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Evaluation Of HF RFID for Implanted Medical Applications

Eric Freudenthal
University of Texas at El Paso, efreudenthal@utep.edu

David Herrera
University of Texas at El Paso, daherrera@utep.edu

Frederick Kautz

Carlos Natividad

Alexandria Ogrey
University of Texas at El Paso, anogrey@miners.utep.edu

See next page for additional authors

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Authors
Eric Freudenthal, David Herrera, Frederick Kautz, Carlos Natividad, Alexandria Ogrey, Justin Sipla, Abimael Sosa, Carlos Betancourt, and Leonardo Estevez

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***Abstract*— Low cost HF RFID scanner subsystems that both deliver power and provide high bandwidth bidirectional communication channels have recently become available. These devices are anticipated to become ubiquitous in next-generation cell phones and enable a wide range of emerging e-commerce applications.**

This paper considers the use of HF RFID to power and communicate with implantable medical devices. We successfully communicated with ten transponders that were implanted at three locations within a human cadaver. In this paper, we present measurements collected from four of these transponders that represent a wide range of transponder sizes. We also describe how RFID for medical implantation requires significantly different privacy protections than previously investigated medical uses of RFID.

Our experiments, which measure communication range, detect a strong sensitivity to the thickness of the insulator separating a transponder's antenna from nearby tissue. This thickness can be tuned to achieve communication range similar to non-implanted transponders. This sensitivity can potentially be exploited to construct specialized implantable pressure sensors useful for a variety of applications.

I. INTRODUCTION

Low frequency RFID (around 134 kHz) is used for implants that identify livestock and pets, and only permits communication at low data rates. In order to enable the growth of field-powered e-commerce applications such as smart billboards that communicate directly with consumer devices, the NFC (Near Field Communication) Forum [10] has adopted protocols upon 13.56 MHz RFID that provide bidirectional communication channels with significantly higher bandwidth.

The increased bandwidth provided by NFC enables the transmission of messages of sufficient length to permit the incorporation of privacy- and integrity-preserving cryptographic protocols necessary to protect health-critical systems and the information they contain. For example, there are standardization activities underway (such as HL7) to enable the storage of electronic health records within NFC-enabled RFID tags.

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Eric Freudenthal and Justin Sipla are faculty at the University of Texas at El Paso. 500 W. University Avenue, El Paso, TX, 79902, USA. {*efreudenthal, jssipla*}@*utep.edu*

David Herrera, Frederick Kautz, Carlos Natividad, Alexandra Ogrey and Abimael Sosa are students at the University of Texas at El Paso. 500 W. University Avenue, El Paso, TX, 79902, USA. {*daherrera, ffkautz, anogrey, canatividad, sosaa*}@*miners.utep.edu*

Carlos Betancourt and Leonardo Estevez are with Texas Instruments Incorporated, 12500 TI Boulevard, Dallas, TX, 75243, USA. {*carlosb, leonardo*}@*ti.com*

UHF (e.g. 900 MHz RFID) is problematic for telemetry with implanted devices due to its high attenuation by water, which is a primary constituent of human tissue. In contrast, HF (13.56 MHz) RFID is not substantially attenuated by water and thus is more suitable to this application. HF RFID scanners will soon be integrated within millions of NFC enabled mobile phones. Our research investigates the effectiveness of commodity HF transponders and scanners for communication with implanted medical devices. While we found that it was important to tune the transponders to the implantation environment, our findings are overwhelmingly positive: Deeply implanted transponders could be read several centimeters from the body at distances-to-transponders similar to those observed for unimplanted transponders.

II. POTENTIAL APPLICATIONS OF IMPLANTED RFID

There has been much excitement about the potential market for Digital Angel's implantable glucometer that can utilize NFC for both telemetry and as a power source [13]. Similarly, monitoring of brain function can be provided by probes implanted within the brain [8] that communicate via an NFC transponder embedded within the skull. These same probes may also be used therapeutically, for example, delivering a sequence of signals that disrupt a seizure.

Should substantial computation be required (e.g. for signal processing), NFC can provide a data communication link to external computers that potentially have larger power budgets than is practical for RFID devices. NFC data links can also be used to coordinate the behavior of several systems (e.g. components that measure glucose and components that dispense insulin).

NFC is also suitable for providing telemetry to self-powered devices. For example, potential applications include collection of historical data from and setting of operating parameters for ICDs (internal cardiac defibrillators) [16].

