Technical Summary:

Q-Track is developing a short range wireless location system that is intended to be compliant with FCC Part 15.219 allowing 100mW input power to an antenna less than 3m in length at particular frequencies in the band 510-1710kHz. The objective of the proposed effort is to develop commercial real-time location systems (RTLS) providing position information and location tracking of people or assets in complicated indoor environments. Range is approximately 30-60m indoors and as far as about 100m outdoors.

Q-Track QT™-400 tag transmitter prototype with four element antenna array.

Typical link parameters are as follows:

Antenna gain: ~ –65dBi (quasi-isotropic pattern)
Transmitter power: ~ +20dBm (100mW)
EIRP: ~ –45dBm (about 17nW)

A photo of the four element antenna array is to the right. The transmitted signal is typically an unmodulated sine wave, although we intend to experiment with PSK with a <500Hz bandwidth.

Requested Experimental Transmit Parameters are as follows:

Antenna gain: ~ –40dBi (quasi-isotropic pattern)
Transmitter power: ~ +30dBm (1 W)
EIRP: ~ –10dBm (about 100μW)

In terms of interference potential, it is worth noting that the 100μW EIRP Q-Track is requesting is comparable to that currently authorized for UWB systems (-41.3dBm/MHZ x 1GHz BW = -11.3dBm). Q-Track does not intend to use a transmit antenna larger than 3m in dimensions under this request. Most testing will be performed at Q-Track's office (515 Sparkman Drive; Huntsville, AL 35816). Occasional testing may be performed at alternate locations to assess propagation in alternate environments. In all cases, Q-Track does not anticipate signals propagating beyond the building within which propagation is being evaluated.

The proposed program of experimentation holds significant promise. Existing RTLS providers typically operate at UHF or microwave frequencies. The high frequencies of these systems are subject to multipath interference in complicated indoor propagation environments. By contrast, Q-Track proposes operating at low frequencies where the wavelength is significantly longer than the range of operation. This novel low frequency approach to RTLS promises to achieve a unique combination of high accuracy, long range, and low cost.

Q-Track's development has partially funded by the government. Q-Track recently received a Phase II SBIR from the NSF (Grant #0646339) to investigate tracking within a warehouse and anticipates soon receiving a Phase II SBIR award from the US Army to investigate tracking soldiers at short ranges in urban environments, and a Phase I SBIR award from NIOSH to investigate tracking personnel in mines.

Following is a more detailed technical discussion. Please contact Dr. Hans Schantz (256) 489-0075 or h.schantz@q-track.com for any further questions or desired information.

1.A Introduction

The emerging real-time location systems (RTLS) subsector of the RFID industry shows great promise to solve many significant real-world problems. From tracking people in dangerous environments, to locating high value assets in logistics or healthcare, RTLS provides location awareness that can save not only dollars but also lives. This request pertains to an innovative low frequency RTLS approach called “near-field electromagnetic ranging (or NFER®) technology. Specifically, this request is for permission to conduct research, development, and testing work required to complete commercial development of NFER® systems as well as to fulfill government contracts associated with NFER® development.

Most commercial wireless systems exploit the leading edge of RF electronics in the microwave realm. The large bandwidths available at gigahertz frequencies are ideal for communications and data network applications. The high tech allure of high frequency RF electronics has led many vendors to develop systems using this spectrum, including UHF (typically 433MHz), 2.4GHz, and ultra-wideband (UWB) systems.

High frequencies, though well-suited for data and communications applications, are not a good choice for wireless tracking. “In general, given typical wood or reinforced concrete buildings, attenuation is an increasing function of frequency. The higher the frequency, the worse the attenuation [1].” High frequencies have wavelengths significantly smaller than typical indoor obstructions, thus, high frequency systems are prone to confusion by multi-path. “Deploying a positioning system that works well indoors is a challenge, because signals are reflected off walls, floors, and ceilings, which tend to confuse sensors [2].”

By taking a low frequency approach to the problem, near-field electromagnetic ranging (NFER®) technology side-steps the many problems associated with high frequency tracking systems. Operating in the AM broadcast band (530-1710kHz) under Part 15 power levels, NFER systems achieve tracking accuracies on the order of 1-3ft (30cm-1m) or better at ranges of 100-200ft (30-60m). Infrastructure costs are less than $1/sqft – lower than any known competitive offering.

