# COVERT RANGE GATED WALL PENETRATING MOTION SENSOR PROVIDES BENEFITS FOR SURVEILLANCE AND FORCED ENTRIES

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## Abstract

Determining of the presence of people, when visibility is obstructed, is extremely valuable for public safety officials for assessing situations, particularly assessing hostage situations or when preparing for forced entries. Time Domain Corporation has developed a man-portable surveillance radar prototype, RadarVision 1000, based on patented time-modulated ultra-wideband (TM-UWB) technology. This device can be used to detect movement of people in well-defined ranges through walls, foliage, or other non-metallic boundaries. TM-UWB technology uses very short duration, pseudo-random time encoded electromagnetic pulses. The resultant transmission is a noise-like signal that is spread over a wider frequency range than conventional systems.

The device has features important to public safety situational management. Three key keys features are: 1) inherit covertness because of its ultra-low power noise-like signal, 2) high resolution at low radio frequencies, for penetrating building materials, and 3) resistance to common spoofing techniques and false alarms. The results from prototype testing , and a proposal for a follow-on product, that will track the movement of people will is discussed.

## Background

Public safety personnel are regularly put at risk, or are forced to put members of the general public at risk, because of a lack of information on activities within structures. This is particularly true in cases of forced entries and hostage situations. Knowing where people are moving within a building or behind some other barrier is valuable situational awareness information, allowing an officer to make improved decisions.

A surveillance device that penetrates barriers that prevent direct visible observation must be mobile, easy to use, quick to set-up, and covert. Covertness is becoming more important, because what were once advanced technologies, for example, scanners and "bug" detectors, are now more available to the public. It is also important that the devices be resistant to false alarms, so the operator's maintain confidence in the devices' reliability.

Time Domain Corporation has developed a prototype handheld radar system, based upon the feedback from a public safety, working group hosted by the University of Alabama, Huntsville, RadarVision 1000, detects the movement and the approximate range of personnel in the presence of obstructions. The radar's signal penetrates walls, foliage, and other non-metallic barriers, and monitors very specific range gates , reducing the potential for alarms by other movements outside the area of interest. For example, the device could be used by a police officer to assess the situation prior to entering a building. Detection of motion would warn the user of probably complications with the entry, whereas the absence of motion would yield relative confidence concerning the safety of the entry. The RadarVision 1000 is based on time-modulated ultra-wideband (TM-UWB) technology offering high resolution signals at frequencies that penetrate non-metallic building materials.

An additional advantage of these short duration pulses is that it spreads the transmit power over a large bandwidth. This makes the system more covert. Low power TM-UWB signals are very difficult to detect.

It has been demonstrated that it is resistant to many of the sources of false alarms and "spoofing" that have been seen with other technologies.

## TM-UWB RADAR Basics

### UWB Radar Introduction

The basic components of a generalized short pulse UWB radar are shown in Figure 1. The transmitter is a pulser that produces pulses of very short duration. This signal excites the transmit antenna, which radiates a radio frequency (RF) electromagnetic signal. The radiated RF pulse penetrates and/or reflects off of nearby objects. Some of the reflections impinge upon the receive antenna. The radar receiver filters, amplifies, and samples this received signal. The command and control block precisely controls the timing between the pulser and the sampler so that the quasi-impulse response of the environment can be captured using repetitive transmissions.  This signal is digitized and processed.

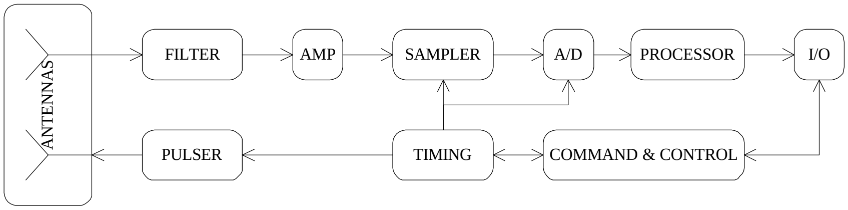

**Figure 1  Block Diagram Depicting a Typical Short Pulse Ultra-Wideband Radar.**

Short pulse UWB radar systems offer advantages over conventional radar systems in terms of speed of acquisition, processing, cost, and clutter rejection.  UWB systems are particularly suitable in applications that are relatively short range, e.g., less than a few hundred meters, or in congested environments.

