THE ARMY RESEARCH LABORATORY ULTRA-WIDE BAND TESTBED RADARS

Marc Ressler, Lynn Happ, Lam Nguyen, Tuan Ton, Matthew Bennett

Army Research Laboratory
ATTN: AMSRL-SS-SG
Microwave Sensors Branch
2800 Powder Mill Road
Adelphi, MD 20783-1197

PHONE: (301) 394-2530
FAX: (301) 394-4690

1. BACKGROUND

Over the years, many different sensor types have been evaluated in an attempt to satisfy the need to detect and discriminate tactical and strategic targets concealed in foliage or underground. In large measure, these early efforts were disappointing because of the lack of appropriate technologies. Recent developments in analog-to-digital (A/D) converter technology, source technology, and signal-processing power have presented new opportunities in this area. In 1988, the Army Research Laboratory (ARL) began a research program to determine the feasibility of bringing these emerging technologies together to analyze the problem of seeing through an inhomogeneous medium such as tree/foliage cover or the ground. The results of these studies indicated that continuing work in this area and sponsoring enabling technologies could produce a realizable system, thus leading to an understanding of the physics associated with foliage and ground penetration radar.[1] Applications of this capability range from military uses (detecting mines and stationary targets in hide) to commercial uses (such as forest characterization and for ground penetration radar, cable and pipe detection, oil and water table measurements, and environmental remediation.

Based on technology available in 1988, ARL instrumented an ultra-wideband (UWB) synthetic aperture radar (SAR) to collect data supportive of foliage penetration (FOPEN) and ground penetration (GPEN) studies. These programs are aimed at measuring and analyzing the basic phenomenology of impulse radar, specifically the propagation effects of targets, clutter, and targets embedded in clutter. At the time, the system developed at ARL lacked real-time data collection capability. Low transmit-power and the relatively slow data-transfer rates from the A/D converter to the data archiving system resulted in a system that needed many pulses to coherently integrate the power up, produced large amounts of collected data, and require a 50-hour data collection period.

Today, by taking advantage of commercial off-the-shelf processors, an advanced A/D converter, a more powerful transmitter, and lessons learned, we ave designed and assembled a more capable impulse implementation. This paper describes this upgraded radar system and the associated components used in the radar.

2. OVERVIEW

The ARL UWB test-bed radars are the basic sensor systems for gathering the data needed to understand FOPEN and GPEN radar phenomenology and to provide the wide variety of data in the varying clutter–foliage and soil–conditions needed to develop target-detection algorithms. These radars typically provide at least 1 GHz of bandwidth and the full polarization matrix to accomplish this task. The components described in this paper have been integrated to improve radar system performance described as Table 1.

3. SYSTEM DESCRIPTION

The objectives of the rooftop testbed are to obtain UWB radar phenomenology of targets, clutter, and targets in clutter (foliage and subsurface). These studies will ultimately allow us to identify characteristics that will permit targets to be separated from clutter. The system requirements for the rooftop testbed system are driven by the need to collect high-resolution, fully polarimetric data using the radar's UWB waveform, and the need to develop two-dimensional (down-range versus cross-range) images of a swath area from the measured data. Within the swath area to be characterized by the testbed radar are targets in

Table 1: UWB Radar Performance Characteristics

Feature	Base rail system	Rail system 1995
Data collection time/aperture	52 hr	1.5 hr
Power	0.5 MW peak	2 MW peak
PRF	40 Hz	750 Hz
System bandwidth	100 Mhz to 1.1 GHz	60 Mhz to 1.1 GHz
Processor	2 x 486 processors	2 x 6 I860 processors
Data storage reqm'ts/aperture	9 GB	600 MB
A/D data transfer rate	120 kB/s	10 MB/s
Positioning system	open loop	closed loop

the clear, targets within foliage, subsurface targets, and natural and manmade clutter. At present, it is desired to image swaths of up to 300 m down range by 225 m crossrange, with range resolution in each dimension of less than 0.3 m. We achieve high range resolution in the down-range dimension by using UWB waveforms with bandwidths in excess of 1 GHz and high-speed sampling techniques to record the radar returns. Currently, an impulse waveform is being used to generate the UWB signal for the rooftop testbed system with a spectral response extending from 60 MHz to over 1 GHz. We achieve high resolution in the cross-range dimension is achieved by measuring returns as the radar is moved along the rail, transmitting and receiving returns in the direction perpendicular to the line of motion along the rail; we then use SAR techniques to process those returns. Pulses are transmitted in two polarizations at right angles. Because the UWB SAR polarization planes are inclined 45° to the slant plane and the radar looks to the north, the polarizations are defined as east and west, resulting in EE, EW, WW, WE transmit-receive polarization vectors.

