

LOW-FREQUENCY ULTRA-WIDEBAND SYNTHETIC APERTURE RADAR 1995 BOOMSAR TESTS*

Lynn Happ, Karl A. Kappra, Marc A. Ressler,
Jeffrey P. Sichina, Keith Sturgess, Francis Le

Army Research Laboratory
AMSRL-SE-RU
2800 Powder Mill Road
Adelphi, MD 20783
(301) 394-2530

ABSTRACT

The Army Research Laboratory has been investigating the potential of ultra-wideband synthetic aperture radar (UWB SAR) technology to detect and classify targets embedded in foliage or in the ground. The UWB foliage penetration (FOPEN) radar program has been extended to include the evaluation of ground penetration (GPEN) radar technology. ARL is investigating these problems by collecting high quality, precision data to support phenomenological investigations of electromagnetic wave propagation through dielectric media. Understanding the phenomenology of wave/target/clutter interactions supports the development of algorithms for automatic target recognition. The latest version of the radar developed by ARL is the UWB BoomSAR mounted on a 150-ft-high mobile boom lift. The BoomSAR is a mobile platform that can travel to various sites to collect target data in a variety of clutter scenarios. This paper provides a description of the boom radar system and imagery from data collections at Aberdeen Proving Ground, MD, and Yuma Proving Ground, AZ.

1. INTRODUCTION

Many organizations, both within and outside the Department of Defense, have a need to detect and identify obscured and/or subsurface targets. Non-DoD interest exists for applications such as environmental remediation, military base cleanup, mine detection, tunnel detection, and pre-construction site analysis. It is known that low-frequency electromagnetic energy penetrates foliage and a variety of soil types to some depth. Furthermore, low-frequency signals when used in an ultra-wideband (UWB) mechanization offer the possibility of high-resolution imaging. This promotes a dramatic improvement in target to clutter ratios, which is necessary for reliable target/clutter separation. Low-frequency UWB data also offer some unique characteristics that may be exploited in the development of innovative target/clutter discriminants to be used as features in effective automatic target detection/recognition (ATD/R) algorithms.¹ Challenges remain in demonstrating effective detection, discrimination, and classification of concealed objects from an airborne platform, but the technology is promising. Recent improvements in sources, specialized algorithms, and computer processing bring the capability within reach and suitable for acceleration.²

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2. OVERVIEW

The Army Research Laboratory (ARL) UWB test bed radars are used to gather the data needed for understanding foliage and ground penetration (FOPEN and GPEN) radar phenomenology.^{3,4} High-quality, high-resolution target and clutter data are collected with the UWB systems in support of the development of innovative ATD/R algorithms whose goal is to provide a high probability of detection with low false-alarm rates under varying environmental conditions and operational scenarios. The ARL UWB impulse radar provides at least 1 GHz of bandwidth and the full polarization matrix to accomplish this task. It also acts as the proving ground for emerging component technology. The UWB synthetic aperture radars developed at ARL emulate a synthetic aperture that would be generated from an airborne SAR system. The purpose of this experimental system is to develop the technology underpinnings to support the identification of the operational parameters required for a fieldable UWB SAR system (e.g., power, signal processing, imaging, ATR algorithms, and operational requirements). The BoomSAR design philosophy allows for the generation of two-dimensional (2D) apertures. A 2D aperture, with very accurate motion compensation information, allows the formation of 3D images that may be an important asset in subsurface target detection. Models and data collections have shown subsurface target detection to be limited by surface clutter. Using resolution in the third dimension, surface clutter can be removed from deep-buried target responses. This attribute of 3D imaging may prove essential for the detection, location, and identification of small subsurface targets.

The BoomSAR initial data collection was August 1995 at Aberdeen Proving Ground (APG), MD, where a deciduous forest of varying density was available for deployment of canonical and tactical targets hidden in treelines for FOPEN studies. Following the APG test, a desert experiment was conducted at Yuma Proving Ground (YPG), Arizona. In addition to the canonical and tactical targets used at APG, other targets were selected and placed for a study of the ground-target-clutter interaction. The data set from these tests is currently being used for phenomenological studies of the electromagnetic properties of the targets and clutter.

