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# UCom: Ultra-wideband Communications in Harsh Propagation Environments

Faranak Nekoogar

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**UCRL-XX-XXXX**

**2007 R&D Award Entry**

# Ultra-wideband Communications in Harsh Propagation Environments


***LLNL's ultra-wideband system provides reliable wireless communications in harsh propagation environments such as heavy metallic and heavy concrete facilities.***

LLNL has developed an ultra-wideband (UWB) system that provides unique, through-the-wall wireless communications in heavy metallic and heavy concrete indoor channels. LLNL's UWB system is the only available wireless communications system that performs successfully and reliably in facilities where conventional narrowband communications usually fail due to destructive reflections from multiple surfaces. These environments include: cargo ships and reinforced, heavy concrete buildings. LLNL's revolutionary system has applications for the military, as well as commercial indoor communications in multistory buildings, and cluttered industrial structures.

# Ultra-wideband Communications in Harsh Propagation Environments

**1. Submitting Organization**


Organization: Lawrence Livermore National Laboratory

Address: 7000 East Avenue, L-229

City: Livermore

State: California

Zip Code: 94551

Country: USA

Submitter's Name: Faranak Nekoogar

Phone: 925-423-3148

Fax: 925-422-3358

Email: nekoogar1@llnl.gov


**AFFIRMATION:** I affirm that all information submitted as a part of, or supplemental to, this entry is a fair and accurate representation of this product.

Submitter's signature: ______________________________

2. **Joint Entry:** No

3. **Product Name:** Ultra-wideband Communications in Harsh Propagation Environments

4. **Brief Description:** A revolutionary wireless communication system based on LLNL's proprietary modulation technique in ultra-wideband (UWB) technology offers high performance in harsh propagation channels, such as heavy metallic and heavy concrete environments, where conventional narrowband communication systems usually fail.

5. **When was this product first marketed or available for order?**

   Early prototypes of the system were available in 2004 for lab demonstration and proof of concept. The field deployable version of this product with low center frequency for improved wall penetration was first available in August 2006 and has been available for marketing since then.

**6. Inventors or Principal Developers:**

Inventor Name: Faranak Nekoogar
Position: Engineer
Organization: LLNL
Address: 7000 East Ave
City: Livermore
State: CA
Zip/Postal: 94550
Country: USA
Phone: 925-423-3148
Fax: 925-422-3358
Email: nekoogar1@llnl.gov

Inventor/Developer Name: Farid Dowla
Position: Engineer
Organization: LLNL
Address: 7000 East Ave
City: Livermore
State: CA
Zip/Postal: 94550
Country:USA
Phone: 925-423-7579
Fax: 925-422-3358
Email: dowla1@llnl.gov

Developer Name: Dave Benzel
Position: Engineer
Organization: LLNL
Address: 7000 East Ave
City: Livermore
State: CA
Zip/Postal: 94550
Country:USA
Phone: 925-424-6114
Fax: 925-422-3358
Email: benzel1@llnl.gov

Developer Name: Alex Spiridon
Position: Retired Engineer
Organization: LLNL
Address:
City: Palo Alto

State: CA
Zip/Postal: 94550
Country:USA
Phone:
Fax:
Email:

7. **Product Price:** This product can be licensed and customized to meet the specific needs of military and commercial customers. The exact list price of the product depends on the required degree of customization and capability required by the licensee. However, the list price remains lower than $100 when mass produced.

8. **Do you hold any patents or patents pending on this product?**

Three patents, and one record of invention exist on this product.

1. "Multiple-pulse Multiple-delay (MPMD) Multiple Access Modulation for UWB," Farid Dowla, Faranak Nekoogar, US patent US20040202230A1, 2004.
2. "UWB Communication Receiver Feedback Loop," Farid Dowla, Alex Spiridon, Faranak Nekoogar, Dave Benzel, US patent US20040242155A1, 2004.
3. "Self Organization of Wireless Sensor Networks Using Ultra-Wideband Radios," Farid Dowla, Faranak Nekoogar, Alex Spiridon, Patent Pending (No. IL-11368) April 2004.
4. "UWB Channel Estimation Using New Generation of TR Transceivers."

