study, the performance of the HF-RFID NDTC antenna over various substrates with deposited conductor thicknesses is conducted. In addition, the effect over a conceivably encountered reflector in the proximity of the antenna is considered. Insensitive reflection coefficient (S11) responses for different substrate permittivities were experienced and the diverse conductor types and thicknesses contributed to a compromised magnetic-field (H-field) and re-calculated matching network. The matching network additionally preserves resonance when the antennas is in close proximity to the reflector and a predictable H-field response for the separation range is shown.**

***Index Terms*—Near-field, magnetically coupled coils, RFID.**

I. INTRODUCTION

Radio Frequency IDentification (RFID) is currently being used for track-and-trace applications. The High Frequency 13.56 MHz band (HF-RFID) is the preferred in near-field RFID systems [1] which employ inductive coupling between the Tag and the Interrogator [2]. Coils are widely used for low-profile antennas and optimized to produced maximum H-field (H) at a predefined tag location. In [3]–[5], a multi-turn coil was used as Interrogator antenna. In the design process, the size of the coil was optimized [1] to enhance H by rearranging the coil's inner turns. Optimization methods, including the constant-L [4], [5] and the unconstrained Q-factor (Q) [5] have been reported, and the latter was preferred for the H enhancement with fair comparison. Based on the optimization using unconstrained Q method, in [6], [7], we proposed a Non-uniformly Distributed-Turns Coil (NDTC) antenna, used as Interrogator, to maximize the H. In this paper, the NDTC antenna is studied over various substrates with deposited conductor types and thicknesses. In addition, for deployments where the NDTC antenna encounters metallic parts (reflectors) in the vicinity, these can affect its performance, and the influence of a reflector over the antenna is therefore studied - any variation of the operating frequency and H is presented.

First, the authors compare the performance of the NDTC antenna for dissimilar substrates with differ conductor types and thicknesses and second, the performance of the antenna when in close proximity to the reflector. The imminent detuning S11 and shift in the operation frequency of the antenna (later given in Section III) is re-tuned to the center frequency, $f_c = 13.56$ MHz and the corresponding matching network parameters provided. Even though the antenna is re-tuned, the H response varies considerably upon the substrate type and the predicted H in these cases is reported in Section III. It will be shown a few decibels (dBs) constrained H when the NDTC antenna is a centimeter (cm) apart from the reflector

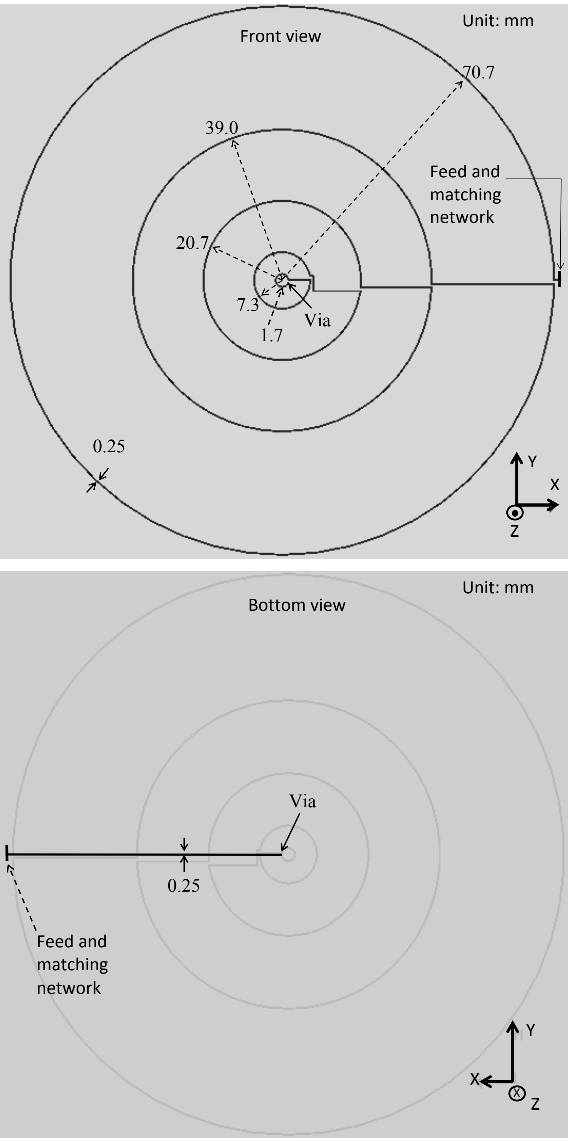

Fig. 1. The NDTC antenna

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and a negligible de-tuning with unconstrained H when ten centimeters apart.

