Document Title: Through-the-Wall Sensors (TTWS) for Law Enforcement: Test & Evaluation (Version 1.2)

Author(s): Chad Huffman, Ph.D., Jon Hayes, Lars Ericson, Ph.D.

Document No.: 245944

Date Received: April 2014

Award Number: 2010-IJ-CX-K024

Through-the-Wall Sensors (TTWS) for Law Enforcement: Test & Evaluation

(Version 1.2)

DOJ Office of Justice Programs
National Institute of Justice
Sensor, Surveillance, and Biometric Technologies (SSBT) Center of Excellence (CoE)

March 18, 2014

Prepared by

ManTech Advanced Systems International
1000 Technology Drive, Suite 3310
Fairmont, West Virginia 26554
Telephone: (304) 368-4120
Fax: (304) 366-8096

Dr. Chad Huffman, Senior Scientist

Jon Hayes, Lead Engineer

Dr. Lars Ericson, Director

UNCLASSIFIED

This project was supported by Award No. 2010-IJ-CX-K024, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

First responders require a high level of situational awareness to perform their duties in a safe and effective manner during emergency and tactical operations. Unknown individuals hidden from view can slow emergency efforts and can increase the inherent dangers of tactical operations. The ability to sense the presence of individuals behind visually obscuring barriers has been identified as a technology need by the National Institute of Justice (NIJ) Sensors and Surveillance (SSBT) Technology Working Group (TWG). This technology may improve situational awareness during emergencies and law enforcement activities such as after a building collapse, during fires in large buildings, and during tactical operations (e.g., building clearance, hostage threat situations). Currently, there are commercial Through-The-Wall Sensors (TTWS) that are available to law enforcement, emergency rescue and firefighting organizations. NIJ has also sponsored the development of a TTWS prototype with standoff (SO) detection capabilities.

This report discusses the test and evaluation (T&E) efforts that the SSBT Center of Excellence (CoE) performed on commercially available TTWS, and evaluates the performance of an NIJ sponsored prototype TTWS. A description of each device that underwent T&E as well as a description of operational factors that may affect the usability of each device is provided. The results of the T&E activities as well as descriptions of the T&E activities are also provided so interested parties can take into consideration the relevancy of any particular test or set of tests in comparison to their organizations specific needs and intended end use.

Four devices were investigated by the CoE. Three of the devices are commercially available and one is a late-stage prototype funded by NIJ. The four devices examined by this report are:

- Range-R by L-3 Communications
- Xaver 100 by Camero-Tech Ltd.
- Xaver 400 by Camero-Tech Ltd.
- AKELA Standoff Through-wall Imaging Radar (ASTIR) by AKELA (NIJ prototype)

These devices were tested and evaluated based on performance and usability. The usability of each device was examined in the context of storage, transportation, ease of operation, and handling. Performance testing was done with each device against several common structural barriers:

- Cinder blocks
- Office Cubicle material
- Glass
- Drywall (Gypsum board)
- Exterior walls with vinyl siding
- Exterior walls with brick
- Exterior walls with wood siding

One of the main delineations between the devices is whether a specific device is best utilized by placing the device directly against a barrier [i.e., Against The Wall (ATW)] or by setting the device up at a distance from the barrier (i.e., SO). The ASTIR is the only dedicated SO device that was investigated. The Xaver 400 is designed to operate in both ATW and SO scenarios, while the Xaver 100 and the Range-R are best used as ATW devices. ATW operation is typically faster than SO because ATW operation uses the barrier to stabilize the device; SO operations require the device to be mounted to a stable surface before measurements can be obtained. However, SO operation has the advantage of being able to operate the device at safer distances, and possibly with the operator working remotely.

Overall each device showed strengths and weaknesses in different areas of evaluation. The Range-R and the Xaver 100 were the smallest and easiest to handle during storage, transport, and use. During ATW tests, the Xaver 400 was superior at target detection, while the ASTIR was superior during SO operation. The overall percent detection of each device over their respective set of tests (ATW or SO) is given in the tables below.