2.1 UWB SAR SYSTEM DESCRIPTION

The objectives of the UWB SAR testbeds are to obtain UWB radar phenomenology of targets, clutter, and targets in clutter (foliage and subsurface). The system requirements for the BoomSAR system are driven by the need to collect high-resolution, fully polarimetric data with the radar's UWB waveform, and the need to develop images from the measured data. Currently, an impulse waveform is being used to generate the UWB signal. These impulses have a spectral response extending from 60 MHz to over 1 GHz.

A flexible design approach was used to allow for easy variation of the radar parameters for a more complete system characterization. A conscious decision was made to use as much commercial-off-the-shelf (COTS) technology as possible, so as to ease the transition of the technology from the laboratory to an airborne system. COTS technology also has the advantage of making the system more affordable for future fielding.⁵ The UWB SAR consists of several major subsystems, which are modular in nature to allow for ease of exchange and the evaluation of alternative approaches. The testbed radar subsystems consist of the antenna, the transmitter, the analog-to-digital (A/D) converter, the processor/data storage system, the timing and control assembly, the positioning subsystem, and the operator interface computer. Much of the system operation is controlled by software and firmware, allowing for a relatively simple path for modification or upgrade.

All the subsystems were selected or designed specifically for a low-frequency UWB SAR application. For instance, the ARL-designed transverse electromagnetic (TEM) horn antennas have a wide beamwidth in

excess of 90° and a bandwidth of 40 MHz to 3 GHz and are fitted with a high-power feed capable of handling the 2-MW peak pulse of the impulse transmitter.

A major consideration in going from a the previous 2D RailSAR system to the BoomSAR was the motion compensation/positioning system of the radar in three space. The BoomSAR Motion Compensation (MOCOMP) system includes a computer and a geodimeter. The Geodimeter 4000 system used in this application consists of a robotic laser-ranging theodolite, a retro-reflector, and a control unit. The theodolite is set up at one end of the aperture. The retro-reflector is mounted on the boom-lift platform near the radar antennas, and aimed to be visible from the theodolite over the aperture. The theodolite tracks the retro-reflector's horizontal and vertical angular positions and measures its range. The retro-reflector's 3D position is transmitted to the geodimeter control unit via an FM radio link updated at a rate of 2.5 Hz. Based on the data collection rates and the motion of the boom over the data collection period, this update rate has been shown to be effective for motion compensation of radar movement. The geodimeter control unit is mounted on the boom lift at the lower control station and transmits the position information to the MOCOMP computer.

The post-collection processing is done in the field immediately after data collection to verify data quality. A VME card-cage with a Sun SPARC 5 host is used to provide the computational power required to form the SAR image. Currently there are eight Intel i860-based CSPI Supercard array processors in the system. Range profiles are presumed, filtered, and back-projected to form the SAR image. In the future, other processing filters such as radio frequency interference may be available in the field.

2.2 BOOM DESCRIPTION

The boom lift platform for the UWB SAR was built by JLG Inc. It is a 150- ft-high telescoping device with several degrees of freedom (Figure 1) It has the unique capability of being able to move while fully extended, with a 500 to 1000 lb. load capacity (depending on the position of the telescoping arms).

The BoomSAR has several features that differ from the original rail mounted SAR. These features include the obvious mobility advantage for travel to areas of differing soil/clutter environments; the ability to move while elevated to generate extended strip maps greater than 100 m; the telescoping arms to allow generation of 2D apertures for 3D image formation; and the ability to collect data at different depression angles and collect data at similar geometries, as may be seen by an airborne system.

The BoomSAR is thought of as the departure point for an airborne UWB radar design. As noted previously, the collection geometries are similar to those of an airborne system. Also like an airborne system, the BoomSAR presents several other issues: processing and storage of extended strip map data, motion compensation, and system size and weight limitations. Thus, the BoomSAR allows us to evaluate most of the issues associated with an airborne system, but in a more precisely controlled, repeatable environment. For instance, we can generate a number of 2D apertures to evaluate the collection geometry of a 2D array that would be needed for adequate 3D image formation and effective target clutter discrimination. Once the required 2D array is defined, we can then determine and evaluate the necessary flight path and motion compensation requirements to achieve the specified 2D aperture.⁶

3. APG DATA COLLECTION

Aberdeen Proving Ground was selected for the FOPEN test site for a variety of reasons. The identified test site contained a variety of clear, foliated, and partially foliated areas for the radar to image. In addition, the Perryman Test Site at APG was designed as a vehicle driving range with straight and curved roads with multiple surface conditions. This made vehicle and target placements more easily accessible. The vehicle

driving range also carved paths through dense foliage where vehicles could be placed in multiple hide and partial hide scenarios. The three-mile straightaway is a wide paved road that can accommodate the wide wheelbase of the boom lift. This test site also had areas where smaller targets could be buried for GPEN studies.