The system requirements for the rooftop testbed radar are met by a flexible design approach that allows variation of the radar parameters as well as test scenarios. The testbed consists of several major subsystems (Fig. 1), which are modular to allow for ease of exchange and the evaluation of alternative approaches. The testbed radar subsystems consist of the antenna, the transmitter, the A/D converter, the processor/data storage system, the timing and control assembly, the positioning subsystem, and the operator interface computer. Many of the subassemblies exist as standard 19-in. rack-mount units or as VME-compatible printed circuit assemblies. Much of the system operation is controlled by software, allowing an easy path to modification or upgrade.

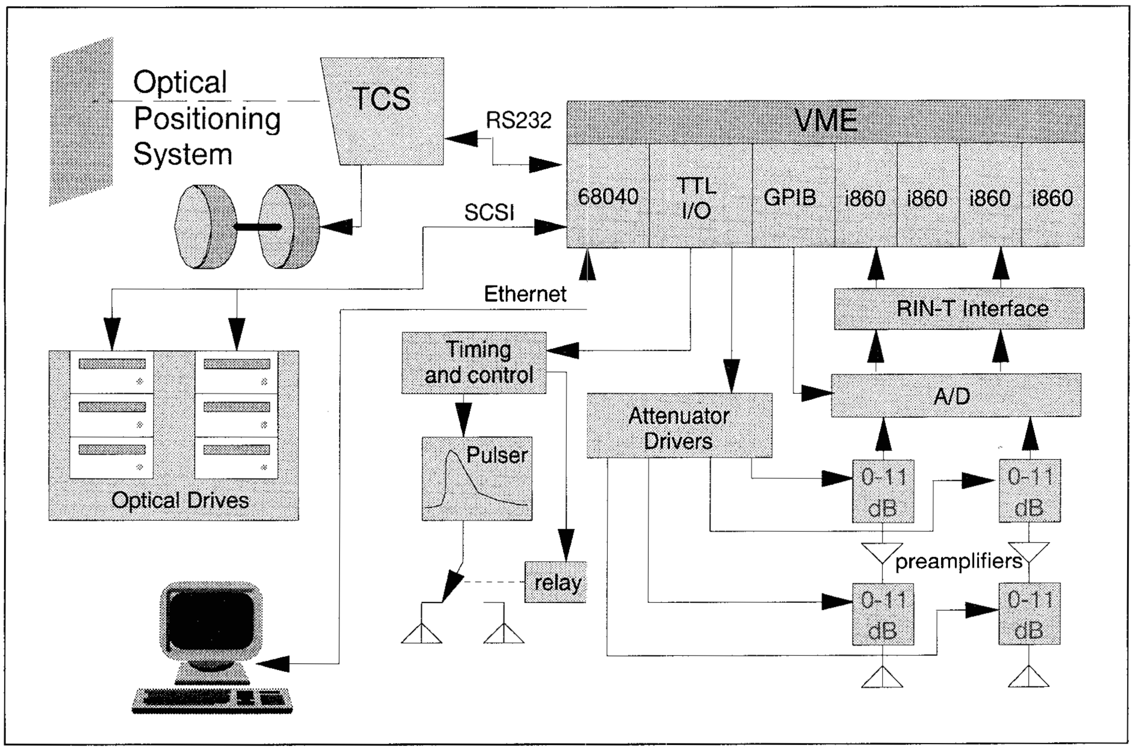

FIGURE 1. Ultra-wideband radar block diagram.