9. **Describe your product's primary function as clearly as possible.**

The LLNL UWB through the wall communications system solves the problem of propagating wireless signals in extremely hostile channels such as in buildings with reinforced concrete walls and heavy metallic environment of cargo ships. UWB communication is fundamentally different from conventional communication techniques because of using extremely narrow (picosecond to nanosecond) radio frequency (RF) pulses to communicate between transmitters and receivers. In the challenging wireless environments addressed by our UWB communications systems, the conventional radio communications systems usually fail due to multiple destructive reflections from various surfaces, hence, require the careful placement of a "leave-behind" mesh of communication nodes. Example of hostile wireless environments are heavily cluttered indoor channels of multiple story buildings, or highly metallic and constricted corridors and holds inside ships. LLNL's UWB communication system excels in situations where bandwidth, mobility, flexibility, security and reliability in a harsh environment are of critical concern such as:

- Maritime communications
- Disaster communications in collapsed buildings for search and rescue team
- Wireless transfer of secure medical data in hospitals
- Communications in industrial facilities
- Communications in mountainous environments or underground land mines

**How does it do it?**

This UWB system is based on LLNL's proprietary "Transmit-Reference" (TR) modulation technique. The TR technique offers advantages over conventional UWB modulation techniques (i.e., pulse position modulation) in terms of channel estimation, relaxed synchronization requirements, and exploiting multipath reflections for improving signal-to-noise ratio.

TR modulation is the transmission of a pair of pulses or doublets separated in time. The first pulse in a TR doublet is a data-modulated pulse, known as the *transmit pulse*. After a defined time interval *D*, the *transmit* pulse is followed by an unmodulated pulse, *reference pulse,* that does not carry any information. The individual pulses in the waveform can be any variety of wideband pulses, such as Gaussian, chirp, or Hermite-based narrow pulses. Data is modulated based on the relative polarity of the reference and transmit pulses. For instance, a reference and a transmit pulse of the same polarity designate a binary value of 1, while a transmit pulse opposite in polarity to the reference pulse corresponds to a binary value of 0, as shown in Figure 1.

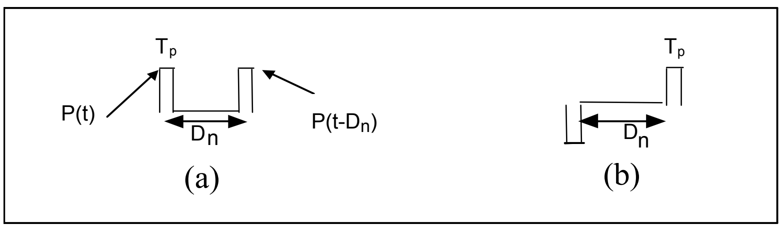


Figure 1: TR pulse modulation. P(t) represent the *transmit pulse* (polarity modulated by data), $P(t–D_n)$ is the delayed unmodulated *reference pulse*; $T_p$ is the pulse duration; $D_n$ is the time interval between the two pulses which is known to the receiver. (a) Symbol for data bit “1” (b) Symbol for data bit “0”

Like the conventional matched filter receivers used in all other available UWB systems, our TR receivers use a correlation scheme, but with a major distinction. Instead of correlating the received pulses with a predefined, “clean” template that has not experienced any channel distortions, a TR receiver correlates the received signal with a delayed version of itself. This way, each *reference pulse* acts as a template for its preceding *transmit pulse*. Therefore, the interval *D* plays a crucial role in recovering data at the receiver. Figure 2 shows the block diagram of a TR receiver, followed by a simple example of TR demodulation.