TM-UWB Advantages

Time modulated ultra-wideband (TM-UWB) technology is based on the transmission of short (duration) electromagnetic pulses, like those in Figure 2.  These pulse's power spectra have a relative 3 dB bandwidth of about 70%.  For comparison, conventional spread spectrum communication systems typically operate with less than a 15% relative bandwidth.  This equates to a signal that takes is already low power level and spreads it over a very large bandwidth.  The result is a system that has a low probability of detection, as desired for covert applications.

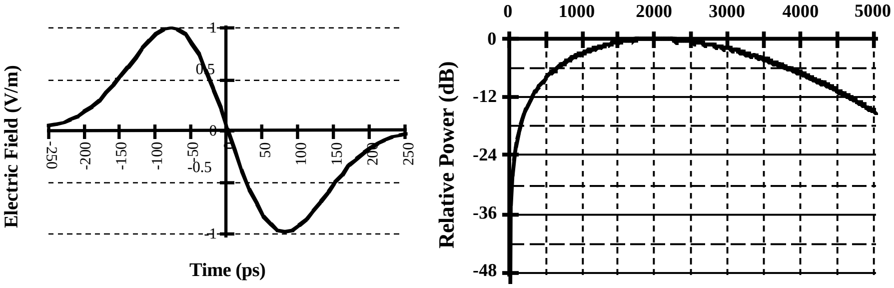

**Figure 2  Example of Radiated Ultra-Wideband Electromagnetic Pulse in Both the Time Domain and Frequency Domain.**

The short pulse duration allows for high resolution signal.  The range resolution of a radar system is the minimum separation in distance, along a radial from the radar, that is required to resolve two point targets.  This technical figure of merit, gauges the radar system's ability to distinguish  between closely spaced objects.

The range resolution for UWB radar system's is one-half of the pulse width duration multiplied by c, the velocity of light.  For the systems tested, the pulse width is 0.7 ns yielding a range resolution of approximately four inches. High resolution radar systems provide more detail of the objects in its view.

There are other high resolution radar systems; but, UWB radar systems achieve high resolution, while operating at lower frequencies. The advantage of operating at lower frequencies is improved penetration of building materials, as seen in Figure 3. A UWB radar operating at 2 GHz may have as much as 10 dB (10 times) less loss penetrating a concrete brick wall than an 10 GHz , X band radar.

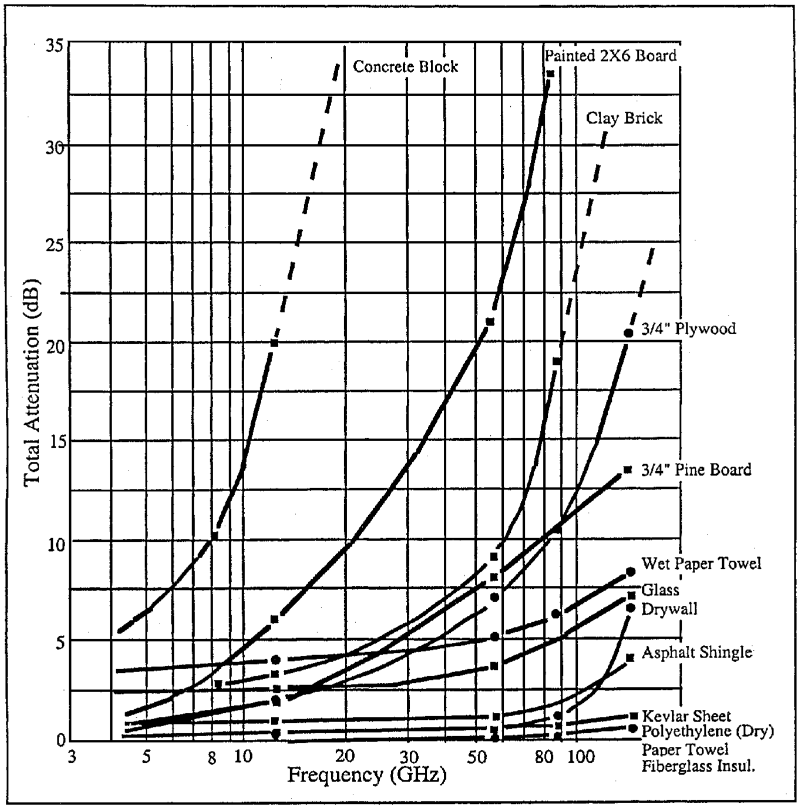

**Figure 3 RF Attenuation versus Frequency for Various Common Building Materials.**[1]

Another advantages of short pulse UWB radar systems is clutter rejection. Clutter is the term used for non-random signals received from sources such as coupling from the transmit antenna to the receive antenna, or reflections from undesired targets. Clutter may be very large compared to the signals from the desired