Table 1: ATW Overall Percent Detection

Characteristic	Range-R	Xaver 100	Xaver 400
Total number of measurements attempted	226	229	226
Percent Detection	74%	62%	93%
Detection time (Seconds) ± Average Deviation	13 ± 7	10 ± 6	8 ± 4
Average Distance Uncertainty	-1% ± 11%	-15% ± 23%	+3% ± 8%

Table 2: SO Overall Percent Detection

	ASTIR	Xaver 400 Overall	X400 Tracker Mode	X400 Expert Mode	X400 HP Mode
Total number of measurements attempted	103	150	50	50	50
Percent Detection	68%	47%	56%	66%	18%
Detection time (Seconds) ± Average Deviation	14 ± 8	9 ± 5	9 ± 6	9 ± 4	12 ± 7
Average Distance Uncertainty	-11% ± 19%	-8% ± 11%	-13% ± 15%	-4% ± 5%	-13% ± 12%

It is important for an organization that is considering obtaining one of these devices to evaluate the capabilities of the devices in the framework of the intended use. For example, the requirements for a law enforcement officer serving warrants at a place of residence would be expected to be quite different than the requirements for officers that are attempting to resolve a standoff or hostage situation with armed suspects.

Some key observations and conclusions are as follows:

- Larger devices tend to have more antennas and better signal processing capabilities, both of which improve detecting and locating targets.
- Smaller devices are more easily stored, transported, and used with a minimum of encumbrance to the operator.
- The Xaver 400 had the best overall percent detection of the ATW devices, but is the largest and heaviest of the ATW devices. The Range-R and the Xaver 100 are more easily stored, transported, and handled.
- The ASTIR had the best overall percent detection of the SO devices tested.
- The ASTIR is a prototype device, and is the largest and most encumbering of the devices tested.
- Each device has strengths and weaknesses between detection, operation, and supporting activities (such as repositioning the device at the scene).

This report leverages the findings of an earlier SSBT CoE report, *Though-the-Wall Sensors (TTWS) for Law Enforcement: Market Survey*, which was published in October of 2012 (https://justnet.org/pdf/00-WallSensorReport-508.pdf). A companion report *(Through-the-Wall Sensors (TTWS) for Law Enforcement: Best Practices),* which is scheduled for publication in early 2014, discusses some of the best practices learned through testing the available TTWS in relevant settings.

2.0 INTRODUCTION

First responders require a high level of situational awareness to perform their duties in a safe and effective manner during emergency and tactical operations. Unknown individuals hidden from view can slow emergency efforts and can increase the inherent dangers of tactical operations. The ability to sense the presence of individuals behind visually obscuring barriers has been identified as a technology need by the NIJ-sponsored SSBT TWG. This technology may improve situational awareness during emergencies and law enforcement activities such as after a building collapse, during fires in large buildings, and during tactical operations (e.g., building clearance, hostage threat situations). Currently, there are commercial TTWS that are available to law enforcement, emergency rescue and firefighting organizations. NIJ has also sponsored the development of a TTWS prototype with SO detection capabilities.

TTWS vary in their capabilities, the information they provide, and their complexity. Compact and easily transportable devices tend to provide a minimal amount of information, but this is balanced with their ease of use and transportability. Larger devices may provide additional information, but at the expense of being more cumbersome and therefore more difficult to manage and position during operational use. The utility of any one device is dependent on the capabilities of that device and the requirements of the situations where the device is utilized. Therefore, before obtaining one of these devices, it's crucial that an organization make an effort to balance the capabilities of a device with the requirements of the situations where the device would most likely be utilized by a particular organization.

2.1 About the SSBT CoE

The NIJ SSBT CoE is a center within the National Law Enforcement and Corrections Technology Center (NLECTC) System. The Center provides scientific and technical support to NIJ's research and development (R&D) efforts. The Center also provides technology assistance, information, and support to criminal justice agencies. The Center supports the sensor and surveillance portfolio and biometrics portfolio. The CoEs are the authoritative resource within the NLECTC System for both practitioners and developers in their technology area(s) of focus. The primary role of the CoEs is to assist in the transition of law enforcement technology from the laboratory into practice by first adopters.

2.2 Purpose of Report

This report discusses the test and evaluation (T&E) efforts that the SSBT CoE performed on commercially available TTWS, and evaluates the performance of an NIJ sponsored prototype TTWS. A description of each device that underwent T&E as well as a description of operational factors that may affect the usability of each device is provided. The results of the T&E activities as well as descriptions of the T&E activities are also provided so interested parties can take into consideration the relevancy of any particular test or set of tests in comparison to their organizations specific needs and intended end use.

This report leverages the findings of an earlier SSBT CoE report, *Though-the-Wall Sensors (TTWS) for Law Enforcement: Market Survey*, which was published in October of 2012 (https://justnet.org/pdf/00-WallSensorReport-508.pdf). A companion report *(Through-the-Wall*

Sensors (TTWS) for Law Enforcement: Best Practices), which is scheduled for publication in early 2014, discusses some of the best practices learned through testing the available TTWS in relevant settings.