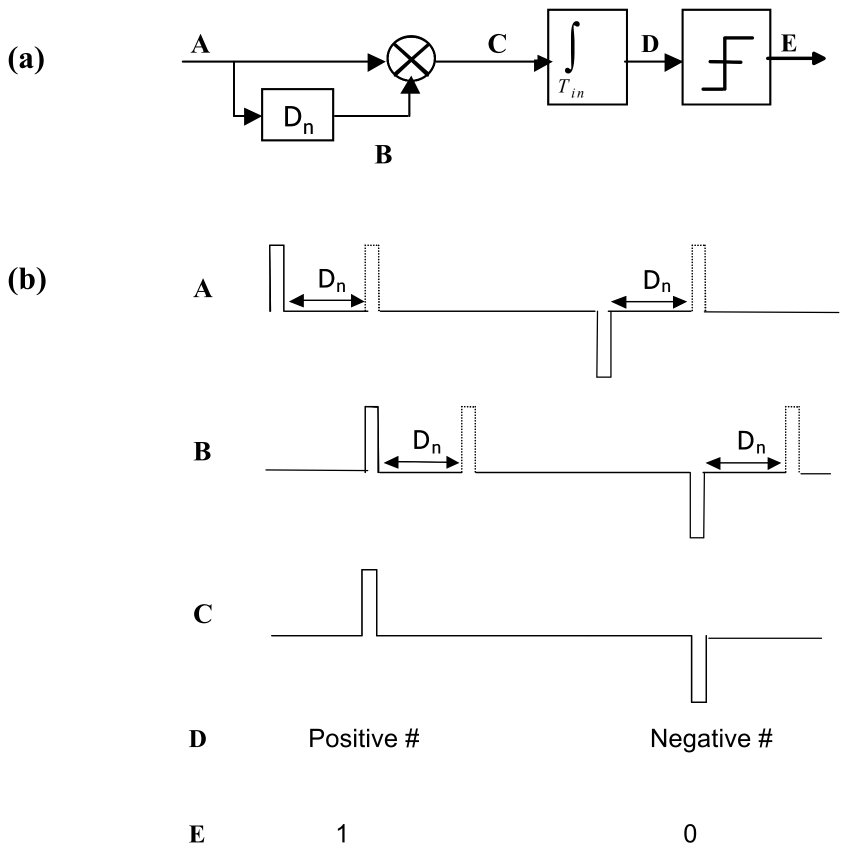


Figure 2: (a) Block diagram of a TR receiver. $D_n$ is the delay between the pulses shown in Fig.1 . (b) Graphical example of TR demodulation. Dotted-line pulses represent the *reference pulse*; solid-line pulses represent *transmit pulses*.

**What theories if any are involved?**

The main theory that distinguishes this system from the currently available wireless communications systems is the combination of UWB technology and LLNL's proprietary TR modulation. A UWB communication system uses short duration pulses (picoseconds to nanoseconds) as the building block for communications rather than the continuous waveforms used in other wireless systems. Some of the key benefits of using these short pulses are summarized below:

### Frequency Sharing

The FCC's power requirement of –41.3 dBm/MHz for UWB systems puts them in the category of unintentional radiators such as TV or computer monitors. This power requirement allows our system to reside below the noise floor of a typical narrowband receiver and enables the UWB signals to co-exist with currently available radio services with minimal or no interference problems. Fig. 3 is a pictorial representation of bandwidth comparison of different types of wireless systems.