Direct internal electrical stimulation has been identified as useful for a variety of medical conditions. This family of applications is particularly well suited for NFC since this stimulation requires very small amounts of energy that can potentially be provided by batteries recharged via NFC [11]. Furthermore, NFC can be used to adjust operating parameters after implantation. Potential applications of implanted NFC for stimulation include:

- Direct mitigation of chronic pain through the use of spinal chord stimulation (see [9], [5]),
- Reduction of Parkinson's disease symptoms through the use of deep brain stimulation (see Krausea, Fogela

et al. [4]).

- For patients with morbid obesity: The prevention of excessive eating by gastric stimulation that creates a feeling of satiation (see Wang. et al, [17])
- Mitigation of diabetic gastroparesis through the use of high frequency stimulation (see Patterson, Thirlby and Dobrio [12]).

A. COMPARISON OF LF, HF, AND UHF RFID

Magellan [7] provides a comprehensive overview of alternative RFID implementations that strongly motivates future use of HF (13.56 MHz) RFID for implanted medical applications. We begin this section with a summary of competing systems' characteristics that we then compare with HF.

LF (134 kHz) RFID is commonly in use to identify pets and livestock since signals are not significantly attenuated by tissue and has been used for more than a decade. Transponders are small - typically about 2 x 10 mm and can be easily surgically implanted. LF RFID provides low data communication rates (5.2 kb/s), and typically does not utilize any sort of cryptography. Due to their small cross-sectional area, these transponders have a limited ability to transfer energy to drive sensors or other devices. Finally, scanners for LF are substantially more expensive than scanners for HF or UHF transponders.

RFID transponders that operate in the UHF (900 MHz) band are also available. Due to their higher carrier frequency, UHF RFID offers significantly higher data rates than LF RFID, but, as described above, are problematic for human implantation. It is difficult to restrict the range of UHF scanners and devices intended for short ranges can have complex dispersion and sensitivity patterns that include *phantom hot spots* several meters from the scanner. Finally, internationalization is difficult due to inconsistent allocation of UHF bands among nations.

Like LF RFID, HF RFID is not significantly attenuated by human tissue and thus is expected to be suitable for communication with implanted medical devices. Both transponders and scanners are small and inexpensive. Due to their commercial value for NFC, small size, and low cost, HF scanners are expected to be common in next-generation cell phones. Unlike UHF RFID, the 13.56 MHz channel is available internationally and short range HF scanners do not have the distant phantom hot spot problem. Finally, due to jitter encoding and other signaling techniques, HF RFID achieves higher practical data rates than UHF.

HF RFID transponders are manufactured as flexible printed circuit board (PCB) *inlays* to be embedded within a carrier such as a security tag or ID card. These inlays contain a printed antenna, a laser-tuned loading capacitor, and an integrated circuit (see Figure 1). Inlay size is dominated by antenna area, and larger tags are genrerally able to transfer a correspondingly greater amount of power. Measurements are presented for four *Tag-it*[1] transponders whose dimensions are enumerated in Table I. Several plastics are available for insulating these devices if used for implantation. For example, Fluoropolymers' (e.g.Teflon) strong C-F bonds make them inert in most environments and have been widely used for implantation applications. These plastics can be formulated to have a range of flexibilities and strengths [1].

[1]Tag-it is a registered trademark of Texas Instruments Incorporated

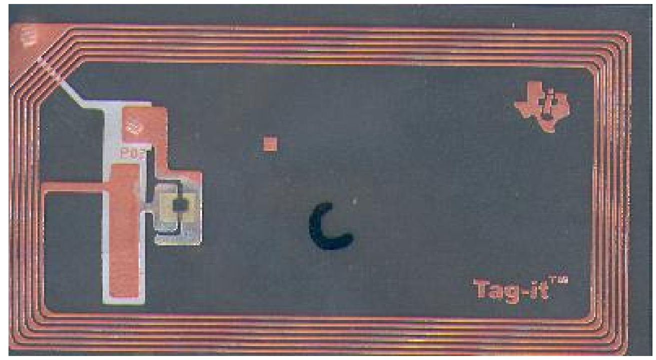

Fig. 1. Texas Instruments' Tag-it^{TM} Transponder Inlay Labeled "C"

TABLE I
DIMENSIONS OF TRANSPONDER INSETS

Label	Length (mm)	Width (mm)	Area (mm^2)
Q	22	38	836
O	45	45	2025
C	65	34	2210
M	76	45	3420

III. IMPLANTATION EXPERIMENTATION

RFID transmission range is normally dependent on a number of factors including scanner power output and antenna characteristics (for both scanner and transponder). Both scanner and transponder antennas serve for transmission and reception; Generally larger size and greater scanner power provide longer range, though we found that transponder antenna area did not reliably correlate with longer range when implanted.