2.3 Technology Background

TTWS operate by emitting radio waves and detecting the signal that is reflected off objects. The signal can also be used to determine the distance (or range) of an object and are therefore considered to be RAdio Detection And Ranging devices (RADAR). Because they use radio waves, the use of these small RADAR units falls under the governance of the Federal Communications Commission (FCC).

To detect the presence of an object, a TTWS device sends out an electromagnetic signal (i.e.., radio waves). The signal propagates from the device and is then reflected by an object. Part of the reflected signal then travels to a receiver that detects the reflected signal. The receiver is typically (although not necessarily) in the same device as the transmission source. The reflected signal then indicates the presence of an object; the strength of the reflected signal may indicate the proximity and/or how reflective the object is (i.e., size, material composition). With advanced signal formation (e.g., pulses) and signal processing methodologies, the operator can deduce other qualities of the target such as the range to the target and whether the target is stationary or moving.

To sense an object on the other side of a wall, the TTWS signal must be able to penetrate through the wall, reflect off an object, travel back through the wall and finally reach the receiver. How easily the TTWS detects an object depends on the amount of signal returned to the receiver. This in turn depends on how much signal the object reflects and how well the signal passes through barriers (e.g., walls) between the object and the TTWS device. Loss of signal due to barriers is known as *attenuation,* and the amount of attenuation depends on the properties of the barrier materials and the thickness of the materials. Figure 1: Attenuation properties of common building materials shows the attenuation properties of several common building materials at different frequencies.

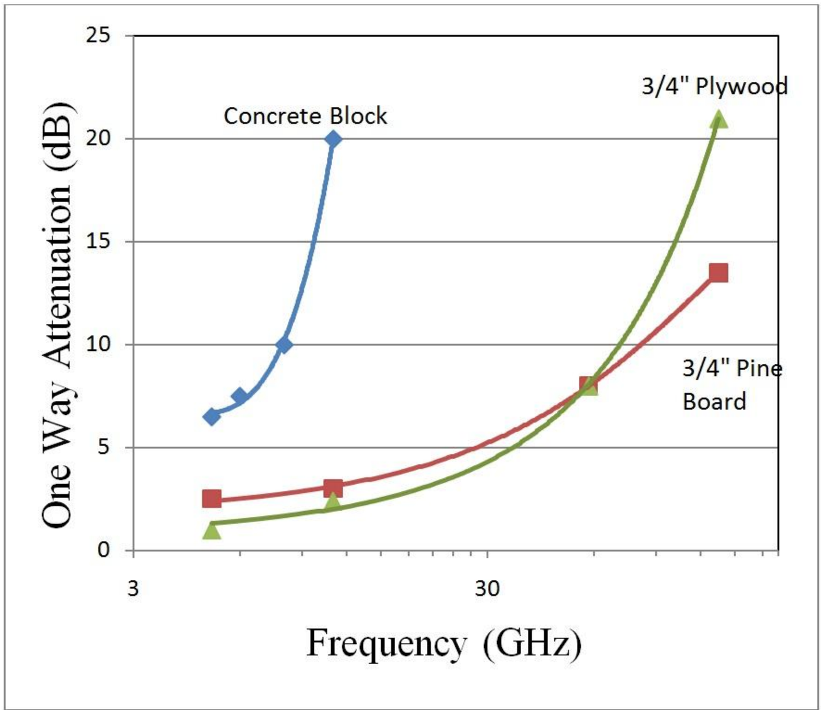

Figure 1: Attenuation properties of common building materials
A subset of data from an SPIE reference.[1]

From Figure 1: Attenuation properties of common building materials, it can be seen that lower frequencies (i.e., longer wavelengths) tend to penetrate barriers better than higher frequencies (i.e., shorter wavelengths), but there is a tradeoff. It is more difficult to detect slight changes in frequencies due to Doppler effects in longer wavelengths than it is for shorter wavelengths. Also, shorter wavelengths can provide better location data than longer wavelengths. In addition, it is possible that a barrier may attenuate a small range of wavelengths (a band) much more strongly than surrounding wavelengths. Note that in the above figure there are only three or four data points for each material and a curve has been fitted to include the points. This may mask highly attenuating areas in between data points. In addition, the composition of building materials may vary significantly from manufacturer to manufacturer. The use of a wide range of frequencies for the signal will help to "probe" the frequency spectrum so that the device uses the best tradeoff of penetration to detection/localization. This can be accomplished by either changing the frequency of the signal (i.e., using a "frequency sweep,") or by using a *wide band* signal that inherently contains a wide range of frequencies.