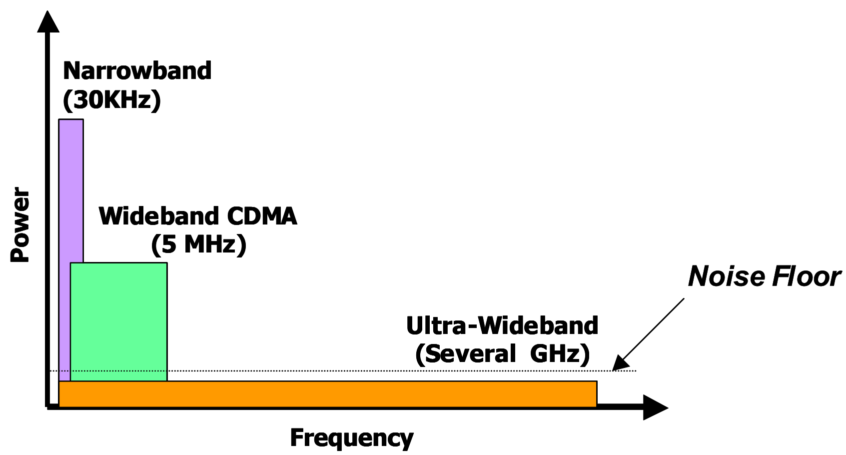


Figure 3: Bandwidth comparison of narrowband, wideband, and UWB systems.

### Large Bandwidth or Channel Capacity

The large bandwidth of UWB pulses generates a large channel capacity. This capacity can be defined as either the number of users in a channel or the amount of data transferred in communications (data rate).

### Resistance to Jamming

Unlike the high power and well-defined narrowband frequency spectrum, the UWB spectrum covers a vast range of frequencies from near DC to several GHz with low power spectral density (shown in Fig.3). The frequency diversity caused the large bandwidth, makes UWB signals from systems such as ours relatively resistant to intentional and accidental jamming. Fig. 4 compares the narrowband and UWB signals in time and frequency domain.

**Superior Penetration of Building Materials**

Unlike narrowband technology, UWB systems can penetrate effectively through different materials. The low frequencies included in the broad UWB frequency spectrum have long wavelengths and allow UWB signals to penetrate through different materials, including walls. This property makes UWB technology viable for through-the-wall communications.

**High-Performance in Multipath Channels**

The very short duration of UWB pulses makes them less sensitive to the multipath effect (destructive reflections of the signal from multiple surfaces) compared to narrowband continuous waveforms. With transmission of pulses shorter than a nanosecond in duration, the reflected pulse has an extremely short window of opportunity to collide with the main Line-of-Sight (LOS) pulse and degrade the signal.