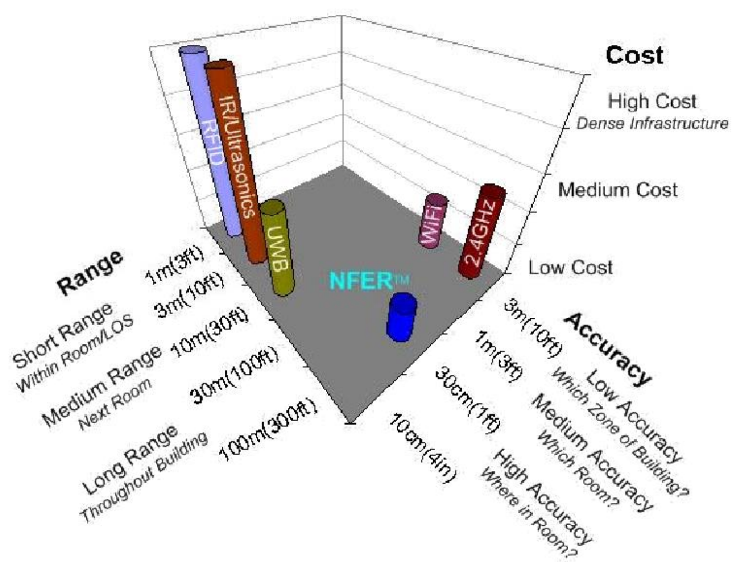

Figure 1: *Q-Track’s NFER technology occupies a sweet spot combining long range, high accuracy and low cost.*

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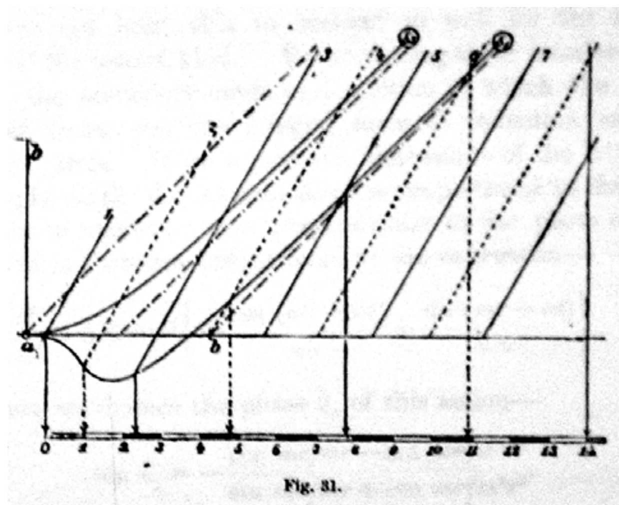
[1] Krzysztof W. Kolodziej and Johan Hjelm, **Local Positioning Systems: LBS Applications and Services**, (Boca Raton, CRC/Taylor & Francis, 2006), p. 95.

[2] Ibid., p. 76.

1.B Theory of Operation

An electromagnetic wave is a superposition of an electric wave and a magnetic wave. In the far field, many wavelengths away from a transmit antenna, this distinction is not terribly important, because the electric and magnetic waves move in lock step with perfectly synchronized phase. In the near field, within about a half wavelength from an electrically small antenna, the electric and magnetic field phases radically diverge. Close to an electrically small antenna, these fields are in phase quadrature, *i.e.* 90 degrees out of phase.

Heinrich Hertz first described the phase relationships around small antennas in the 1880's (see Figures 2a and 2b) [3]. These phase relationships are the basis of a novel wireless tracking system pioneered by Q-Track using Near-Field Electromagnetic Ranging (NFER) technology [4].



Figures 2a (left) and 2b (right): *Heinrich Hertz discovered the phase relationships for small antennas.*

The difference in phase angle (in units of degrees) between the electric and magnetic components of a radio wave is described by [5]:

$$\Delta_\phi = \frac{180}{\pi}\left(\cot^{-1}\left(\frac{\omega r}{c} - \frac{c}{\omega r}\right) - \cot^{-1}\frac{\omega r}{c}\right) \tag{1}$$

where ω is angular frequency, r is range and c is the speed of light. Figure 3a plots these phase relationships in the near field of a typical small antenna. The green and red curves show the electric and magnetic phase relationships. The blue curve is the difference between the electric and magnetic phase as defined by Equation 1. The phase delta formula of Equation 1 may be inverted to yield a formula for range:

$$r = \tfrac{\lambda}{2\pi}\sqrt[3]{\cot \Delta_\phi}\ . \tag{2}$$

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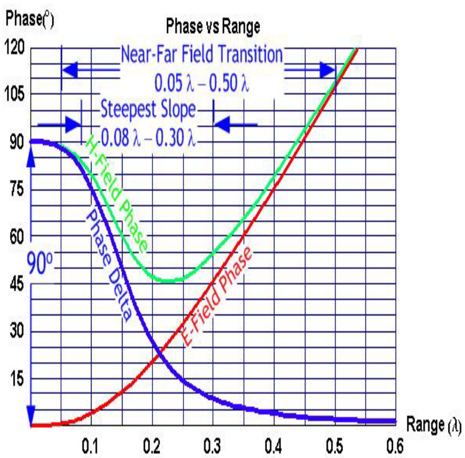
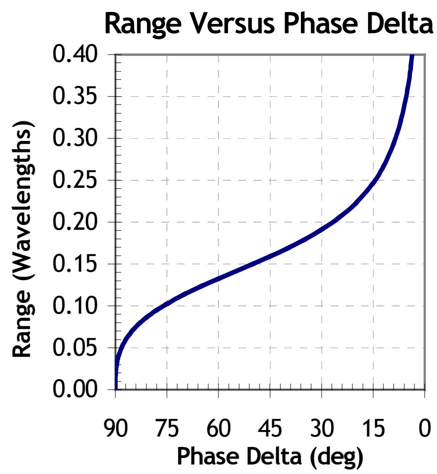
[3] Heinrich Hertz, **Electric Waves**, London: Macmillan and Company, 1893, p. 152.
[4] Hans Schantz and Robert DePierre, "System and Method for Near Field Electromagnetic Ranging," U.S. Patent 6,963,301, November 8, 2005.
[5] Hans Schantz, "Near Field Phase Relationships," IEEE APS Conference July 2005. Reprint available at http://www.q-track.com. The discussion of this section is excerpted in part from this paper.

Between approximately 0.05λ and 0.30λ, this phase delta varies sufficiently quickly with range to be a good indicator of distance (see Figure 3b).

Using microwaves, with wavelengths of 30cm or less, the relationships of Figure 3a and b are merely a curiosity. However using low frequencies, such as those below 3MHz (3000kHz), the phase relationships of Figure 3a and b yield a good measure of range. The table in Figure 3c shows how the range of a NFER system varies with frequency. These low frequencies rarely compete with other uses. Moreover, the low power, near-field signal yields an inherently low probability of intercept (LPI).





Min-Max Range (m)

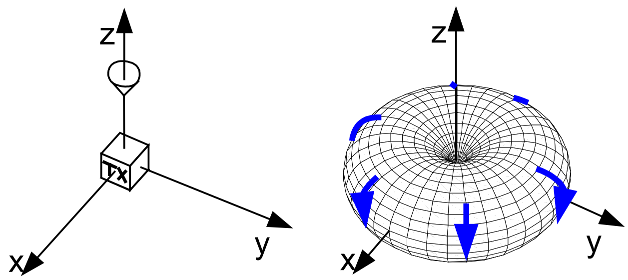
f (kHz)	0.05λ	0.30λ
300	50	300
500	30	180
700	21	128
1000	15	90
1300	12	69
1700	9	53
2000	7	45
2500	6	36
3000	5	30

Figure 3a (left): *Comparing the phases of the electric and magnetic signals in the near field of a small antenna yields a measurement of range.*
Figure 3b (center): *Range versus phase delta.*
Figure 3c (right): *Table of wavelengths at various frequencies.*

A typical frequency choice of 1300 kHz yields useful ranges from the transmitter tag to the receiver between 12 and 70 meters. Closer than 12 meters, no range would be available using a phase measurement but range could still be accurately determined using near field relative signal strengths. Beyond 70 meters, NFER is not available and the less accurate signal strength estimation method must be used for range. A different frequency (say 3000 kHz) would give higher precision and better readings close to the receiver (down to 5 meters) at the cost of limiting the NFER system's range to 30 meters or less. Two ranges from two distinct receivers can yield a position in two dimensions (the ambiguity between the two resulting positions can be resolved by manipulating signals from the loop antennas). There is a trade-off as the frequency is reduced. Low frequencies provide better penetration and range but reduce overall accuracy. Nevertheless, even with reduced accuracy, an accuracy of about 1m (3ft) should be achievable.

