

# Suitability of NFC for Medical Device Communication and Power Delivery

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**Abstract**—Near Field Communications (NFC) is a 13.56 MHz inductively coupled power delivery and communication protocol that extends the ISO 14443 RFID standard. Low cost NFC scanner subsystems are anticipated to be widely incorporated in coming generations of commodity cellular phones.

We consider the potential of this emerging infrastructure to provide convenient and low cost power distribution and communication channels for a range of medical devices. For example, an NFC device within a cell phone could relay measurements collected from a defibrillator-pacemaker to a monitoring physician, remotely control an insulin pump, or activate an implanted neural simulation system.

NFC devices pose similar bio-compatibility challenges to other implanted electronics without requiring the provisioning of battery power to support communication. Furthermore, an NFC communication subsystem's power-independence provides a measure of defense against potential denial-of-service attacks that consume power in order to discharge a capacity-limited power source.

The 13.56 MHz band has minimal interaction with human and animal tissues. We conducted several successful proof-of-concept experiments communicating with with ISO 14443 tags implanted at multiple locations within a human cadaver.

Magnetic field strength decays with the cube of distance-to-antenna, limiting limits the range of potential eavesdroppers. At present, NFC protocols do not provide an appropriate set of privacy properties for implanted medical applications. However, NFC devices are implemented using embedded general purpose processors and thus only software modifications would be required to support protocol extensions with enhanced privacy.

## I. 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 communication and as a power source [14]. Similarly, monitoring of brain function can be provided by probes implanted within the brain [7] that communicate via an NFC transponder embedded within the skull. These same probes may also be used therapeutically,

This research was supported by a gift from Texas Instruments Incorporated.

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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 practical for implanted and/or field-powered devices. NFC data links can also be used to coordinate the behavior of several cooperative systems (e.g. components that measure glucose and components that dispense insulin).

NFC is also suitable for providing communication for self-powered devices. Potential applications include collection of historical data from and setting of operating parameters for ICDs (internal cardiac defibrillators) [18]. In such configurations, NFC communication subsystems may be field-powered and thus not impose any additional drain on limited battery resources.

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], [4]),
- Reduction of Parkinson's disease symptoms through the use of deep brain stimulation (see Krausea, Fogela et al. [3]).
- For patients with morbid obesity: The prevention of excessive eating by gastric stimulation that creates a feeling of satiation (see Wang. et al, [19])
- Mitigation of diabetic gastroparesis through the use of high frequency stimulation (see Patterson, Thirby and Dobrio [12]).

## A. Related Approaches

Low frequency RFID (around 134 kHz) is used for implants that identify livestock and pets, and only permits communication at low (5 kbit/s) data rates. RFID transponders that operate in the UHF (900 MHz) band are also available. Furthermore, the 402-405 MHz MICS band has been reserved for communication with medical devices, and thus could be used for field-powered communication with implanted devices. Due to their higher carrier frequency,

HF, UHF RFID (and potentially, MICS) offers significantly higher data rates than LF RFID, Recent research on short-range magnetically coupled UHF indicates that highly efficient coupling through tissue is possible [13]. However, absorption; of energy at 400 and 900 MHz is significantly greater than at 14MHz or 134kHz. This absorption can limit the amount of power than can be safely transferred through tissue due to thermal heating.

It is difficult to restrict the range of UHF scanners and devices. UHF RFID is particularly prone to being reflected large distances by small metallic objects. This effect may facilitate eavesdropping or confuse emergency responders' efforts to identify patients with radio-equipped medical devices. Finally, internationalization is difficult due to inconsistent allocation of LF and UHF bands among nations.

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 a significantly higher data rates than available for UHF RFID (up to 400 kbit/s from powered "scanner" devices and up to 100kbit/s from field-powered "passive" devices)[6]. Unlike LF and UHF RFID, the 13.56 MHz channel is available internationally and short range HF scanners are not prone to UHF's distant phantom hot spot phenomenon.

The increased bandwidth provided by NFC can enable a wide range of data-intensive applications and facilitates the inclusion of privacy- and integrity-preserving cryptographic protocols appropriate for medical systems. There are standardization activities underway (such as HL7) to enable the storage of electronic health records within NFC-enabled RFID tags. NFC uses magnetic coupling, which results in a very localized range (generally less than 20cm), providing a measure of privacy against eavesdroppers. This short range also facilitates patient selection in hospital and other "first responder" environments where it is important that medical personnel reliably identify patients with radio-equipped medical devices. NFC is not substantially attenuated by tissue and thus is even suitable for communication with implanted medical devices.

Incorporation of NFC within implanted or ingested medical devices poses bio-compatibility challenges typical of other electronic devices with the advantage of not necessarily requiring a battery or external electrical connections. Few additional components are required: A minimal commodity NFC transponder is implemented as a flexible PCB (as small as a 2.5cm circular disk) on which a spiral antenna is printed (in metal or ink) and upon which a single IC containing radio, power supply and computational subsystems is mounted. Programmable variants of these ICs are available with power output and i/o pins.