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[1] Lawrence M. Frazier, Raytheon, “Radar Surveillance through Solid Materials”, SPIE Photonics East conference, Enabling Technologies for Law Enforcement and Security, Boston, MA November 18 - 22, 1996. Paper 2938-20.

target. While it is difficult to maintain large dynamic ranges, the ratio of the largest observable signal to smallest with these radars, clutter rejection can more than make up for it. The short time response means the signal can be time isolated and techniques, such as gating or a time varying gain to emphasize signals in the regions of interested. The receiver can be allowed to saturate as long as it is allowed to recover to its linear region for the desired time window. This saturation would be disastrous for a stepped frequency system that relies on the steady-state response of sinewaves and Fourier transforms.

UWB systems performance can be enhanced by time modulating the pulses. If a uniform pulse train is transmitted, the signal is still UWB; but, the energy is concentrated at discrete harmonic frequencies within the bandwidth. These harmonics correspond to integer multiples of the pulse repetition rate. By randomizing the timing of each pulse, as illustrated in Figure 4, harmonics are eliminated. This produces a noise-like signal that appears to have little structure. Time modulation improves the covertness, as well as the electromagnetic compatibility, in existing systems.

This also has a reciprocal effect. Time encoding forces the receiver to randomly sample jamming signals. The desired signal is processed coherently while jamming signals are processed non-coherently. Therefore the system takes full advantage of available processing gain. This allows a TM-UWB radar system to not only reject narrowband signals, such as commercial broadcasting, but to also operate in close proximity with other TM-UWB radar system without frequency coordination or interference.

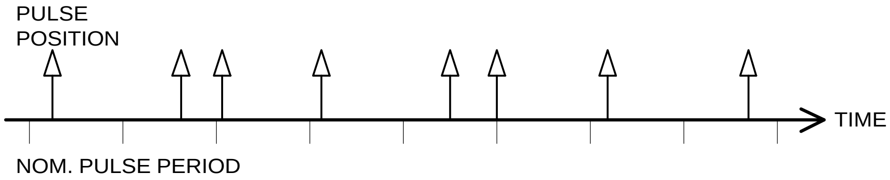

**Figure 4 Time Encoding of the Pulses Varies the Delay from the Periodic Position of a Uniform Pulse Repetition Rate.**

An additional benefit to time modulation for radar systems is the reduction of range ambiguities. Range ambiguities occur when a radar system transmits pulses at a uniform rate. This produces an ambiguity because the signal being received may be the result of a particular transmitted pulse or its predecessor(s). For some systems, a large object at a great distance may appear as if it is a smaller object, closer to the radar. Random timing of TM-UWB transmission forces reflections to be decorrelated so they can be easily reduced via integration. A TM-UWB radar system monitors a small range window, e.g., 4 inches, away from the radar that is not impacted from reflections from objects beyond that range window, even if the object is as big as a truck.

## Time Domain Corporation’s Circuit Enhancements

There are several circuit implementations developed by Time Domain Corporation (TDC). Discussed here are the antenna, the correlator, and the timer ASIC.

TDC uses antenna designs that have a short ringdown, without the use of resistive loading. The short ringdown is inherent in a UWB antenna that has little phase dispersion, thus minimizing the distortions to the quasi-impulse response. These antennas are generally planar shape, although there is flexibility in terms for shaping, such as cylindrical. These antennas can also be formed to make time delay arrays, in order to increase antenna gain, and to reduce the energy directed at undesired objects. The RadarVision 1000 uses an array of two antennas, one for transmit and one for receive, and a back reflector. This is a simple design in which the reflector provides forward gain and rejects false alarms from the movement of the user holding the device.