A simplistic device would continuously emit radio waves of a single frequency and would be able to detect any changes in the strength of the reflected signal. For instance, a device may be situated near a wall in an effort to detect if someone walks by on the other side of the wall. If the TTWS uses a frequency that penetrates the wall and reflects off a target, then when a target approaches the device, the TTWS receives more and more reflected signal. An increase of the reflected signal above a predetermined threshold could then trigger an alarm of some kind (e.g., audible, visual, recording device,). While it may be able to detect the larger movements of people on the other side of a wall, this simplistic device would not be able to accurately determine the distance to the reflective target. Also, small movements may not be able to be detected by changes in the reflective intensity. More advanced methods and technologies can be used to determine the distance to the reflecting object and to detect small movements such as chest expansion and contraction during breathing.

Although signal strength may be used to indicate relative distance from the transceiver, a much more accurate technique is to use pulsed methods. In this method, a *pulsed signal* travels toward an object, is reflected and returns to the receiver at the same speed. Since the pulse speed is known, the amount of time required for the pulse to make the round trip depends on the distance of the object from the transmitter/receiver. A pulsed system determines the distance to an object by measuring the time difference between transmission and reception of a pulse.

Higher sensitivity to movement is accomplished by the use of Doppler radar techniques. Doppler radar takes advantage of the fact that a reflected signal from a moving object will have a slightly different frequency than the initial signal sent out by the transmitter, whereas signals reflected from stationary objects will have the same frequency as the initial signal. The use of Doppler techniques allows for the detection of small amounts of movement, such as the movement of a chest cavity during breathing.

Combining Doppler effects with pulsed systems can allow a system to detect small amounts of movement and to determine the distance of an object from the transmitter/receiver. In addition to using a combination of the above techniques, the use of a technology known as *ultra-wide band (UWB) radar* has several advantages over conventional techniques, including better penetration properties, better range determination and decreased signal detection by second/third parties. Commercially available products use UWB, Doppler and/or pulse technologies to gather as much information as possible.

Because TTWS use the emission and reception of radio waves for detection, TTWS devices have an inherent technology limitation: solid metal surfaces, such as aluminum siding, will block radar signals. The device will not be able to detect movement beyond these barriers. Even metal used in construction, such as rebar or “chicken” wire used on walls to hold plaster in place, sometimes present confusing or erratic results, requiring multiple measurements or a repositioning of the device.

Device performance is complex and depends on both system design and the composition of the environment. System factors include antenna design, system integration, signal processing algorithms, and operator interface. Environmental factors include intervening barriers (materials, construction), structural architecture, and outdoor objects.

Antenna design, size, and number of antennas affect characteristics of the emitted signal and how well the reflected signal is received. The shape, design, and size of an antenna affect emission strength and directionality as well as how well the reflected signal is received. Increasing the size and number of antennas can increase directionality and reception, make triangulation calculations more accurate, and improve the sensitivity of identification algorithms. However more and larger antennas require the device itself to be larger and more difficult to carry, manage, and operate. It is important that the device/operator interface be well designed so that using the device requires as little thought and attention as possible while still conveying pertinent information to the operator in an easily understandable way.

Environmental considerations also affect the performance of the devices. The barriers themselves may be constructed of different materials that have varying abilities to transmit the signals, structural components within the barriers (e.g., supports, duct work) may block or reflect the signal. Components within the structure may reflect the signal in unpredicted ways (e.g., adjacent walls, file cabinets, and mirrors may cause multiple reflections). Small animals, oscillating fans, and trees moving in the breeze may cause unforeseen signal reflections and potential detections.

2.4 FCC and Commercially Available Devices

Since TTWS transmit radio waves during operation, the FCC governs the use of these devices. Operation is limited to certified TTWS equipment, and only by law enforcement and first responder agencies. All the tested devices have been tested and certified in compliance with applicable FCC regulations for operation in the United States. Since the Center is not directly involved with law enforcement or first responder activities or operations, the Center obtained a Special Temporary Authority license from the FCC in order to operate the devices for T&E purposes.

2.5 Disclaimers

1. This project was supported by Award No. 2010-IJ-CX-K024, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice (DOJ). The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

2. Commercial products included herein do not constitute an endorsement by NIJ, DOJ, or ManTech. NIJ, DOJ, and ManTech assume no liability for any use of publication content. This publication is a reference for educational purposes only. Please carefully consider the particular needs/requirements of your agency and any applicable laws before developing policies or procedures governing the use of any technology.

3. All legal aspects regarding expectation of privacy issues, probable cause, warrants, and any other operational law enforcement procedures should be researched by agencies and their officers in accordance with local, state, and federal laws prior to the implementation of technology described herein.