1.C Description of Hardware

One of the principal challenges of a NFER tracking system is developing compact, efficient antennas. Vertical polarization (V-pol) antennas exhibit superior performance because V-pol signals propagate better than horizontal polarization (H-pol) signals between the “parallel plate” arrangement of the floor and ceiling of typical building structures. Figure 6a shows an electric whip antenna with corresponding omnidirectional V-pol pattern.



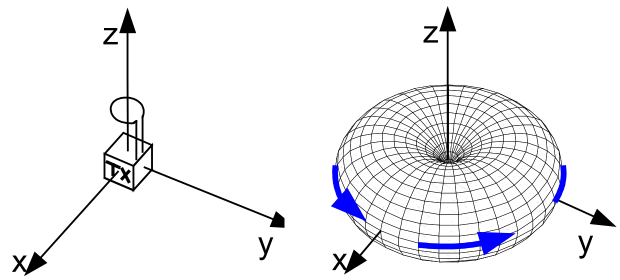
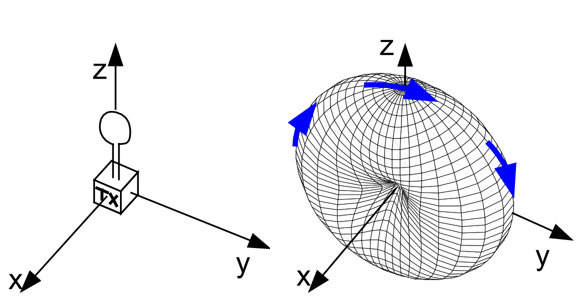


Figure 6a (left): *Electric whip antenna and corresponding vertically polarized omni dipole pattern.*
Figure 6b (right): *Magnetic loop antenna and corresponding horizontally polarized omni dipole pattern.*

An electric antenna is prone to coupling with nearby objects, however, so a magnetic antenna is preferred. A typical magnetic antenna also has an omnidirectional dipole pattern, however the polarization is horizontal. Figure 6b shows a magnetic loop antenna and the corresponding H-pol dipole pattern.

The secret to a successful low frequency transmit tag antenna is to devise a magnetic antenna system with an omnidirectional vertically polarized pattern. Figure 7a shows how a loop antenna whose normal aligns with the x axis yields nulls along the x-axis and vertically polarized signals along the +y and –y-axes. Adding a second orthogonal loop antenna and phasing signals in quadrature between the two antennas yields a dipole pattern that rotates at the RF frequency yielding the desired effective omnidirectional vertically polarized pattern. The quadrature-fed orthogonal magnetic loop antenna system of Figure 7b was successfully demonstrated by Q-Track under a Phase I NSF Grant (0539073) in 2006.



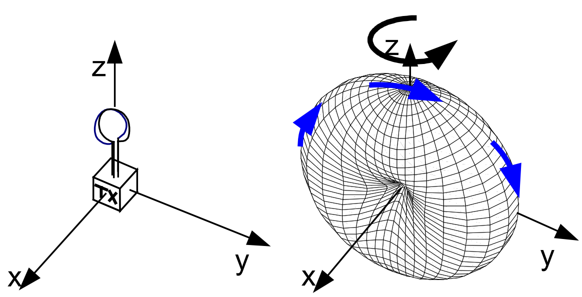
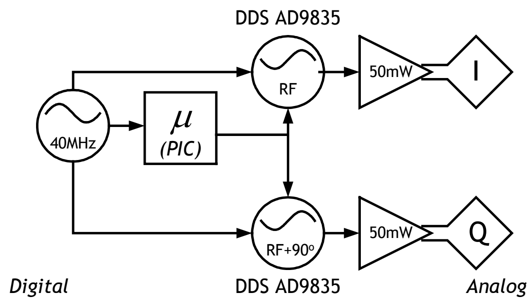


Figure 7a (left): *Magnetic loop antenna and corresponding vertically polarized pattern.*
Figure 7b (right): *Quadrature fed magnetic loop antennas yield a rotating dipole pattern that is effectively omni-directional and vertically polarized, as desired.*

Figure 8a shows this antenna system incorporated in Q-Track's QT™-400 Tag. A PIC microprocessor controls a pair of direct digital synthesizers operating at the RF frequency (typically 1-1.7MHz). One (Q) is offset 90 degrees from the other (I) so as to be in quadrature. A power amplifier raises the signal level to 50mW so the total power output meets the FCC Part 15 limit (Section 15.219) of 100mW. Figure 8b presents a block diagram of the transmitter tag. These quadrature fed orthogonal antennas yield the rotating pattern of Figure 7b. The resulting time average pattern is vertically polarized on azimuth and circularly polarized in the vicinity of the poles. Figure 8c shows a NEC simulation of the 3D pattern.