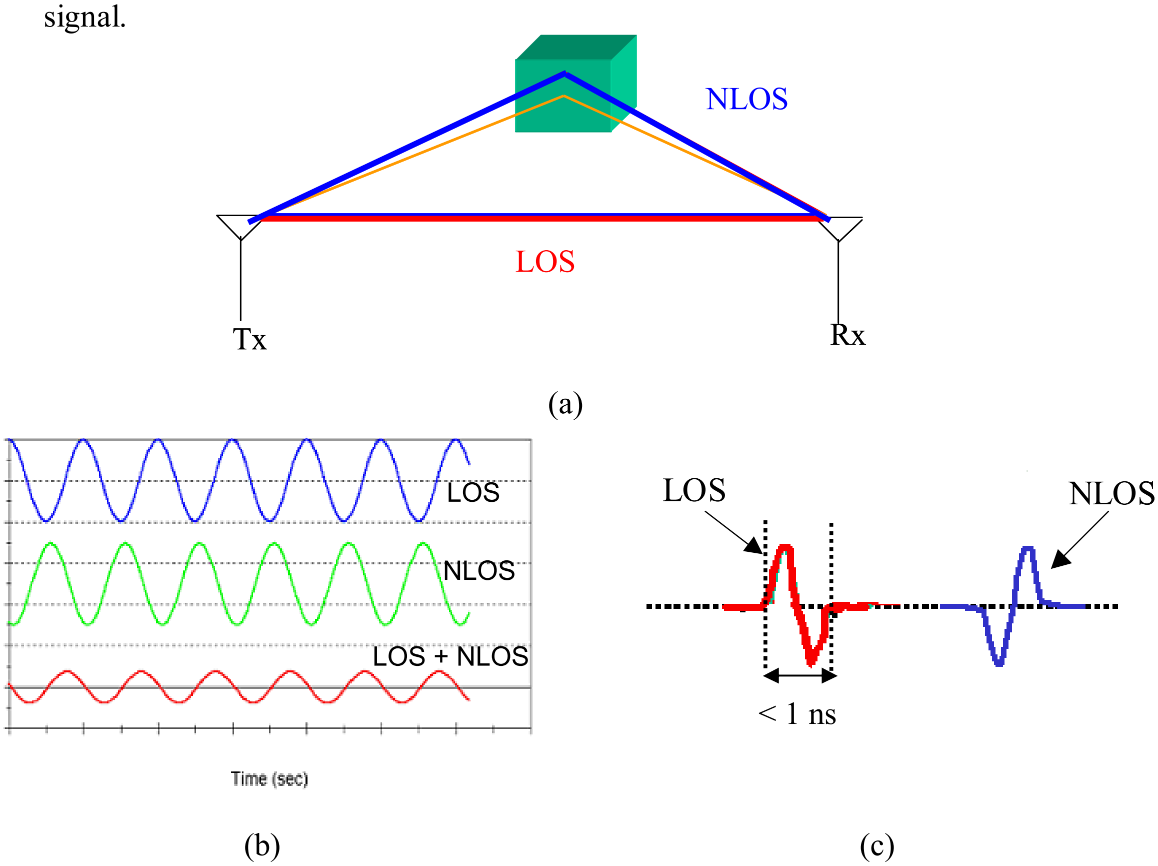


Figure 4: (a) Representation of multipath phenomenon in wireless links (b) Multipath effect on narrowband signals (c) multipath effect on ultra-wideband pulses

**Low Probability of Interception and Detection**

The low transmission average power of UWB systems makes them inherently immune to detection and interception. Because the transmission power is so low, an eavesdropper must be very close to the transmitter (about 1 meter) to detect the transmitted information. Therefore, UWB communication systems have a low probability of having signals intercepted and detected, making these systems highly secure.

**Simple Transceiver Architecture**

UWB transmission is carrierless, meaning that data is not modulated on a sinusoidal waveform with a specific carrier frequency as in narrowband and wideband technologies. Carrierless transmission requires fewer radio-frequency components than carrier-based transmission. Therefore, the frequency translation stage in the transmitter side and the carrier recovery stage in the receiver side are not required in UWB transceivers. For this reason, UWB transceiver systems are significantly simpler and thus cheaper to build than carrier-based systems.

**10A. List your competitors by manufacturer, brand and model number.**

There is no known direct competition for LLNL's UWB communication systems. Most of the promised commercial UWB communications systems are designed for use in home entertainment systems and wireless personal area networks, not for communications in harsh propagation environments. Many of these other UWB commercial systems use the multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) convention, in which narrowband-type signals are used in different frequency bands to generate a UWB-type bandwidth. However, many of the advantages generated by the physics of narrow pulses such as frequency diversity and high penetration properties are missing in the MB-OFDM technique.

**10B. Supply a matrix or table showing how the key features of your product compare to existing products or technologies, include both numerical and descriptive comparisons.**

| **Features** | **LLNL's UWB Communications System** | **Staccato Communications** | **T-Zero** |
|---|---|---|---|
| UWB Technology | Yes | Yes | Yes |
| Pulse Based | Yes | No | No |
| Long Range | Yes | No | No |
| Operable in Harsh Environments | Yes | No | No |
| Low Power | Yes | No | No |
| Low Probability of Intercept/Detection | Yes | No | No |

Table 1. descriptive comparison of LLNL's UWB communications system with commercial products. Since the commercial products are not a direct competition to our UWB system, the numerical comparison can not be provided.

**10C. Describe how your product improves upon competitive product technologies.**

Because the commercial products based on MB-OFDM techniques use narrowband signaling, they cannot be compared to the LLNL's UWB communications system. Thus, only pulse-based products can be considered as being competitors to our system.