II. THE NDTC ANTENNA

Earlier the authors designed an NDTC antenna and reported in [6], [7]. The coil, designed for a read range of $D = 5$cm, is shown in Fig. 1. The radiative elements (conductor) of width 0.25mm were etched on an FR4 substrate of 1mm thickness. The equivalent circuit model of the coil (resistance R and inductance L) with L-matching network made of lumped capacitances C1 and C2 is presented in Fig. 2; the capacitors are designated to resonate the coil at the f_c.

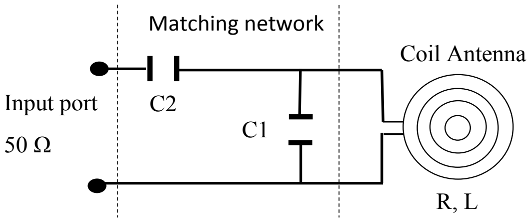

Fig. 2. The equivalent circuit model of the coil with matching network.

In this paper, the authors evolve from these results to analyse the influence of typically utilized substrates in the HF-RFID applications, such as the Printed Circuit Board (PCB) based on laminate FR4 and Polyamide, the Liquid Crystal Polymer (LCP), the Low Temperature Co-fired Ceramics (LTCC) and the Polyethylene Terephthalate (PET), whose properties including the corresponding conducting materials [8] are provided in Table I.

TABLE I
SUBSTRATE TYPE WITH CORRESPONDING CONDUCTOR PROPERTIES.

	E_r	$tan\delta$	conductor	thickness
PCB FR4	4.3	0.025	copper	35
LCP	2.9	0.002	copper	18
LTCC	5.7	0.001	gold	10
PET	3.4	0.002	silver	20
PCB-Polyamide	3.4	0	copper	17.5

III. RESULTS

Using Zeland IE3D, based on the Method of Moments (MoM), the NDTC antenna of Fig. 1 with substrate/conductor types of Table I is simulated. The unloaded NDTC antennas are first simulated for R and L to evaluate corresponding matching elements (C1 and C2) of Fig. 2. The simulated R, L and corresponding Q are presented in Table II; the necessary C1s and C2s to preserve antenna matching are also included.

TABLE II
UNLOADED COIL R, L, Q, AND MATCHING NETWORK ELEMENTS.

	$R(\Omega)$	$L(\mu H)$	Q	C1(pF)	C2(pF)
PCB FR4	2.2	1.48	58.0	73.78	19.47
LCP	3.9	1.47	32.3	67.79	26.26
LTCC	9.1	1.47	13.7	53.84	40.51
PET	3.3	1.47	37.8	69.62	24.25
PCB-Polyamide	4.0	1.47	31.3	67.22	26.62

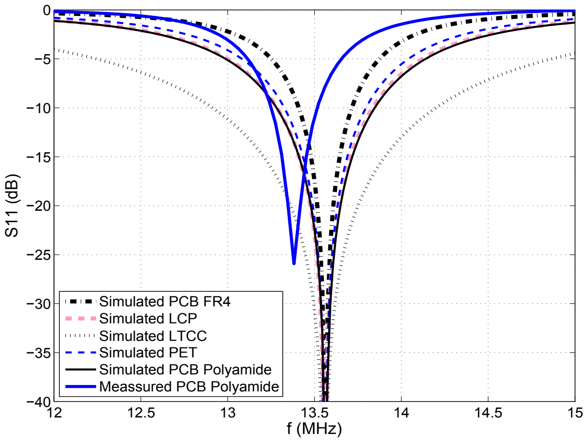

Fig. 3. S11 of the NDTC antenna with various substrates (and matching network).

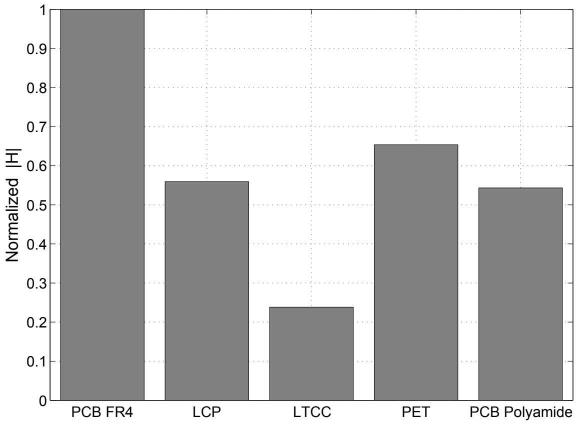

Fig. 4. H-field comparison of NDTC antenna with various substrates (and matching network).