The RadarVision 1000 uses TDC’s patented UWB correlator receiver. A correlator receiver is an optimal filter. Many communication systems with correlator receivers, such as FM radios, perform the correlation with template waveforms of long duration, i.e.. sine waves. The UWB correlation receiver uses a template of very short duration that is similar to the received signal to maximize signal-to-noise ratio, while minimizing distortion.

TDC has just finished testing its first ASIC correlator. Though it is not yet implemented in the RadarVision 1000, this custom chip will allow future products to have lower cost, lower power consumption, and the ability to collect data several times faster.

One big innovation has been the development of a custom timer ASIC. This chip precisely positions the trigger signals for the pulser and correlator, for both time modulation and delay control. Precise positioning is critical for high resolution as bandwidth increases. The timer can control the trigger with 3 ps precision over a large temperature range. It has demonstrated a jitter level that it is comparable with the measurement equipment, making jitter measurements problematic. In the current implementation, the jitter from the pulser's output to the correlator template trigger has a standard deviation of approximately 20 ps. This is adequate for a 2 GHz system whose ¼ pulse width is 125 ps.

## Detecting Motion

The basic algorithmic approach is to measure a quasi-impulse response of the environment and to monitor that response for changes. If changes are significant, then a hit is indicated. Once a predetermined number of consecutive hits are detected, an alarm is reported.

The response of the environment is measured at four fixed ranges. The microprocessor controls the ranges by controlling a system delay parameter value. When this delay parameter is set, the microprocessor dwells on the range and integrates the response of the correlator. For example, by setting this parameter equal to 10 nanoseconds, the correlator will integrate the response of the environment at a range of 5 feet. (Ten nanoseconds of delay corresponds to a range of 5 feet). This process is then repeated for ranges at 10, 15 and 20 feet. During this process, running averages and other statistics are generated on a range by range basis.

The final alarm algorithm compares these statistics against sensitivity thresholds, and if the changes are substantial, definite and associated with velocities compatible with human motion, then a hit is indicated. An alarm is announced only when the number of consecutive hits exceeds predefined criteria.

With a single look angle, as in the case of RadarVision 1000, a subject moving in a close range gate may “cast a shadow” at a more distant range gate. The radar system effectively "sees" not only the presence of the target motion; but, also detects the apparent absence as the signal is prevent from reflecting from objects that are more distant. To reduce confusion, the RadarVision 1000 only indicates motion in the closest range gate that the movement is detected. Monitoring multiple targets requires additional look angles.

## RadarVision 1000™

The RadarVision 1000, shown in Figure 5, is a test bed product. The goal of this radar is to provide a product for testing by agencies, for evaluation and guidance for future developments. It is primarily designed to be as a hand-held radar system for detecting motion behind non-metallic walls. This unit has the flexibility to also be

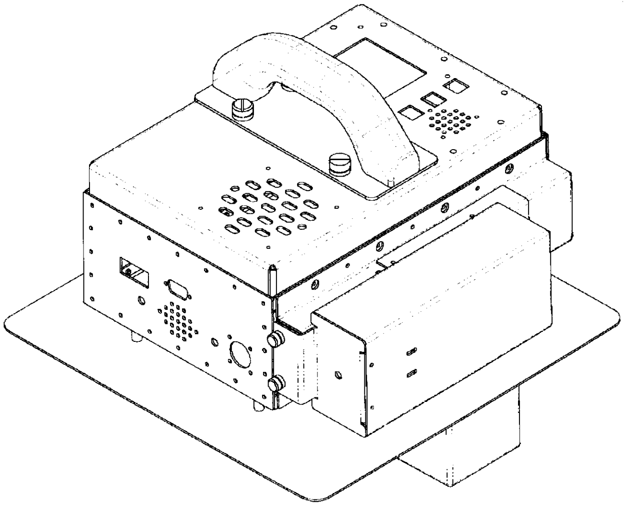

**Figure 5 Drawing of RadarVision 1000**.

used to capture data, allowing future development for motion mapping, radar imaging, and target discrimination. The interface to the device is a graphical display and four buttons, along with a standard PC serial port. The detailed specifications are listed in Table 1.

| characteristic | value |
|---:|:---|
| pulse repetition rate | 5 MHz |
| center frequency | 2 GHz |
| 3 dB bandwidth | 1.4 GHz |
| 6 dB bandwidth | 2 GHz |
| field of view | 100° |
| antenna gain | 6 dBi |
| high power | 5 mW EIRP |
| low power | 0.05 mW EIRP |
| low power range | 20 feet |
| range resolution | 4 inches |
| time encoding range | 20 ns |
| chip length | 512 |

**Table 1 RadarVision 1000 Specifications**

## INITIAL TESTING

RadarVision 1000 is currently undergoing tests similar to those tested on its predecessor by the US Army's Night Vision Laboratory, Fort Belvior, Md. The purpose of these tests is to evaluate 1) detection of personnel, 2) rejecting clutter, and 3) rejecting undesired targets.