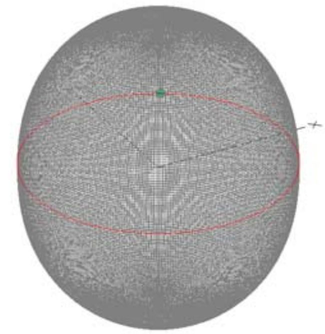


Figure 8a (left): *Transmit tag incorporating the quadrature-fed orthogonal magnetic antenna system developed by Q-Track under NSF Phase I SBIR grant 0539073 in 2006.*
Figure 8b (center): *Block diagram for the quadrature-fed orthogonal magnetic antenna system developed by Q-Track under NSF Phase I SBIR grant 0539073 in 2006.*
Figure 8c (right): *NEC simulation of the resulting pattern. The rotating loop pattern of Fig. 7b yields a quasi-isotropic pattern that is vertically polarized on azimuth and circularly polarized in the vicinity of the poles.*

Measured gain of the transmit antenna is –65dBm, and Q-Track uses dual 50mW power amplifiers to achieve a target transmitter input power of +20dBm (100mW). The EIRP is –45dBm (17nW).

Figure 9 shows a typical QT™-400 Locator Receiver with orthogonal magnetic antennas (A and C) and an electric whip antenna (B).

Figure 10 shows an experimental transmitter for use in taking propagation data. This experimental transmitter uses a 1W (+30dBm) amplifier into an approximately –40dBi whip antenna. The EIRP is –10dBm (100μW).

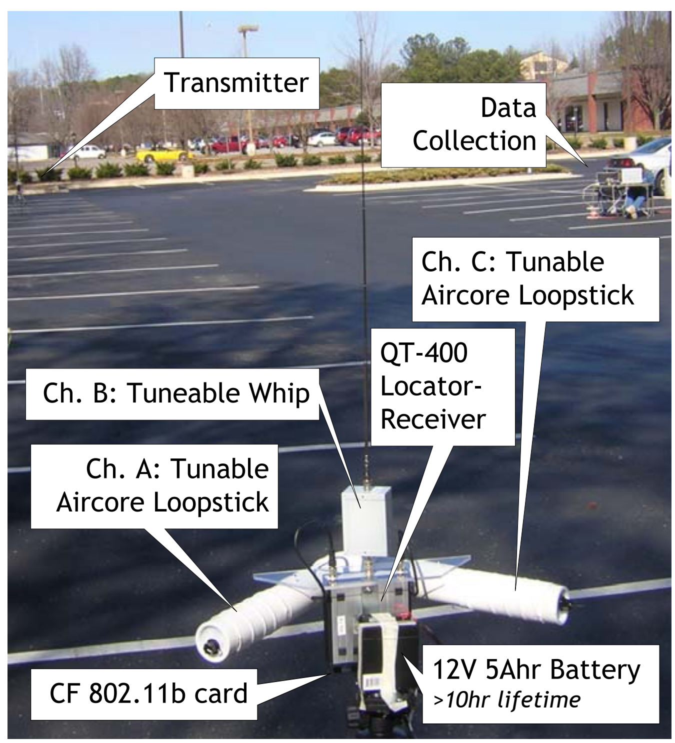


Figure 9: *QT™-400 Locator-Receiver showing orthogonal magnetic antennas (A and C) and electric whip antenna (B).*

Figure 10: *QT™-400 Locator-Receiver showing orthogonal magnetic antennas (A and C) and electric whip antenna (B).*

2. Specific Objectives

The specific objectives of the proposed effort include:

- Investigation of near-field propagation within complicated indoor environments
- Identification and characterization of location-dependent near-field properties suitable for exploitation in a real-time location system operating in complicated indoor propagation environments.
- Characterization of electrically small antennas suitable for use in near-field links.
- Development of commercial RTLS hardware exploiting near-field phenomena and capable of being authorized for unlicensed use under the provisions of FCC Part 15.219.

Investigation of variation of near-field properties propagation within complicated indoor environments

3. Contributions to the Radio Art

As previously noted, conventional RTLS systems operate primarily at high frequencies (UHF or microwave). The proposed effort investigates a new range of phenomenology that could enable accurate indoor tracking in complicated environments using low power, near-field transmissions.