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Ultra-wideband Communications

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Disclaimer

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I. Purpose of the Research Project

Many applications in wireless communications often require short-range systems capable of rapidly collecting data and transmitting it reliably. Commercial communication systems operate in fixed frequency bands and are easily detectable and are prone to jamming by the enemy, among other shortcomings. The new ultra-wideband (UWB) communications system in the 3.1 to 10 GHz band is of significant interest to a number of Lawrence Livermore National Laboratory (LLNL) programs including the Nonproliferation, Arms Control, and International Security (NAI) Directorate. Ultra-Wideband (UWB) technology has received a significant degree of attention from communications industry since the Federal Communications Commission (FCC) rulings in February 2002. According to FCC, UWB signals have fractional bandwidth (B_f) of 20% or larger at –10 dB cut-off frequencies, with minimum bandwidth of 500 MHz. Unlike traditional communication systems, UWB systems modulate carrier-less, short-duration (picosec to nanosec) pulses to transmit and receive information.

A number of programmatic problems at LLNL, particularly in the NAI and other national security Directorates, require collecting information from multiple sensors distributed over a local area. The information must be collected covertly and by wireless means. The sensors produce data using low power devices and the communication link must operate in severe multipath environments over tens of meters; often the links must be channelized to handle multiple sensors. The communications links between these sensors is a critical issue in the development of LLNL programs to demonstrate distributed sensor network performance in real-time. In summary, such systems must be robust; have a low probability of detection and intercept; employ low-power, small-size hardware; and interface easily with other systems for analysis or to establish long-distance links.

The purpose of this work was to develop a new UWB radio-frequency (RF) communications system for the UWB RF band. In this project we addressed the need for robust UWB communication systems with low-power, small-size sensor communication hardware. Our research results have successfully addressed these issues and we developed UWB radios and interfaced these radios with repeater radios for longer distance links.

In particular, research and development challenges included signal processing and communication design problems, including developing novel UWB modulation and demodulation schemes, link budget analysis for ultra-wideband signals, multipath mitigation, short-pulse signal synchronization, and building real working radios. We have had a significant degree of success in solving these technical challenges. As a result, several programmatic efforts have spun off from our R&D work in FY04.

II. Research Activities

Through this project we have designed and built novel UWB radios for both communication and compact sensor applications. A typical photo of the UWB radio transceiver is shown in Figure 1. For a sensor node (see Figure 2), the node is also equipped with an antenna, global positioning system (GPS), UWB radar, micropower impulse radar (MIR), processing unit, and batteries. Network protocols were developed to interface with our UWB radio design. Sensor radio nodes of this type will play a critical role in modern wireless sensor networks for intelligence and battlefield applications.

Our UWB communication transceivers have been tested with voice, video, and digital-data communications. We have performed modeling and propagation analyses and developed a UWB radio and bit error (BER) boxes with a capacity of 1 Mbps, a range of 100 m power requirement of < 0.5 W. We also developed MATLAB graphical user interface for our modeling and simulations. Finally, we developed radio networking, including architectural design and implementation.

Radio networking was one of the main objectives in the last year of our work. We have completed and tested UWB radios for (a) star networks; and (b) mesh network with UWB repeater nodes. The features of the mesh network includes flood routing, directional communication, redundant transmission with media access control by pseudo slotted fixed re-transmission back-offs. These provide a very wide set of network protocols for increasing the range of our transceiver.

Currently, we have been working with various national agencies to continue our work for real applications and several new projects have begun in FY04. We have also published several papers to peer-reviewed publications and conferences, filed one patent, and in the process of filing another. In summary, we have developed UWB radios meeting the radio specifications we had hoped to achieve. Our final design has resulted in small-size, low-power, low-cost hand-held transceivers that can be networked for various national intelligence and defense applications.

III. Technical Achievements

The technical achievements of this project can be summarized into three major categories: (1) signal processing, modeling, and system design; (2) radio electronics hardware development; (3) networking software and applications.

3.1 Signal Processing, Modeling and System Design

The signal processing, modeling, and system design work is documented in detail (in a hundred-page LLNL technical report entitled "Ultra-wideband communications: system analysis, design and research directions," (Dowla, et al., UCRL-ID-151166, November 2002.) In that report we establish basic performance models for impulse radio, including bit error rate and probability of detection versus environmental conditions and radio parameters. We outline in that report a new robust approach to impulse radio technology that resolves current issues in synchronization, propagation path equalization, and platform mobility with capacity at a 2 Mbps at ranges of 100's of meters. We discuss how longer ranges can be achieved at lower data capacities. We further discuss our design and demonstrate these compact low-power transceivers, and discuss communication system performance on different applications.