Most of these commercially available pulse-based UWB products use some form of pulse-position modulation (PPM), in which information about the exact position of the pulse is needed at the receiver to detect the pulse. Systems based on PPM face challenges with multipath channels, high frequency synchronization, and channel estimation. Our UWB technology, based on the Livermore-developed TR technique, overcomes all these challenges as described below.

**Multipath Channels**

Since multipath channels can stretch the UWB pulse at the receiver and cause pulse overlap, detection becomes challenging based on the prior knowledge of the pulse positions in PPM systems. On the other hand, TR receivers exploit reflected signals from multiple surfaces to improve their performance in dense multipath channels. This is because the *reference* and *transmit* pulses in TR doublets (shown in Fig. 1) are correlated with each other. The multipath channel stretches the TR pulses of the received signal, thus increasing the overall signal energy when *reference* and *transmit* pulses are correlated with each other at the receiver. In other words, the strong multipath components in the received signal contain significant energy and the ability to capture that energy by correlating the received signal by its delayed version is quite important in low-power UWB communication systems, as shown in Figure 5.

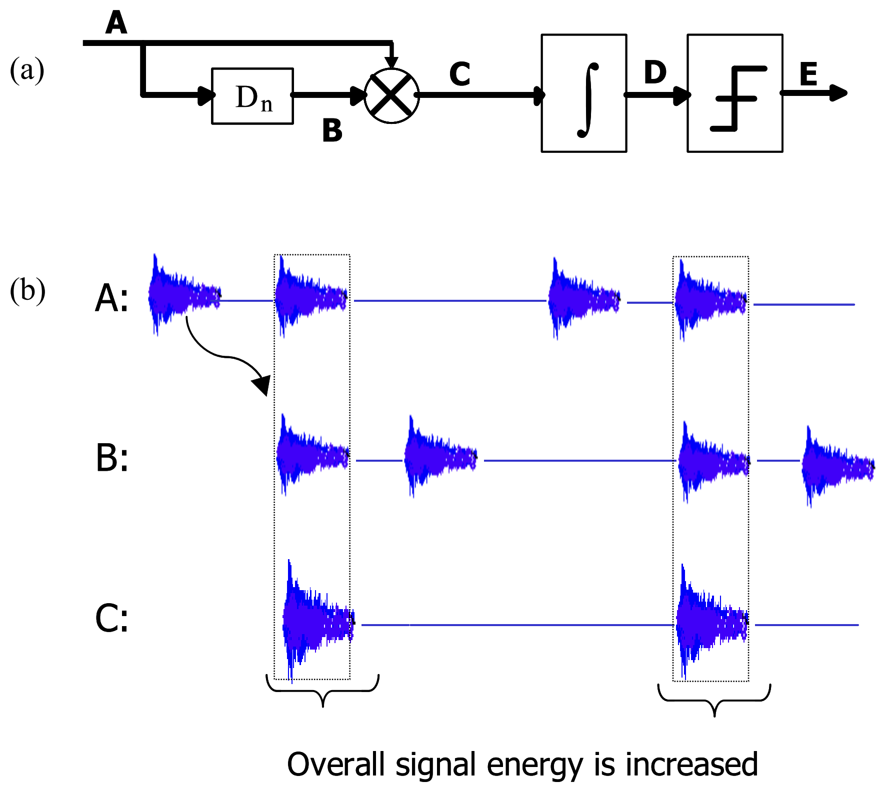


Figure 5: (a) Block diagram of a TR receiver (similar to Fig.2). $D_n$ is the delay between the *reference* and *transmit* pulses shown in Fig. 1. (b) Signal representation of TR receiver in multipath channels. Compared to signals in Fig. 1, the signals here are stretched due to multipath effect. Since both *reference* and *transmit* pulse are stretched the same way, due to passing through the same channel, the signal energy for correlation is stronger.