3.1 Antenna Subsystem

The antenna subsystem consists of the antennas, receiver preamplifiers and limiters, baluns, programmable attenuators, a polarity switching assembly, a trigger assembly, and low-loss, high-voltage coaxial cabling. There are two transmit antennas and two receive antennas to provide the full polarization matrix. Each antenna has a wide beamwidth, in excess of 90°, and a bandwidth of 40 MHz to 3 GHz. Therefore, the swath area to be imaged is fully encompassed, and the spectral response of the transmitted signal is not adversely affected by the antennas. A pair of dual polarized impulse radiating antennas (IRAs) is also being examined. The preamplifiers increase the signal level to that needed by the A/D converters and use limiting amplifiers to protect the preamplifiers from overload when the transmitter fires. The attenuator assemblies act as the gain control for the A/D converters, ensuring maximum use of their dynamic range, and providing signal reduction when large or close targets are involved. The baluns match the antenna impedance to that of the transmitter and A/D subsystems. Recent design changes allow for a more compact balun structure with a wider bandwidth, greater power handling capability, and an improved transient response that, along with antenna improvements, should reduce undesired ringing. The trigger system provides transmit time reference to the A/D converters, so that no adjustment of system parameters is necessary if a different transmitter is used.

3.2 Transmitter Subsystem

The transmitter for the rooftop testbed is a Power Spectra BASS 103A pseudo-exponential waveform impulse system with a 2-MW peak output. A single transmitter drives separate antennas. Polarization control for the transmitted signal is provided by a relay controlled by the processor/data storage subsystem, allowing rapid polarization switching. Expected pulse repetition frequencies (PRFs) are approximately 1 kHz, limited by the capabilities of the A/D converters. The original BASS impulse source had a 0.5-MW peak output. This change not only increases the net power, but also increases the proportion of energy in the low-frequency end of the frequency spectrum.

3.3 A/D Converter Subsystem

The A/D converters developed for the ARL UWB radar are 8-bit Analytek VX2000 series systems. They have a 3-dB bandwidth of dc to 1000 MHz, and in single-channel mode can provide up to 2 giga-samples per second (Gs/s). They have a fixed input range of ±250 mV, although a dc offset feature allows this to be shifted by ±250 mV. A preamplifier and a set of programmable attenuators is used external to the A/D to improve sensitivity and provide a method of gain control. The observed rise time of these A/Ds is approximately 400 ps when they were driven with a 75-ps rise-time pulse. The choice of internal and external trigger is available with programmable slope, level, and coupling, as well as an arming gate function. An acquisition event includes a programmable number of pretrigger samples (8192 minimum to provide proper operation) and a programmable number of post-trigger samples. The VX2000 can store up to 8 MB of samples on a single acquisition. The clock for the VX2000 runs continually and is not locked to the transmit timing; this arrangement results in a jitter in the received sample, which amounts to a loss at higher frequencies. A unique feature of the system is that it provides time interpolation to allow the processor to generate an interleaved record equivalent to up to 64 Gs/s. The transmitter timing is intentionally dithered to avoid interference to and from broadcast and communications frequencies that occupy the frequency spectrum. A sense antenna located near the transmitting antennas feeds a detector circuit that drives the external trigger input of the A/Ds, thus referencing transmit time from either antenna that is independent of delays inherent to changes in transmitter, cabling, or antenna configurations.

The A/D modules are controlled by, and status and data retrieved over, an IEEE-488 bus, with each module having a separate device address. For high-speed data transfer, a parallel output port is available on each module that can support transfer rates of 20 Ms/s. The VX2000 provides a programmable number of output samples and a programmable starting address although the starting address relative to the trigger exhibits an undesired offset and is only programmable to modulo 4 values. This provides the same kind of functionality that delayed sweep does on an oscilloscope.

This SAR maximizes the useful energy that can be integrated over the region. Based on the geometry of the test region, a variable delay is prograqmmed to the start of each data record for each position along the track (see Figure 2). With a sample length of 2048, the A/D can acquire and off-load data and re-arm for a new acquisition at approximately a 1-kHz rate, 25 times faster than the first-generation rail SAR. Aside from a major time savings in data collection, a more realistic simulation in continuous-motion SAR and an absence of diurnal effects in the data are also significant improvements.

An ARL-designed interface board converts the bus signals of the A/D and provide buffered data to the Mercury RIN-T bus format for preprocessing and data storage. This custom interface also allows extra radar status bytes to be added to the data record trailer.