4. Organizations and individuals should seek legal counsel before operating through-the-wall systems. These devices are subject to FCC regulations under Title 47, Parts 15 and 90 of the Code of Federal Regulations (CFR).

3.0 SUMMARY OF TESTING

TTWS tests were performed by the SSBT CoE from October 2012 to October 2013. A summary of test devices, sites, and variables is included here as a quick reference and introduction. A detailed discussion of the test procedures, devices, and test results follows in later sections.

3.1 Devices

All FCC-certified TTWS devices currently commercially available in the U.S. were included in the T&E:

- Range-R by L-3 Communications – FCC-Certified, Commercially Available
- Xaver 100 by Camero-Tech Ltd.– FCC-Certified, Pre-Production Model
- Xaver 400 by Camero-Tech Ltd.– FCC-Certified, Commercially Available
- AKELA Standoff Through-wall Imaging Radar (ASTIR) by AKELA – Not Certified, Late Stage Prototype funded by NIJ.
    - Note: Halfway through T&E, AKELA received FCC certification of ASTIR[2]

3.2 Sites

Test site locations were chosen based on availability, proximity to the SSBT CoE, and a mixture of commercial and residential construction layouts reflective of real-world environments encountered by law enforcement.

- Camp Dawson Urban Training Range (Kingwood, WV) – Simple two-story block buildings
- Alan B. Mollohan Innovation Center (Fairmont, WV) – Modern, steel frame, office building with traditional layout
- Robert H. Mollohan Research Center (Fairmont, WV) – Modern steel frame office building with open layout
- Residential House (Fairmont, WV) – Two-story mid-large sized residential house

3.3 Variables

Tests were performed to investigate the performance of TTWS devices across key environmental, target, and operator variables. Due to resource, logistics, and schedule some variables originally outlined in the test plan were not explicitly investigated.

- **Barrier Composition**
  - **Exterior Walls** – Brick, Block, Vinyl siding, Wood siding, Glass
  - **Interior Walls** – Gypsum board, Cubicle walls
  - **Wall Structure** – Metal studs, Wood studs, Fiberglass insulation, Plywood
  - **No Walls**
- **Target Environment**
  - **Clean Area** – Single penetrating wall
  - **Cluttered Area** – Unobstructed, Partially obstructed, Fully obstructed
  - **Clean Area** – Multiple penetrating walls
- **Target**
  - **Movement** – Standing, Walking perpendicular, Walking parallel, Walking on an arc
  - **Target Position** – Distance, Angle
  - **Target Orientation** – Facing towards, Sideways, Facing away, Sitting, Lying down
- **Device Position** – ATW, SO
- **Multiple Targets**
- **Usability**
  - **Physical Properties**
  - **Deployment Metrics**
  - **Operational Properties**
  - **Device Status**
  - **Miscellaneous**

The following variables were not explicitly tested, but qualitative observations are included later in the report.

- **Target Environment**
  - Aluminum foil wall/window covering
  - Oscillating fan(s)
- **Electronic Interference to TTWS**
- **Electronic Interference from TTWS**

4.0 DEVICES TESTED

The Center tested all FCC-certified TTWS devices that were commercially available in October 2012. The market survey identified three commercial devices available for use in the U.S. These devices were obtained by the Center through either direct purchase or loan from the manufacturers for the purposes of this evaluation. In the event that some devices were overlooked during the market survey, an RFI notice was put out in the Federal Register (https://federalregister.gov/a/2012-23873).[3] There was only one response to the notice, and that vendor was already included in the test plans.

The SSBT CoE tested four (4) TTWS devices. The devices consisted of three FCC-certified, commercially available devices and one late stage prototype funded by NIJ:

- Range-R by L-3 Communications – FCC-Certified, Commercially Available
- Xaver 100 by Camero-Tech Ltd.– FCC-Certified, Pre-Production Model
- Xaver 400 by Camero-Tech Ltd.– FCC-Certified, Commercially Available
- AKELA Standoff Through-wall Imaging Radar (ASTIR) by AKELA – Not certified initially, but received certification midway through this effort, Late Stage Prototype (funded by NIJ).

Before testing the devices, Center personnel received training in the operation of each of the TTWS from the manufacturers or through their authorized distributors. During the testing phase, all devices were operated according to the manufacturer's instructions supplied with the device and obtained through training.