**High frequency synchronization**

The strict timing synchronization of narrow UWB pulses in PPM receivers (used in other available UWB systems) requires very fast (GHz) analog-to-digital converters (ADCs). Also the performance of PPM receivers are quite sensitive to timing errors such as jitter since the detection is exclusively based on the position of the received pulses. In contrast, our TR receiver is self-synchronized and eliminates the need for the individual pulse synchronization with locally generated templates required by the PPM scheme. For the TR receiver, each reference pulse acts as a preamble for the transmit pulse and provides rapid synchronization. Furthermore, synchronization in TR receivers occurs after correlation between the *transmit* and *reference* pulses, thus the sampling requirements are relaxed to baseband signals. Therefore, the need to synchronize the received short duration radio frequency pulses and very fast ADCs is eliminated.

**Channel Estimation**

Almost all UWB receivers correlate the received UWB pulse with a predefined pulse template. However, a weak and low-powered UWB pulse can be significantly distorted by the transmission link, to the point that the received pulse shows little or no correlation with the clean template. Therefore, reliable detection of pulses becomes a major challenge for techniques such as PPM, requiring estimation of channel parameters to provide templates that are similar in shape with the received pulse. LLNL's TR modulation technique has the advantage of sending the same pulse twice through the same channel. Both *transmit* and *reference* pulses are distorted in the same way, making detection easier with a correlation receiver. Instead of correlating the distorted received pulse with a clean template pulse, as in PPM, the TR technique correlates a received pulse with its delayed version. Thus, our TR receiver does not require estimates of channel parameters.

**11A. Describe the principle applications of this product.**

The LLNL UWB communications system provides reliable wireless communications inside buildings with thick concrete or metal walls as well as shipboard wireless communications. These situations present daunting challenges to conventional radio systems. The LLNL system has been successfully tested in several large ships as well as inside buildings with thick concrete walls shown in Fig. 6, Fig. 7 respectively.