The technical report UCRL-JNRL-201559, entitled "On the Performance of Ultra-Wideband Transmitted-Reference Receivers," (Spridon, et al., 2004, January), we describe the performance of our UWB radios.

The technical report, UCRL-JC-153893, entitled "Multiple access in ultra-wideband communications using multiple pulses and the use of least squares filters," (Dowla, et al., June 2003) we discuss how multiple access schemes can be implemented in the context of the transmitted-reference method.

3.2 Electronics and Hardware Development

We developed UWB radios that are small in their form factor and power efficient. Examples of our radios and their overall block diagram structures are shown in Figures 1 through 8, in following.

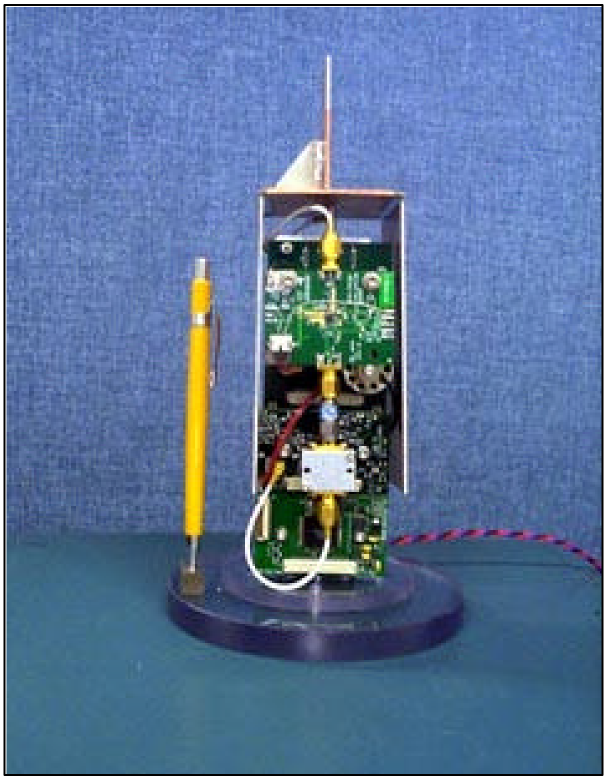

Figure 1: The UWB radio designed is a small and low-power system.

As shown in Figure 1, the size of the transmitter and receiver boards is approximately 2” x 1.5”. The entire radio, including the interface hardware and sensor boards, is shown in the picture in Figure 1. We have designed a variety of antennas to fit the radios. A particularly useful observation was that the radios performed very well with omni-directional antennas.

Figure 2: The UWB radio bit error rate tester (BERT) is a small and low-power system.

We have developed a bit error rate tester (BERT) to evaluate the performance of our radios in various environments. A number of experiments conducted in and around our laboratory indicates excellent performance in multipath environment as expected from our design in theory. In fact, we have shown, unlike other radios, the LLNL UWB design actually performs better in many multipath situations. This is a significant result on radio communications.

The functional block diagrams of the receiver and the transmitter of our design are illustrated by Figures 3 through 5 below. Note, various design challenges such as baseband serial data interface, synchronization, and other issues such as automatic gain control have been successfully addressed in this development work.

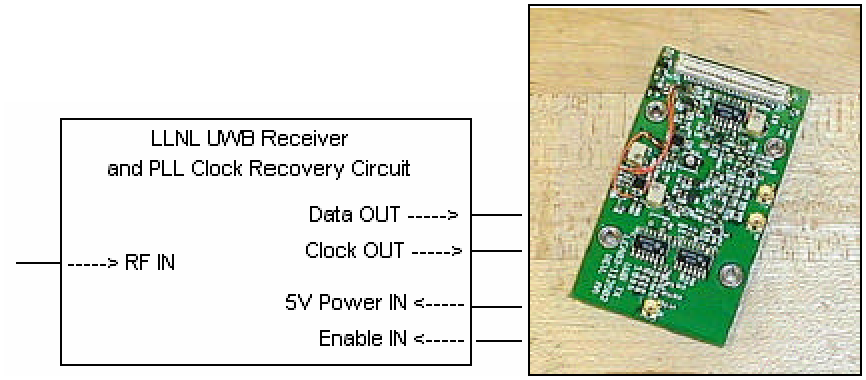

Figure 3: UWB Receiver Board Block Diagram and early LLNL prototype.