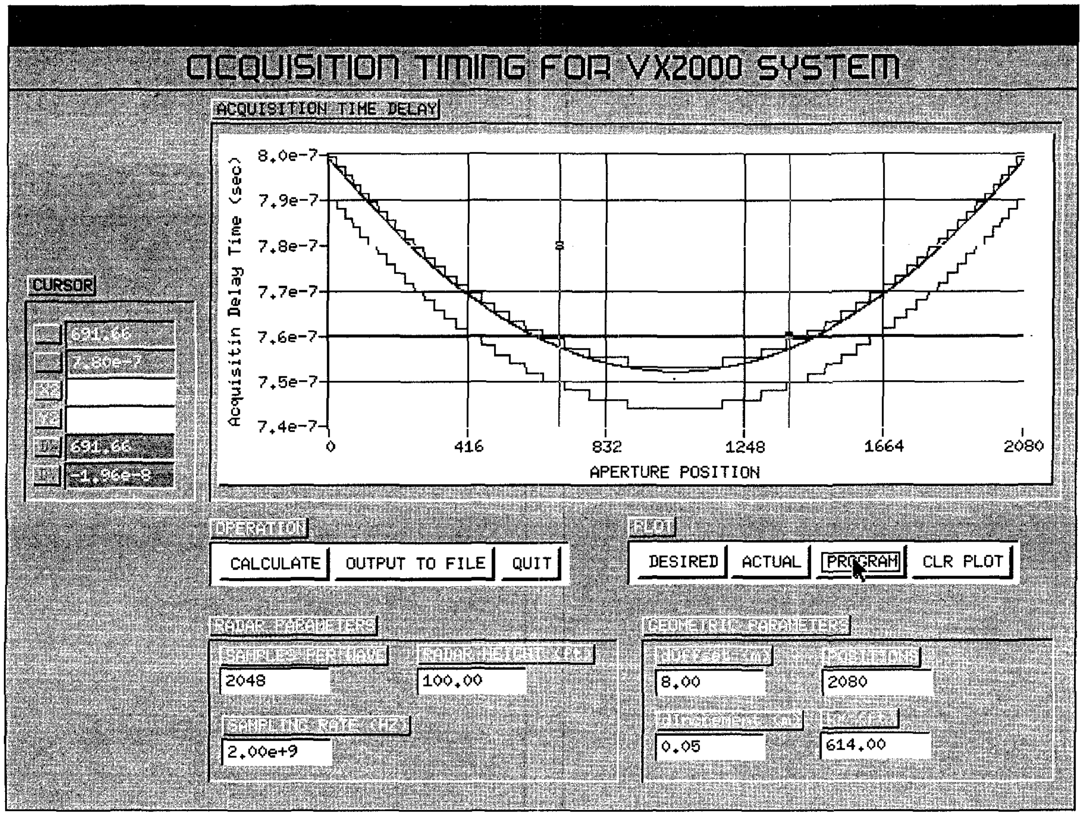

FIGURE 2. UWB programmed acquisition delays

3.4 Processor/Data Storage Subsystem

The processor/data storage system orchestrates the operation of the radar, arming the A/Ds for an acquisition phase, initiating the timing and control to produce a transmit sequence, recovering and preprocessing data from the A/Ds, and commanding the platform to its next position. The system also controls the built-in test and calibration procedures and allows stand-alone operation of the system for specialized test procedures. The interconnection of the various radar assemblies with the processor subassembly is depicted in figure 3. The processor is a Motorola 68040-based, VME chassis, running under VxWorks, with two separate groups of six i860 array processors running under the Mercury Computer Operating System (MCOS). One of the i860s in each group is responsible for operating the RIN-T high-speed interface. The RIN-T bus is the entry point for A/D data into the processor. The i860 array processors perform the data interleaving, integration, filtering, and re-sampling to produce 8-Gs/s equivalent data records. The processor also supports an IEEE-488 interface for A/D control and a SCSI interface for recording the data from each channel on separate magneto-optical (M-O) CD drives. Bit-wide parallel I/O control supports bus initialization and handshaking control for the high-speed data interface.

A typical data acquisition sequence calls for 128 transmit pulses (a "burst") to be sent in one polarization, followed by 128 pulses in the other polarization for each data collection position along the track. A burst of data for each receive polarization is assigned to one of the remaining five i860 processors in that array processor group. For each pulse, 4088 A/D samples are converted from offset binary to floating point and are stored in the appropriate subsample (1 of 32) array. This time offsetting of data, which we refer to as interleaving, not only includes the delay due to the time difference between the trigger and the A/D reference clock (recovered from the status bytes in the record trailer), but also acts to time align, on a fine scale, the four polarization sets to account for system delays. These system delays result from fixed delays that vary between the four channels (measured during system calibration) and the variable delays that are due to path length changes as the programmable attenuators are switched. An automatic gain control (AGC) algorithm is used to independently control the attenuators for each polarization channel. This maximizes the use of the A/D