The detection tests consist of testing adults in upright and prone positions and at closing velocities of 0.1 ft/s and 15 ft/s. The two different positions prove a significant difference in the human body's radar cross section, which is typically between -10 dBsm and 0 dBsm. The prone position was tested by using a wheeled automotive creeper. Variations in velocity is an important test in systems that use post processing to filter out very fast movement, such as fan, and very slow movements, such as normal temperature expansion and contraction. In order to detect prone personnel, the radars system works best when the antenna used horizontal polarization. This is because the maximum dimension would be the person's shoulders. The systems detect movement by an average sized adult in all four situations. Tests with children or small adults were not complete at the time this paper was written.

Clutter rejection tests consisted to testing the radar system's ability to detect personnel moving within a metal structure. This was tested at Fort Belvior by using a stand of scaffolding and having personnel climb through the bars. RadarVision 1000 was tested by using industrial metal shelving holding various pieces of electronic equipment and personnel crawling underneath. The unit successfully detected the movement.  Cluttered areas may actually help detection by producing multi-paths and shadows.  In an open field the unit monitors distinct range gates that are approximately 6 inches deep.  When the area is cluttered, particularly with metal structures, personnel moving inside the range will reflect signals in many directions, some towards other objects that may then be detected by the radar.  As discussed previously, personnel cast shadows on objects behind them.  However, the radar system still only processes signals that arrive in the specific time window.  The interaction with various objects means the radar will monitor a thicker range window in congested environments where the outer edge is still very distinct.  This is why it is stipulated that an alarm indicates there is movement within between two adjacent cells.  As with all radars, the TM-UWB unit can not penetrate metallic sheets or tightly meshed metallic screens.

Rejecting undesired targets is a common problem in many radar systems.  Ventilation or circulation fans are among  the most common  sources of false-alarms for Doppler based radar systems, because the fan blades provide a variety of velocities.  The Army tested this phenomenon by using a metallic anemometer, activated by bursts of compressed air at the range being observed.  The test included evaluating the alarm due to the movement and whether the movement effected the ability to detect personnel.  The cups of the anemometer were modified to form trihedrals to provide very strong reflections have varying closing velocities.  To a TM-UWB radar, this appears as a rapid cyclic noise source that is reduced by detection and processing algorithms.  This was demonstrated by the predecessor motion sensor.  To demonstrate a similar point, TDC applied metal to two of three blades on an eight-inch oscillating fan.    Therefore the motion was very complex due to the rotation of the fan blades and the combination of interactions plus the back and forth movement of the fan's head every 1.3 seconds.  The RadarVision rejected movement of the fan and was still able to detect personnel.  The fan did not generate any false alarms until it was within 32 inches of the radar system antenna and appeared to be shadowing objects at the range cell monitoring 20 feet.

Finally, the radar unit was left on for extended periods for many hours monitoring a hallway.  During this period, there were not any false alarms and the unit consistently detected the normal movement of personnel.

## FUTURE DEVELOPMENT

The RadarVision 1000 is limited to detecting the closest range that motion is detected in.  Although the movement of multiple targets may be observed over time, only one target can be monitored instantaneously.  To monitor multiple moving targets simultaneously will require several look angles, to discriminate between reflection from desired targets and the shadows they cast.  Multiple look angles also provide additional information so that both range and bearing can be determined.  TDC is planning on using the RadarVision 1000 as a test bed to develop such a system.  The objective is to use a sparse array antenna and synthetic aperture radar (SAR) techniques to produce radar image type data.  However, the detail provided by these images would generally be too complex for the size of zones desired, so it has been proposed to reduce this data to map motion instead. That way the user can quickly access the desired information rapidly, yet the potential for more complex algorithms such are target discrimination will be available for future development.