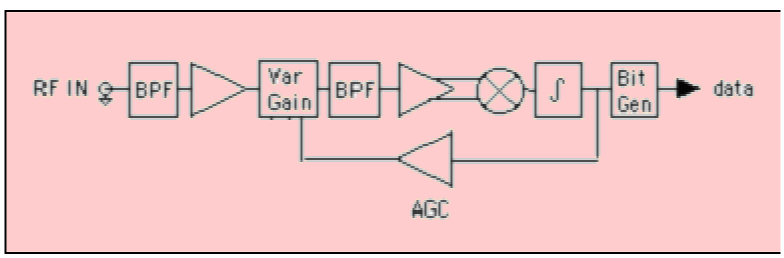

Figure 4: UWB Receiver Block Diagram.

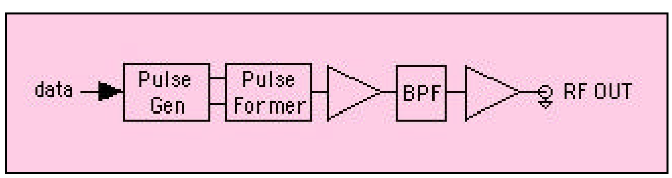

Figure 5: UWB Transmitter Block Diagram.

<u>Interface and Packaging</u>

The systems consist of two independent packages that can be moved relative to one another to measure the UWB bit error rate – the transmission unit and the receiver unit. Block diagrams and module layout diagrams of these subsystems are shown below in Figures 6 through 8 below.

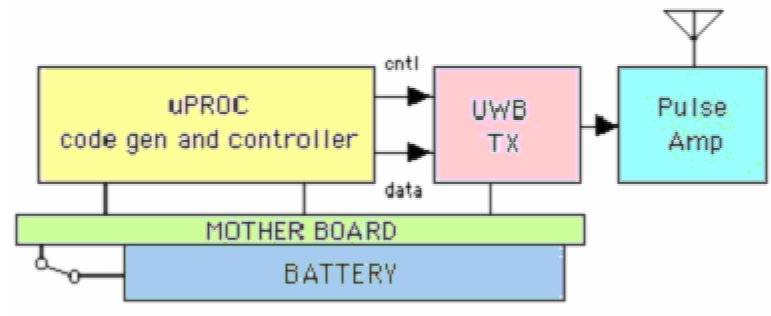

Figure 6: Transmission Unit Block Diagram.

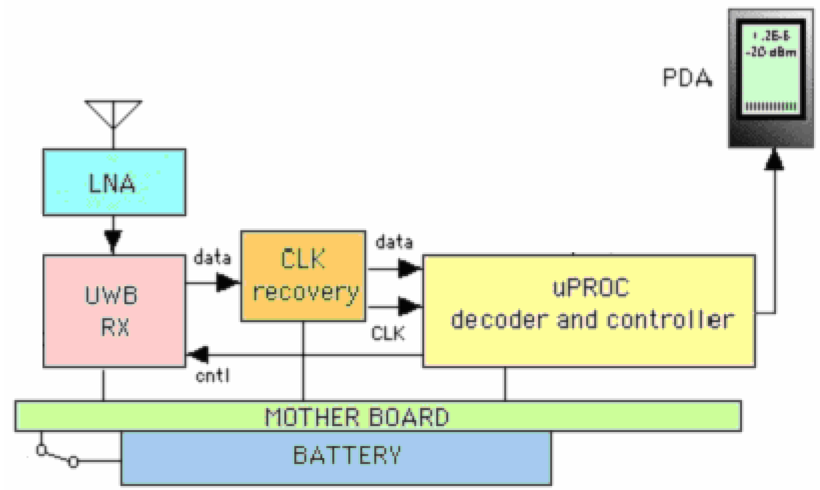

Figure 7: Receiver Unit Block Diagram.