There is a paucity of published research on HF RFID transponders implanted within animals. An esoteric application of HF RFID implanted within a dog's tooth has been investigated [2] that achieved very short-range communication, but we are unaware of other studies of communication with commodity printed-antenna transponders.

Our research indicates that HF RFID is suitable for communication to transponders within cavities at a wide range of depths within a human or other animals. A variety of transponder inlays whose antennas are printed upon flexible PCBs were implanted at three locations within a preserved cadaver of an elderly male. An RFID scanner based on the Texas Instruments TRF7960 chipset with an integrated 4 x 5.5 cm PCB antenna was used to query the transponders. Raw beef fat was observed to have similar coupling and signal transmission properties to the preserved cadaver.

Ten transponders (5 to 35 cm^2) with similar designs were implanted:

1) below the cadaver's chest's sub-cutaneous fat and directly above investing fascia of pectoralis major,

TABLE II

IMPLANTATION DEPTHS.

Location	Depth (mm)
(1) Below dermal fat	11
(2) Below ribs	27 (includes 11mm dermal fat)
(3) Within skull	15 (includes 6.5mm skin & superficial fascia)

TABLE III

SENSITIVITY TO INSULATOR THICKNESS FOR TRANSPONDER C IMPLANTED BENEATH DERMAL FAT AND WITHIN BEEF FAT.

# layers 6 μm plastic insulator	Minimum distance (cm) to chest	fat
1	1.5	2.5
2	6	4
3	10	7
4	9.5	*not measured*

2) beneath the 6th rib, on anterolateral surface of the right lung, and
3) upon the dorsal surface of the brain's cerebral hemisphere.

To determine correspondence between measurements taken within a preserved cadaver and more easily replicated conditions, in-vitro measurements were taken using transponders implanted between 12 mm layers of fresh beef fat. Photographs of typical implantations appear in Figure 2. Implantation depths are indicated in Table II. The maximum usable range at which each transponder could be reliably read (scanner-to-flesh) was measured.

Capacitance between a transponder and its carrier can substantially affect the tuning of its antenna. To minimize mutual coupling among nearby transponders and to compensate for capacitance to carriers, HF RFID transponders are typically tuned not to resonate at the scanner's carrier frequency. Our range experiments indicate that proximity to tissue can dramatically affect transponder tuning and thus can modulate communication range.

The Texas Instruments TRF7960 scanner can transmit at two power levels. We found that the lower *half* power level only slightly reduced communication range. All of the measurements presented in this paper were obtained using the high power level except those presented in Table III.

Transponder antennas are uninsulated and unable to communicate when in direct contact with tissue. For our investigation, transponders were insulated from tissue by bags constructed from 6μm plastic film. Transponder antennas were significantly detuned at this small distance to tissue, but as indicated in Table III, the addition of a small number of additional layers of insulation was sufficient to substantially increase range. As is indicated in the second column, transponder *C*'s range was slightly reduced when too much insulation was present. Table IV presents similar insulator thickness sensitivity for transponders implanted in locations (1) and (3). Most transponders implanted in our experiments showed similar sensitivity to insulator thickness.

All implanted Tag-it transponder inlays that were insulated by at least two 6 μm layers of insulating film had sufficient range to communicate with a scanner at least 4 cm, and sometimes as much as 10 cm from the body *in all locations*. Transponder inlay *C* (see Figure 1) had a particularly long range of more than 7 cm outside of the body when implanted at any of the locations we examined when insulated by at least 12 μm of plastic film.