4.1 Range-R

The Range-R is a 1D handheld TTWS made by L-3 Communications CyTerra Corporation (FCCID: YKD-25TWD3000).[4] The Range-R uses a radar technology known as Stepped Frequency Continuous Wave (SFCW), which sweeps a range of frequencies instead of using only a single frequency. This method improves the probability that the signal will penetrate a barrier and still provide enough sensitivity to detect targets. The Range-R uses Doppler techniques to detect motion, even the slight motion associated with breathing. When the Range-R detects a moving object, the instrument displays a numerical value for the range of the detected object. The Range-R also indicates to the operator whether the detection was based on target movement or on breathing. Detection is within a 160-degree field of view and the Range-R can detect movement at 15.25 m (50 ft) without barriers. Like all TTWS, the detection range will decrease depending on the attenuation properties of any barrier between the target and the device. The Range-R costs approximately $6,000. A variant model, the Range-R Link, uses the same device, but adds a communication module for wireless control and monitoring.

4.2 Xaver 100 (Pre-Production Model)

The Xaver 100 (pronounced "Saver") is a 1D handheld TTWS made by Camero-Tech Ltd. and distributed in North America by Mistral Security, Inc. (FCCID: A42X100F).[5] The device tested (a pre-production model of the Xaver 100) was purchased on an "Early Adopter" program. The U.S. distributer, Mistral Security, ran this program to make pre-production units available to interested organizations; the buyer would receive the production model when it becomes available at a later date. The final production Xaver 100 is reported to retail for $9,000.[6]

Only the pre-production model was tested as the production model has not yet been received by the Center. According to Mistral Security, the pre-production and final devices were to differ only in external packaging and device orientation (horizontal vs. vertical). However, since the start of the testing activities, information on the final Xaver 100 has been made publically available, indicating additional differences. The production model literature indicates that it will able to detect targets out to a maximum distance of 20 m (~66 ft), whereas the pre-production model has a maximum range of 8 m (~26 ft). The increased range may indicate improvements and/or modifications in the target detection algorithms as well.

The Xaver series of TTWS uses Ultra Wide Band (UWB) pulse technology to sense through walls. The Xaver 100 is a 1D single-user handheld device. The field of view of the Xaver 100 is 120° and the device has an 8 m detection range (pre-production model). While it is possible to operate the instrument in stand-off mode by hand, it is best to have the device mounted to a stable mount (on a tripod, for instance) because even small movements by the operator can interfere with the operation of the device.

4.3 Xaver 400

The Xaver 400 is a 2D two-handed TTWS made by Camero-Tech Ltd. and distributed in North America by Mistral Security (FCCID: A42X400F).[7] Compared to the Xaver 100 (see Section 4.2 Xaver 100 (Pre-Production Model)), the Xaver 400 is a larger two-handed device that provides additional information, such as approximate direction (azimuth) and tracking, for user interpretation. The Xaver 400 can detect living as well as static objects within a maximum range of 20 m with a field of view of 120°. The Xaver 400 operates in three modes (Tracker, Expert and High Penetration) and has three maximum detection ranges (4 m (~13 ft), 8 m (~26 ft) and 20 m (~66 ft). Because it can detect static objects, the Xaver 400 can provide information about room dimensions and major infrastructure elements. Signal quality in cluttered environments is improved by the use of reconstruction algorithms. The device is available from the U.S. distributer, Mistral Security, at a price of approximately $47,500.

4.4 ASTIR

The ASTIR is a portable TTWS device currently being developed by AKELA under NIJ R&D funding (FCCID: ZZM-ASTIR3300). The prototype device, the size of a small suitcase, is mounted on a tripod or other stable surface during operation. ASTIR uses an array of four antennas to gather location data and detect motion. It operates by scanning between 3,101 – 3,499 MHz with a maximum output power of 50 mW (1 dB antenna gain mid band).[8] The ASTIR operating range is 70 m (~230 ft) (includes up to 30 m (~98 ft) SO distance). The ASTIR detects moving and stationary objects with enough sensitivity to detect motion associated with breathing.[9] The ASTIR has a nominal viewing angle of ±22° from directly in front of the device; although detection outside of this range is possible, the detection will be severely degraded.

5.0 USABILITY ASSESSMENT

How easily the device can be operated, transported, and deployed can be just as important as how well a device performs. These factors influence the decision to utilize a device in particular situations and not in others, and should be taken into account when an organization is considering obtaining a TTWS. Usability factors reviewed were:

Table 3: Usability Assessment Factors

Attribute	Value
Physical Properties	
Form Factor	Intended use as an onsite portable device or a fixed device
Weight	Approximate weight of the device and associated accessories
Deployment Metrics	
Set-up Time	Approximate time required to get the device operational from a “stored” state
Power-up Complexity	Amount of button/software manipulations required to get the device operational once it has been removed from the cases and physically set up
Hands to Operate	Number of hands to hold, activate, and operate
Battery Life	Amount of time the device can be operated with a single set of fresh batteries
Operational Properties	
Instrument Capabilities	
Detection Range	Maximum target detection range
Display Map	How the device displays information
Multiple Target Detection	Whether the device is able to simultaneously detect more than one target
Data Display	
Level of Detail	Whether the display is 1D or 2D; whether the display indicates target range and movement
Ease of Interpretation	How difficult it would be for an operator to translate the displayed information into real world meaning
Screen Readability (in Sunlight)	Ease of visually observing the display in sunlight
Device Status	
Fault / Error Reporting	Presence of fault/error reporting and the level of detail to help the operator correct the error.
Indication of Signal Strength	Direct indication of the strength of the reflected signal
Battery Status Indicator	Display information about the state of charge of the battery
Miscellaneous	
Remote Viewing	Whether the data reported by the device is able to be remotely viewed on a secondary device or computer

Attribute	Value
Remote Control	Whether measurements are able to be started/stopped from a distance away (typically by the use of a secondary monitoring/control device)
IP Addressable	Whether the device is able to communicate with other devices through IP
Record Session	Whether the device has the ability to store data. Data may be stored either on the device or on a remote device

Each device was qualitatively assessed based on portability and handing, storage and transportation, power requirements, ease of power-up and operation, information display, and multiple target detection. Portability and handling referred to how easily the device was able to be moved during operation in order to locate or relocate the device for optimal placement. Storage and transportation referred to the physical storage space required, how well the device is protected during storage, and the relative ease of transporting the device from storage to the site where the device is needed. Power requirements were assessed on the ease of power maintenance and battery replacement. Ease of power-up and device operation referred to the amount of manipulation required to bring the device from a power off state to a ready state. Information display referred to how the information was presented to the operator, how easily the information was interpreted, and how well the display was able to be read in various lighting conditions (especially in bright sunlight). Assessment of multiple target detection was based on the whether the device had the ability to simultaneously report the detection of more than one target to the operator.

5.1 Range-R

Table 4: Range-R Usability Assessment Summary

Attribute	Value
Physical Properties	
Form Factor	Handheld
Weight	1.2 lbs
Deployment Metrics	
Set-up Time	5 seconds
Power-up Complexity	Low – Two buttons required to power up
Hands to Operate	One
Battery Life	400 uses (~ 4 hours)
Operational Properties	
Instrument Capabilities	
Detection Range	15.25 m
Display Map	1D
Multiple Target Detection	No
Data Display	
Level of Detail	Range/Still/Moving
Ease of Interpretation	Easy
Screen Readability (in Sunlight)	Easy
Device Status	
Fault / Error Reporting	Yes – Red LED to indicate faults
Indication of Signal Strength	No
Battery Status Indicator	Yes
Miscellaneous	
Remote Viewing	No (Range-R), Yes (Range-R Link)
Remote Control	No (Range-R), Yes (Range-R Link)
IP Addressable	No
Record Session	No

Figure 2: L-3 CyTerra Range-R
Photo by NLECTC SSBT CoE

5.1.1 Portability and Handling

The Range-R is easily transported by an individual from one location to another by hand carrying or even placing the device in a large pocket. The Range-R is not overly cumbersome when carried by one hand, however when holding the device, it feels that the hold on the device is not quite as stable as it could be. While it is doubtful that an operator would accidently drop the device during normal operation (in part because of stabilization against a barrier), it does feel that there is more than a slight chance that the operator may lose their grip on the device while hand carrying it from one location to another. This would be especially true if the operator had smaller hands, were moving quickly, or the device was accidently bumped against an object during hand carry transport.

Physically, the Range-R has a nice “heft” to the feel of the device and appears to be well ruggedized. The device appears to be capable of handling the typical wear and tear that might normally be expected when operated in the field.

5.1.2 Storage and Transportation

The device comes with a case for storage, which appears to be well suited for protecting the device against normal drops and bumps that may be encountered during storage or when relocating for deployment at a site of interest. With batteries stored in the device, the device can be removed from the case and be operational within a few seconds.

5.1.3 Power Requirements

Four (4) “AA” batteries are accessed and replaced by removal of a small knurled multi-turn knob at the bottom of the device. The knob is easily accessed, but might present some minor difficulty manipulating it with a thick gloved hand. The knurled knob releases a hinged cover at the base of the device exposing the batteries. Even with the hinged battery cover open, direct observation of the correct orientation of all the batteries is not possible without removal of the batteries.