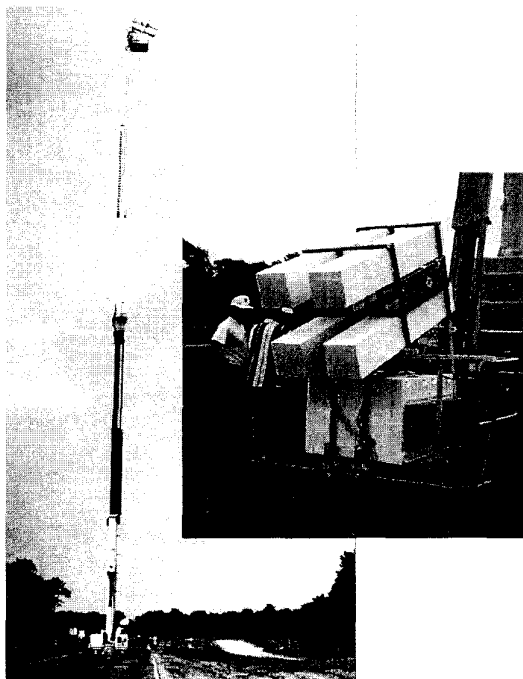


Figure 1, Boom Mounted Ultra Wideband Synthetic Aperture Radar.

Canonical targets such as dipoles, trihedrals, and dihedrals were arranged so that radar calibration as well as radar performance could be assessed across the radar image. Tactical vehicle targets, mostly commercial utility cargo vehicles (CUCVs) and high-mobility multi-purpose wheeled vehicles (HMMWVs), were set out at 15° increments in aspect angle throughout the scene imaged by the radar. Both canonical and tactical targets were placed in the clear, in layover, and within foliage. Figure 2, shows a map of the Perryman highway test range with a representative view of targets.

Early analysis shows exceptional radar imagery when the radar was autofocused to trihedrals in the target scene. In Figure 3, the data demonstrate a 5-in range resolution.

4. YPG DATA COLLECTION

Yuma Proving Ground was selected for GPEN studies. YPG, which has test support facilities and personnel that could support our test, identified a test site adjacent to the Phillips Drop Zone, which would be permanently called the Steel Crater Test Site. The soil at the site has relatively low conductivity (0.1 to 8.4 dS/m). A complete soil characterization was conducted by the University of Florida before target placement.⁷ Half the site includes part of the dropzone, which had been plowed to a depth of 48 in, insuring a vertically homogeneous soil distribution for phenomenology tests. The plowed section of the test site holds mines and mine simulants, wires, pipes, and barrels buried at various depths, while the natural area is used predominantly for tactical targets, although there are also mines, wires, and pipes placed within the

natural clutter area. We considered likely operational deployments when choosing target placements. For instance, the mines and mine simulants are on the surface, flush buried, and buried 6 in. For anti-personnel mines, trip wires were strung between the mines and rows. The multiple-gage wires and multiple-diameter pipes at various depths, as well as buried 55-gallon drums, are representative of military targets and other environmental or commercial interests.

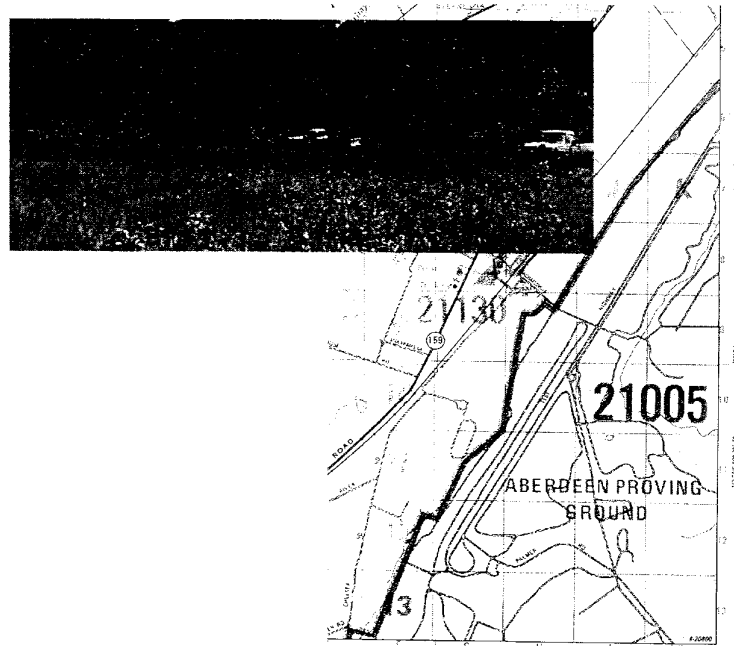


Figure 2, Test Site at Aberdeen Proving Ground, MD, Location Map and Sample Target Photo.