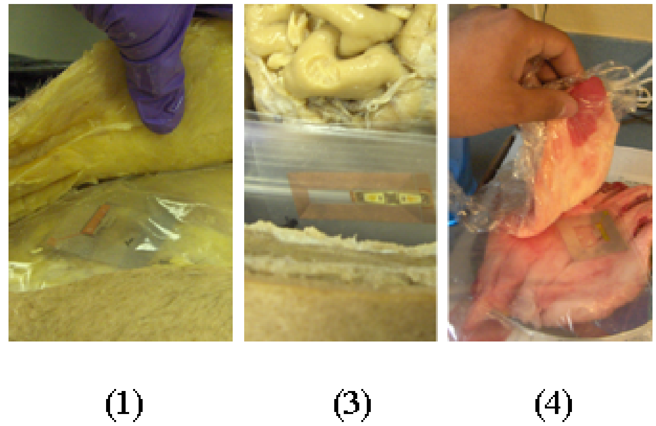

Fig. 2. Transponder implantation (1) below fat attached to chest derma, (2) below ribs (not shown), (3) within skull, and (4) within layers of beef fat. Communication range was significantly affected by the thickness of insulation separating implanted transponders and nearby tissue.

TABLE IV

SENSITIVITY TO INSULATOR THICKNESS FOR IMPLANTATIONS AT LOCATIONS (1) AND (3)

Location (1): Sub-dermal Chest Implant

# layers 6 μm plastic insulator	Maximum distance (cm) skin to scanner M	C	Q	O
1	3.5	4.5	3	2
2	4.5	7.5	5	3.5
3	5.5	8	6	5

Location (3): Cerebral Implant

# layers 6 μm plastic insulator	Maximum distance (cm) skin to scanner M	C	Q	O
1	3	6	5	4
2	4	6.5	6	4.5
3	5.5	7.5	6	7

A. Exploitation of Sensitivity to Antenna Capacitance

At the time of manufacture, the capacitor loading an RFID transponder's antenna is tuned for the anticipated installation carrier [15]. As described above, we observe that the communication range can be substantially attenuated by an antenna detuned by a thin insulator. Thus a simple transponder could be used as an implanted pressure sensor if the insulator was made from a compressible material. The compressible material can be selected or designed to be sensitive to pressure ranges useful for a particular target application. Potential applications include measurement of static pressure within cavities (e.g. hemorrhaging within a skull) and audio-frequency monitoring of circulatory or respiratory systems (such as provided by stent pressure monitors). They also may be embedded within clothing or shoe-soles.

IV. Privacy and Security Concerns

While implanted RFID/NFC may provide health benefits, it also potentially reduces personal privacy and may expose users to dangerous malfunction due to security vulnerabilities.

The presence of an implanted RFID device may be surreptitiously detected by scanners not authorized by an implantee. Thus, strong cryptographic techniques must be employed to prevent the involuntary disclosure of (1) private medical information (e.g. the presence of an implanted medical device) and (2) the time and date that the implantee passes by scanners. These risks and several potential strategies for mitigation are described in [6].

The *blocker tag* approach of Rivest et al. [3] has been proposed as appropriate for the protection of medical information. A scanner that does not possess an appropriate authorization can not obtain any data from a blocker transponder. However, we observe that an implantee will reasonably wish to limit disclosure of their implant's presence, and this approach will not prevent such detection.

We advocate the development and adoption of cryptographic protocols that enable communication between a transponder and authorized scanners, but inhibit a transponder from responding in any manner to a query from an unauthorized scanner. For example, a symmetric or an asymmetric cryptographic protocol could be used to encrypt and authenticate an initial scanner query. Such an approach could be hardened against replay attacks through the incorporation of a *salt* field whose value increases monotonically.

In their provocatively titled paper *Is Your Cat Infected with a Computer Virus* [14], Rieback, Crispo, and Tannenbaum argue that RFID/NFC devices, like other networked systems, are vulnerable to various forms of attack by malicious software. We observe that a successful attack upon an implanted medical device could disrupt its life-critical functions. Fortunately, the most common forms of vulnerability are due to software coding errors and thus are potentially preventable. Replay-attack resistant symmetric cryptographic protocols may be sufficient for this application since implanted medical devices will generally only need to communicate with a small number of designated scanner-equipped systems that can be explicitly given copies of an implantee-specific shared secret key.

V. Conclusion

As confirmed by experiments with commodity transponders and scanners, 13.56 MHz RFID is suitable for implants in fascia where (1) stronger security, (2) higher data rate communication and (3) greater power delivery (for powering attached devices) is required. However, as with other applications of distributed systems, this connectivity can enable the unintended disclosure of private information (including evidence of whereabouts and health status) and corruption of system integrity. Since even the presence of implanted RFID may serve as evidence of a medical condition or positional history, and the corruption of device integrity can be harmful to implantee health, it is imperative that appropriate safeguards and engineering practices are rigorously applied.

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