As an exercise to illustrate the imaging potential of RadarVision, a early engineering prototype was used to collect scans of several metallic object suspended in an open room. Data was recorded as the radar was moved in a straight line at one foot increments for a total of 18 feet. The voltage versus time record was then process using very simple SAR processing techniques to focus the received energy. Figure 6 shows both the setup of the scanned objects and the resulting SAR image. This image can be enhanced significantly through advanced processing and further hardware development but clearly shows the potential of future developments.

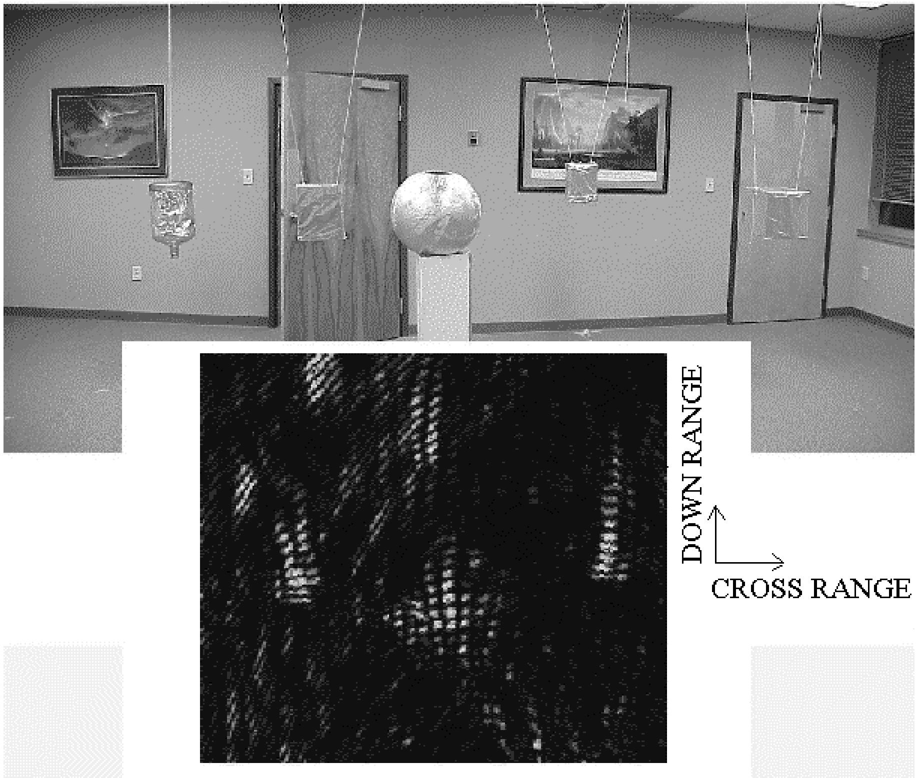

**Figure 6 Picture of Suspended Metal Targets and the Associated RadarVision Synthetic Aperture Radar Image.**

## SUMMARY

Time Domain Corporation has developed a hand-held radar system, RadarVision 1000, for detecting motion through non-metallic obstructions. One unique feature of this time-modulated ultra-wideband device is its inherit covertness. This covertness is obtained by use of very low transmit powers that are spread over very large bandwidths. These bandwidths are located at relatively low frequencies that penetrate building materials while maintaining the high resolution associated with these bandwidths. In addition to this point, this technology is well suited for this application because its ability to reject clutter experienced in such congested environments. The net result is a device that is resistant to many weaknesses commonly observed in motion detectors as is illustrated by preliminary testing. Future development of a portable motion mapper was also discussed and the concept is substantiated by a synthetic aperture radar image generate using a RadarVision unit.

## BIBLIOGRAPHY

Mark A. Barnes has been an electrical engineer at Time Domain Corporation, Huntsville, Alabama for seven years. In that time he has worked on the theory and practice of UWB propagation and link analysis, compliance engineering, antenna design, circuit design, and signal processing for both communication and radar systems. He is currently serving as project engineer for the radar development team.

Mr. Barnes has published several papers on ultra-wideband technology and has several patents. He received his Masters of Science in Electrical Engineering from the Ohio State University where his research focused on ultra-wideband ground penetrating radar.