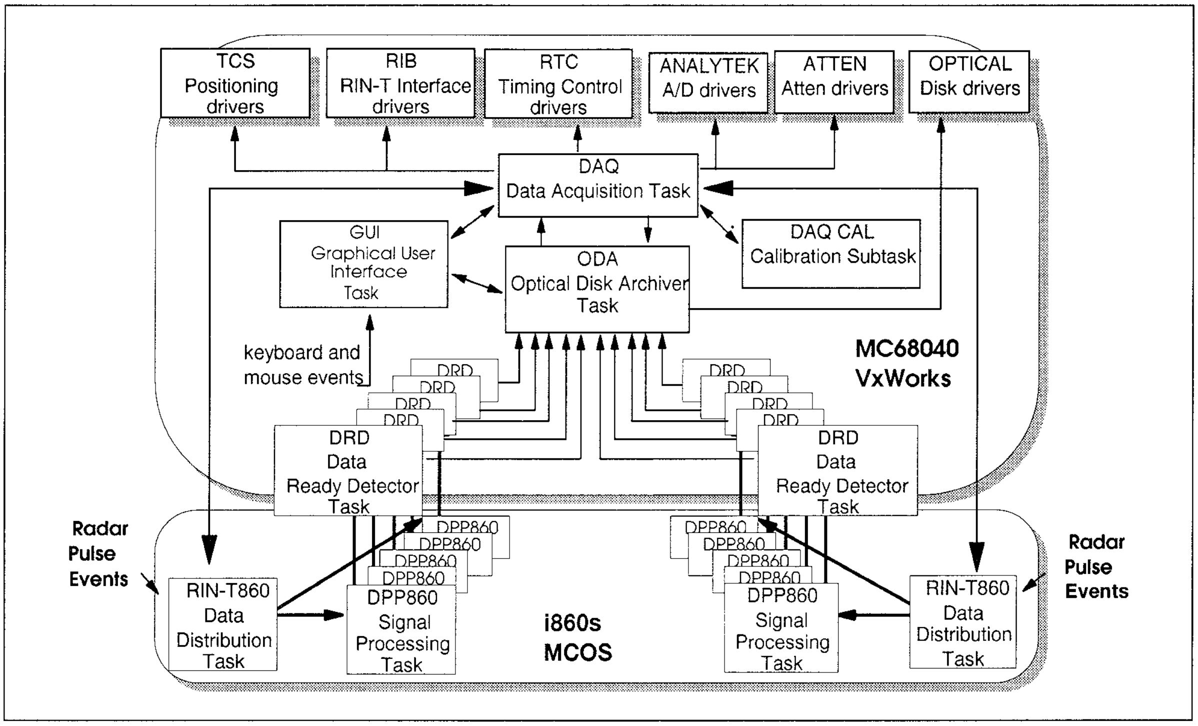

FIGURE 3. UWB radar software architecture.

dynamic range while allowing autonomous operation of the system. A starting set of attenuator values is determined during the calibration phase of each run. These values will normally be different for each transmit polarity. For each attenuator pair (0 to 110 dB and 0 to 11 dB), a calibration is done to develop a table that maps attenuator setting against delay time and attenuator error (±dB). Once all the pulses for a particular transmit polarization have been acquired, each subsample bin is averaged. All the interleaving and averaging are coherent with the radar transmitter, but incoherent with any interfering signals. This improves the signal-to-noise ratio and is the major source of the signal-to-interference rejection that takes place in the radar.

The averaged array is then transposed to generate a time-ordered array that can be read out as an equivalent 64-Gs/s record of the received signal. This vector is then low-pass filtered and resampled to an 8-GHz equivalent sampling rate. At this time in pre-processing, the data are scaled by the attenuator error and converted into a 2-byte integer format; this conversion preserves the maximum amount of dynamic range available in 16 bits. It also allows postprocessing to appropriately scale and shift the data to do SAR image formation with resolution of less than 1 ft. The expected file size for each polarization is 135 MB (32 kB x 2080 data points), well under the capacity of one side of a high-density optical CD. Thus, the volume of collected data is significantly less than for the first-generation system. In the future, paralleled optical drives could provide adequate data storage without the need for an operator to exchange optical disks for much larger apertures.