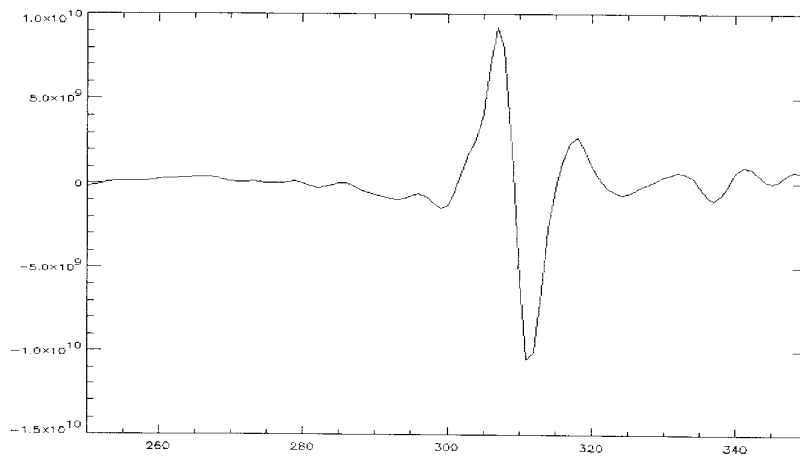


Figure 3, Down Range Plot of 2 ft Trihedral.

As at APG, canonical targets such as dipoles, trihedrals, and dihedrals were arranged so that radar calibration as well as radar performance could be assessed across the radar image. Tactical targets were placed so that the data contained multiple views of each target in various ground clutter arrangements. Figure 4 shows an aerial view of the Yuma data collection area and a sample of the mines that were used in the mine area.



Figure 4, Yuma Proving Ground Data Collection, January 1996.

Like the APG data, the YPG early data shows exceptional radar sensitivity, according to our early analysis. At a 25° depression angle and approximately 60 m in range, 12-in. diameter anti-tank mines buried to a depth of 6-in. are visible in -80 dB dynamic range imagery. After the images were cleaned of radio frequency interference, 4-in. diameter Valmara mines were also clearly visible in the -80 dB imagery.

5. SUMMARY/CONCLUSION

ARL has demonstrated the ability to collect high-quality repeatable UWB SAR data using the BoomSAR. Imagery shows resolutions of 5-in. in range. These fully polarimetric data support the development of automatic target detection and identification algorithm. The BoomSAR design is flexible for future upgrades to enhance FOPEN or GPEN performance.

¹ V. Sabio, "Resonance-Based Target Recognition Study," SPIE International Symposium, April 1995.

² J. W. McCorkle, "Early Results from the Army Research Laboratory Ultra-Wide-Bandwidth Foliage Penetration SAR," SPIE International Symposium, April 1993.

³ M. Mirkin, S. Ayasli, K. Kappra, K. Sturgess, "Results of the June 1993 Yuma GPEN Experiment Using SARs," IEEE Radar '95 Conference, May 1995.

⁴ T. O. Grosch, "Ground Penetration Radar Technology Review", Lincoln Laboratory Project Report, GPR-1, 1994.

⁵ A. McAuliffe, "Military R&D Labs Redefine Themselves for COTS Era," Military & Aerospace Electronics, Aug. 95, Vol. 8, No. 6, pp. 8-12.

⁶ K. Kappra, M. Ressler, J. McCorkle, J. Sichina, A. Bencivenga, and G. Pace, "Low-Frequency Ultra-Wideband Foliage and Ground Penetration Radar Systems," Tri-Service Radar Symposium, June 1995

⁷ M. Collins, R. Kuehl, D. Heuberger, J. Kurtz, Soil Properties at the Yuma Proving Grounds as Related to Ground-Penetrating Radar, University of Florida Report, Gainesville, FL, Dec. 95.