The matched NDTC antenna of Fig. 1 having the matching network (C1 and C2 of Table II) was simulated; the designs were fed with peak 1V signal. The corresponding S11 responses are shown in Fig. 3. Initially, the simulated response for the PCB Polyamide is compared to measurements to corroborate that the simulator settings were adequate. The slight shift in frequency was due to available values of commercial capacitors that were slightly away from the calculated C1 and C2 (Table II); the simulated responses were therefore well matched to f_c with assigned matching networks. The simulated H of the NDTC antennas with substrates and read range $z = D = 5$cm are compared in Fig. 4 and show the highest H when using the PCB FR4 and the lowest for the LTCC; that for the antenna with LCP, PCB polyamide, and PET is about 46%, 44%, and 35% lower than that using the PCB FR4; therefore, PCB FR4 is valid for low-cost HF-RFID NDTC antenna realizations. For brevity, the influence of the reflector on the NDTC antenna was simulated using the PCB FR4 substrate exclusively and is provided subsequently.

The reflector was placed at $z = -d$, where d is the separation distance with respect to the NDTC antenna. The simulated S11 responses for various d (in range of 1-11cm) are shown in Fig. 5. The reflector resulted in an up shift of the operating frequency; this effect gradually decreases for higher d and becomes insignificant for $d > 11$cm. To compensate these shifts, the matching network elements were recalculated to preserve matching at f_c for each d (1, 2, 3, 5, and 11cm); the modified C1 and C2 values are provided in Table III. With the new centered f_c S11 responses, the simulated H of the NDTC antenna with respect to d (quantified for a near-field of $z = 5$cm) is depicted in Fig. 6; the normalization was made for an H (without reflector) in free space. By observation, the H is compromised due to the reflector proximity even the NDTC antenna matching network was recalculated to preserve matching - that was about -6dB H for $d = 1$cm and insensitive (0dB) for $d = 11$cm. This suggests that contextual metallic parts in the vicinity of the NDTC antenna should be considered and to preserve the reading range $D = 5$cm, the H loss should be compensated by an equal increase in input power.

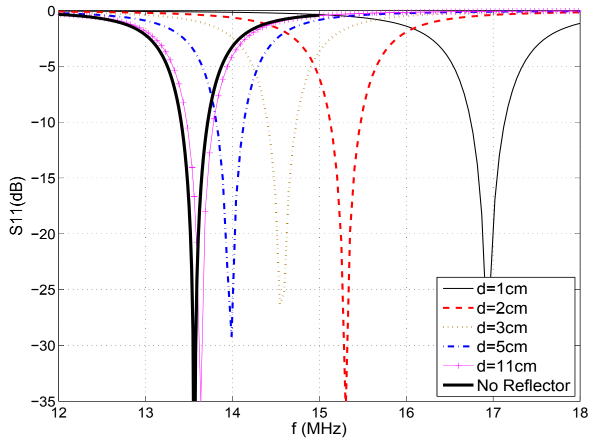

Fig. 5. The simulated S11 response of the NDTC antenna (PCB FR4) for various d.

TABLE III
RECALCULATED MATCHING NETWORK C1 AND C2 TO PRESERVE MATCHING.

d (cm)=	1	2	3	5	11
C1 (pF)	92.67	83.46	79.40	75.77	74.14
C2 (pF)	24.56	22.05	20.97	19.99	19.56

IV. CONCLUSION

Earlier designed NDTC antenna showing enhanced H-field in HF-RFID applications [6] was assessed for use on various substrates with different deposited conductors types and thicknesses and the influence over a reflector in the vicinity studied. The S11 response of the NDTC antenna was insensitive to the substrate permittivity, and independent to the conductor type due to the well defined matching network. The PCB-FR4 was therefore valid for the application given the positive effect of a thicker deposited conductor, which translated into an unconstrained H. For the NDTC antenna with a reflector, a negative influence was observed when in close proximity and negligible for a reasonable separation - the compromised H can be compensated by an equal increase in input power; this would allow the antenna to be used near reflectors.

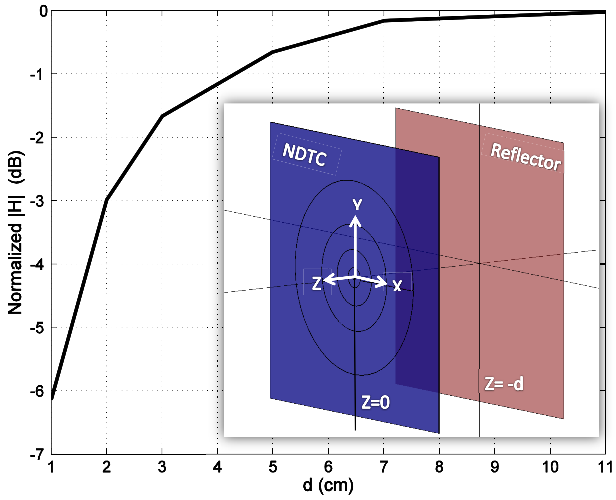

Fig. 6. The simulated H of the antenna (NDTC on PCB FR4) with respect to d (quantified at $z = 5$cm).

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