3.5 Timing and Control Subsystem

The timing and control subsystem takes transmitter requests from the processor/data storage subsystem and produces a selectable number of pulses at programmable pulse repetition frequencies (PRFs). It can produce a pseudo-random, staggered PRF to reduce the interference that the system may cause to other transmitting and receiving systems and to improve the radar's resistance to interference from other transmitters. It can control (based on transmitter capabilities) transmit polarity and polarization and provide pre-trigger timing for receiver protection or blanking functions on other equipment. The timing and control system accounts for many of the differences between various transmitter and receiver systems and has a large number of software, firmware, and switch options to allow evaluation of emerging components.

3.6 Positioning Subsystem

The testbed equipment mounted on a robotic cart travels on a rooftop track at the ARL facility in Adelphi, MD. The active aperture is 104-m long with 2080 sample positions at 5-cm spacings. An infrared rangefinder and closed-loop position control system provide repeatability to 0.5-cm accuracy down the length of the track, whose guide rail is laser aligned to better than 0.6 cm in all other directions. The upgraded positioning system for the cart consists of a Compumotor servo amplifier controlling a direct-drive motor and a Geotronics TCS 4000 dynamic positioning controller. The TCS 4000 is a proportional/integral/differential system (PID) controller for the motor, which uses an optical rangefinder for feedback. Position is referenced to a retro-reflector at the edge of the roof, and commands and status are communicated to the processor/data storage subsystem over an RS-232 interface. The TCS 4000 is an intelligent control system that will dynamically adapt to changes in the system's mechanical characteristics. Once it has been through a calibration phase, it will store precomputed motion compensation values for the robotic cart. This improvement reduces rangefinding overhead in data collection by at least 2 hours per aperture.

3.7 Operator Interface Subsystem

A SPARC notebook computer acts as the operator interface and communicates with the rest of the system over an ethernet connection. It provides the system with a graphical user interface (Motif/Xwindows) that includes programmable buttons and menus, and can provide charts and graphs to measure system performance and monitor system operation. This computer also provides for software development and debugging of the code that supports the processor/data storage subsystem to allow rapid testing of new components.

4. POSTPROCESSING

The preprocessed data are transported to an analysis center for further processing.[2,3] For the postcollection processing, a VME cardcage with a Sun SPARC 1E host is used to provide the computational power required for SAR image formation. A Silicon Graphics Iris Crimson workstation, networked to the signal processor, is used for displaying the image. The Silicon Graphics workstation also has a 4-mm (digital audiotape) drive that is used to back up the raw data from the optical disks. This provides a convenient means for data exchange among other agencies and academia.

5. CONCLUSION

The UWB radar testbed described in this paper has been constructed to take advantage of recent improvements in transmitter, antenna, A/D converter, and signal processing design. Judicious selection of commercial-off-the-shelf components translates to reduced cost and simplified migration from military research into commercial applications. Because of a faster data collection cycle, data collected for foliage-penetration and ground-penetration experiments will be free of weather induced and diurnal variations in the media and will allow a more realistic evaluation of motion compensation equipment and techniques. Being able to perform multiple data runs in a single day allows us to analyze the effects of diurnal variations and simplifies the logistics of recording multiple look angles for visiting targets. The nearly 40:1 reduction in the amount of data recorded simplifies the exchange of information with other researchers, as well as reducing operating costs. In addition, the reduced data size also results in reduced postprocessing computation requirements, and focused images are more quickly available for evaluation.

6. ACKNOWLEGEMENT: The authors acknowledge the hard work and dedication the UWB team at ARL including John McCorkle whose vision continues to inspire all of us; Jeff Sichina for his fearless leadership; Karl Kappra, Arthur Harrison, George Pace, Laura Mann, and others who braved hardware and software battles and won only to expose themselves to harsh weather conditions to collect seemingless endless apertures of data and to start fresh with a new system design for the system described in this paper.

References:

[1] John W. McCorkle, "Early Results from the Army Research Laboratory Ultra-Wide-Bandwidth Foliage Penetration SAR," SPIE International Symposia, April 1993.

[2] John W. McCorkle, "Focusing of Synthetic Aperture Ultra Wideband Data," IEEE International Conference on Systems Engineering: August 1991. ISBM 0-7803-0173-0

[3] Vincent Sabio, Lynn Happ, and CPT Keith A. Sturgess, "Army Research Laboratory Ultra-Wideband SAR: System Overview and Results of Resonance-Based Target Recognition Studies," 19th Army Science Conference, June 1994.