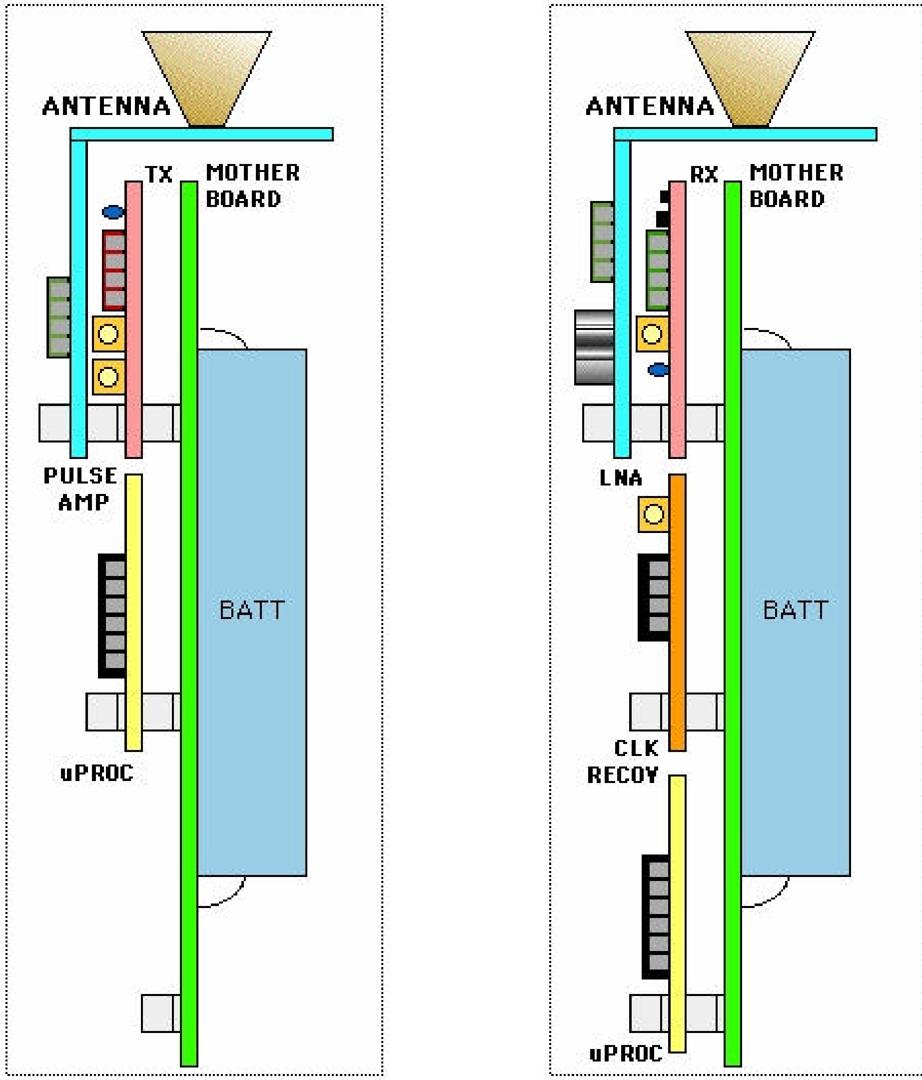

Figure 8: Transmission Unit (left) and Receiver Unit (right) Board Layout Diagram.

3.2 Networking Software and Applications

We have integrated our UWB radios with UWB radars and other sensors. A picture of a node (for sensor network of nodes) is shown in Figure 9 below. Software protocols have been designed and implemented for sensor network communications.

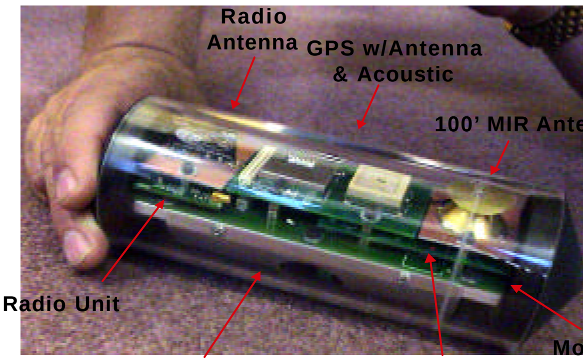

Figure 9: Integrated UWB sensor and radio devices in a small form factor.

IV. Conclusions

The design and implementation of low-power, small, and covert UWB radios have been studied in depth in the LDRD project. We have built hardware in several radios for various range and capacity specifications. We have also developed networking software for UWB radios for sensor networking. The LDRD has resulted in several new programmatic projects that are currently under way.