A range of packaging suitable for implantation are available. 13.56 MHz RFID tags are available for implantation within livestock that are encapsulated within 2.5cm glass disks. Layered epoxy and paraline were used successfully to encapsulate Riistama et. al's field-powered experimental

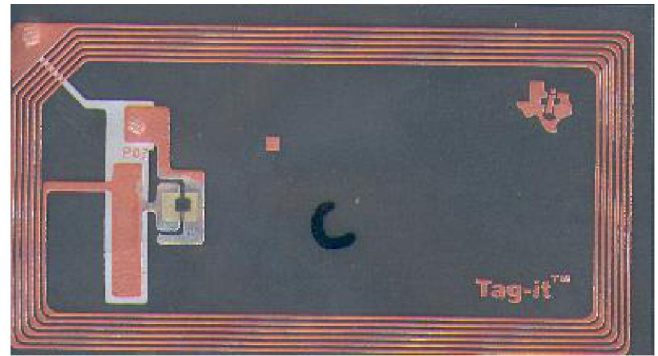


Fig. 1. Texas Instruments' Tag-it™ Transponder Inlay Labeled "C"

TABLE I  
DIMENSIONS OF TRANSPONDER INSETS

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

implantable ECG[16].

## II. IMPLANTATION PROOF-OF-CONCEPT EXPERIMENTS

To validate that passive NFC is suitable for communication with implanted medical devices, we conducted proof-of-concept experiments in which 13.56 MHz RFID tags were implanted within a human cadaver. Measurements are presented for four Tag-it<sup>1</sup> transponders whose dimensions are enumerated in Table I.

## 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.

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 [1] that achieved very short-range communication, but we are unaware of other studies of communication with commodity printed-antenna transponders.

Our preliminary investigation indicates that HF RFID is suitable for communication to transponders within cavities at a wide range of depths. 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.

<sup>1</sup>Tag-it is a registered trademark of Texas Instruments Incorporated

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 $\mu\text{m}$ plastic insulator	Minimum distance (cm) to	
	chest	fat
1	1.5	2.5
2	6	4
3	10	7
4	9.5	<i>not measured</i>

Ten transponders (5 to 35  $\text{cm}^2$ ) with similar designs were implanted:

- 1) below the cadaver's chest's sub-cutaneous fat and directly above investing fascia of pectoralis major,
- 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  $\text{mm}$  layers of fresh beef fat. Photographs of 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 were observed to 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 is a ISO 1443 evaluation scanner with selectable power output of 100 and 200mW. We found that the lower 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 6 $\mu\text{m}$  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. Table IV presents similar insulator thickness sensitivity for transponders implanted in locations (1) and (3).



(1) (3) (4)

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 $\mu\text{m}$ 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 $\mu\text{m}$ 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

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

#### IV. DISCOVERY AND DISCLOSURE OF MEDICAL INFORMATION

A NFC-enabled medical device could potentially also be used to provide health history to first responders in an emergency. This information could either be held within the device itself, or instead be held in escrow by a infrastructure service such as Microsoft's recently announced Healthvault service [8]. In either case, it is important that this sensitive information only be disclosed to appropriate personnel, and even so, only in appropriate situations. [17] provides a discussion of protocols with appropriate properties.



While NFC is a descendant of a communications protocol principally designed to expose the presence of tags and transmit their contents, they can be extended to do neither. Furthermore, NFC provides a unique robustness to denial-of-service attacks upon limited battery power reserves.

The presence of a medical device implementing RFID may be surreptitiously detected by scanners not authorized by the person wearing the device. This involuntary exposure of personal information is related to Lee and Kim's *location threat* model [5]. We advocate the incorporation of strong cryptographic techniques in a manner that prevents such devices from emitting signals in response to queries from unauthorized readers.

The *blocker tag* approach of Rivest et al. [2] has been proposed as appropriate for the protection of medical information. A reader that does not possess an appropriate authorization can not obtain any data from a blocker transponder. However, a device implementing this algorithm will engage in a bi-directional conversation with unauthorized readers and thus remains vulnerable to Lee and Kim's location threat.

We advocate the development and adoption of cryptographic protocols that enable communication between a medical device and authorized readers, but inhibit the device from responding in any manner to a unauthorized queries.

In their provocatively titled paper *Is Your Cat Infected with a Computer Virus* [15], 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. Thus, it is imperative that these systems be rigorously engineered and incorporate robust cryptographic access control mechanisms.

We observe that field-powered devices provide a unique robustness to a radio-based power consumption attack: A conventional radio system must expend energy processing, and possibly replying to incoming messages. Therefore, a such systems can be vulnerable to malicious radio requests intended simply to expend the devices limited power resources. In contrast the communication subsystems of field-powered devices require no local power source and thus are immune to this type of attack.

## VI. SYNOPSIS

As confirmed by experiments with commodity transponders and scanners, 13.56 MHz RFID is suitable for personal medical networks including implanted devices. 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 the detection of implanted RFID may provide evidence of compromised health, 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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