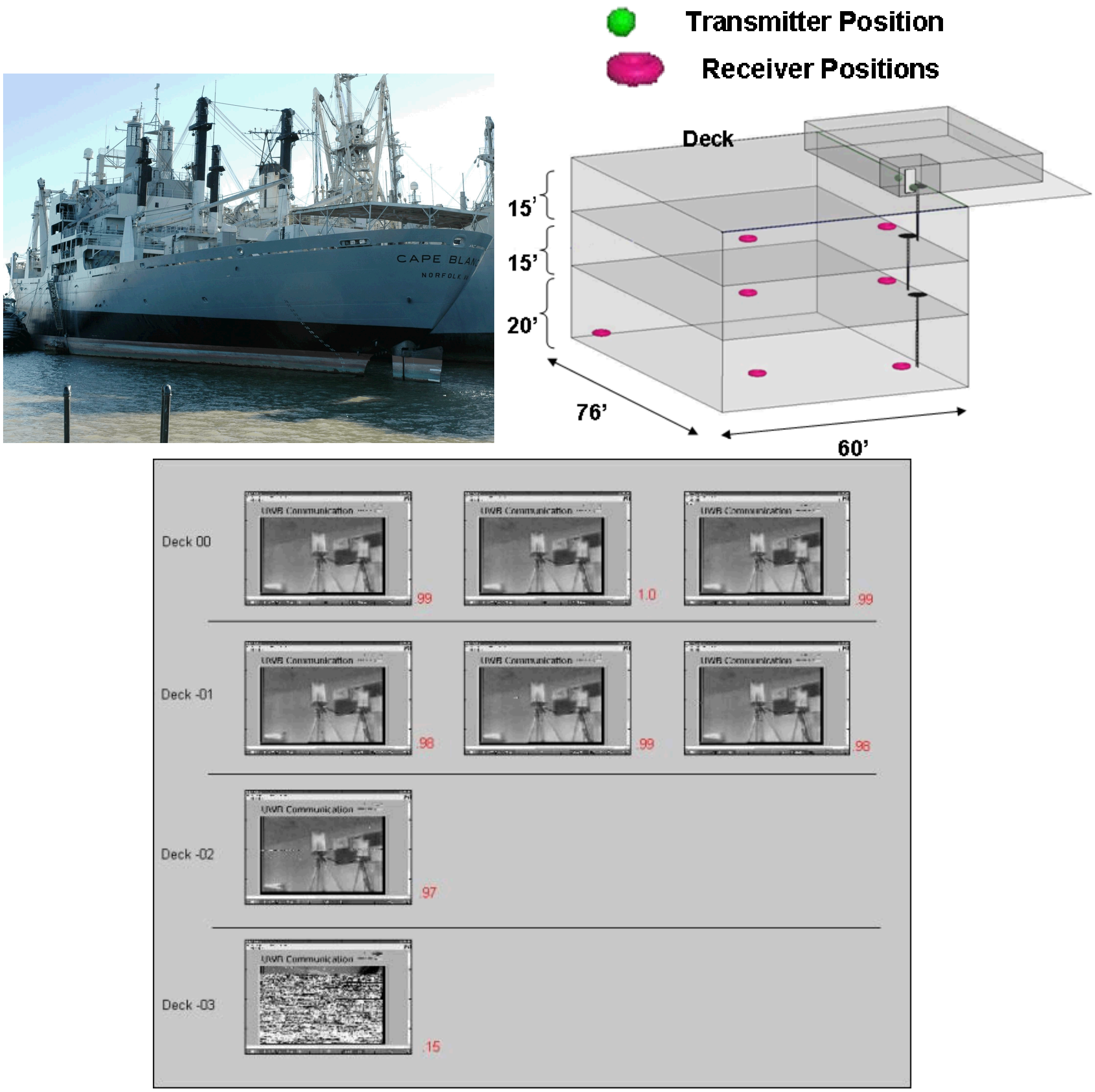


Figure 6. UWB-TR communications system has shown excellent performance in large ships.

Figure 7. Example of thick re-enforced concrete walls at the Fort Ord military training village of Naval Postgraduate School where LLNL's UWB-TR communications system has shown excellent performance.

**11B. List all other applications for which your product can now be used.**

The Livermore UWB system could also be used for wireless personal area networks in commercial as well as medical applications. Such applications could include wireless connectivity of multimedia networks in multistory buildings. Secure transfer of medical files in hospitals where multiple stories and corridors include metallic instruments and devices.

**12. Summary.**

Our UWB system permits reliable, secure wireless communications in extremely harsh environments—such as inside concrete buildings and ships with lots of metallic surfaces around. No other commercially available product has these capabilities. Conventional options limit communications to either very small distances with line of sight or require the careful placement of a mesh of communication nodes. Our system would fulfill the need for wireless, reliable communications in difficult situations, such as inside ships and urban facilities such as hospitals. Additionally, such a system could be extremely helpful under any conditions where bandwidth, mobility, flexibility, security and reliability in a harsh environment are of critical concern.

**ORGANIZATION DATA**

**13. Contact person to handle all arrangements on exhibits, banquet, and publicity.**

**Name:** Yvonne King

**Position:** Partnering Services Administrator

**Organization:** Lawrence Livermore National Laboratory

**Address:** 7000 East Avenue

**Address:** L-795

**City:** Livermore

**State:** CA

**Zip:** 94550

**Country:** USA

**Phone:** 925-422-7299

**Fax:** 925-423-8988

**Email:** king26@llnl.gov

Appendix A. Co-developers

**MIR Team: Steve Azevedo, Dave Benzel, Chris Chubb, Greg Dallum, Farid Dowla, Peter Haugen, Richard Leach, Joan Levy, Mike Newman, Doug Poland, Garth Pratt, Carlos Romero, Alex Spiridon, Mark Vigars, Ken Waltjen, Pat Welsh,**

Appendix B. Patent Information

Appendix C. Letter of Support