5.1.4 Ease of Power-up and Device Operation

Operation of the device requires the concurrent depression and holding of two easily accessible buttons on either side of the device. This method of powering up and operating the device reduces the chances of accidental operation, but it can get tiring during extended use. Also, having to use the thumb to depress one of the buttons seems to add to the “unstable” feel of the device during operation.

5.1.5 Information Display

Information is shown on a green monochrome display that indicates whether a target has been detected or not. If a target has been detected, the device displays the numeric distance to the target and whether the detected target is believed to be moving or breathing. The brightness and contrast is sufficient to be viewable in a variety of lighting conditions and the display is able to be viewed from multiple angles.

Figure 3: Range-R Display Viewed in Direct Sunlight
Photo by NLECTC SSBT CoE

5.1.6 Multiple Target Detection

If there are multiple targets in an area, the Range-R will report the location of the single target that is providing the strongest reflection signal. However, if conditions change such that the weaker reflector becomes the stronger reflector, then the display will update to indicate the distance to the target that is now the stronger reflector. Thus during a reading, the display may alternate between multiple distances which would indicate that more than one target is present.

5.2 Xaver 100 (Pre-Production Model)

Table 5: Xaver 100 Usability Assessment Summary

Attribute	**Value**
Physical Properties	
Form Factor	Handheld
Weight	1.2 lbs
Deployment Metrics	
Set-up Time	3 seconds
Power-up Complexity	Low – Single button
Hands to Operate	One
Battery Life	3 hours
Operational Properties	
Instrument Capabilities	
Detection Range	8 m
Display Map	1D
Multiple Target Detection	Yes (High Penetration mode only)
Data Display	
Level of Detail	Range/Still/Moving
Ease of Interpretation	Moderate (Normal), Moderate (High Penetration)
Screen Readability (in Sunlight)	Easy
Device Status	
Fault / Error Reporting	Yes – Message on screen
Indication of Signal Strength	Yes – Total reflected strength / HP mode indication by colorimetric display
Battery Status Indicator	Yes
Miscellaneous	
Remote Viewing	Yes – With optional viewer
Remote Control	No
IP Addressable	No
Record Session	No

Figure 4: Xaver 100 (Pre-Production Version)
Photo courtesy of Camero-Tech Ltd.

5.2.1 Portability and Handling

The pre-production model of the Xaver 100 is easily transported by a single individual from one location to another by hand carrying or even by placing the device in a large pocket. The hold on the device feels solid and an operator would be unlikely to accidently drop the device under typical movement and operation.

The pre-production Xaver 100 does not have the "feel" and heft that would be expected from a fully ruggedized device, but does appear as if it would be able to handle a basic level of unintentional abuse. The production model reportedly has a different housing case and form factor. The production models may be more ruggedized than the pre-production model.

5.2.2 Storage and Transportation

For storage, the device has a small protective case that appears to be able to provide significant amount of protection from typical dropping and bumping. The case has a handle for easy transportation to and from different sites. If batteries are stored in the device, the device can be removed from the protective case and operational within a few seconds.

5.2.3 Power Requirements

Battery replacement requires four commercially available "AA" batteries. The battery compartment is easily accessible by a slide cover which is held in place with a single turn wing nut type fastener; although the fastener may be difficult to access and manipulate if thick gloves are being worn by the operator. Removal of the slide cover allows easy access to the battery compartment and battery insertion. Another benefit of the slide cover is that removal of the cover allows for quick observation of battery orientation without having to remove the batteries from their holder.

5.2.4 Ease of Power-up and Device Operation

Once in position, the device is powered up by a single button. Different options and modes are accessed by the use of the same button and the use of one additional button. The buttons are well placed and the device is able to be held in place and operated with one hand.

5.2.5 Information Display

Screen brightness and contrast allows for adequate viewing in a variety of lighting conditions and allows for wide angle viewing. Data presentation can be interpreted in the normal mode with minimal training or even informal operation. High Penetration mode may be considered more difficult to be interpreted, but this can be achieved with basic instruction or observation.

In the normal mode, the detection of a target is indicated by the display of a human stick figure icon on the screen along with a numerical distance measurement. The icon also indicates whether a target is believed to be moving or standing still. The direction of movement is also indicated by the icon. Normal mode only reports the strongest reflector identified as a target. The layout of the figure and its associated movement can be confusing because of its orientation in relation to the target. The display shows a left-right movement with left being closer to the operator and right farther away. However, when held against a wall the target movement will be perpendicular to what is shown. In other words, when the target moves away from the operator the display figure will move to the right. This difference in orientation confused practitioners observing its use on more than one occasion. This is likely the reason for the change in display shown in literature for the final production version of the Xaver 100.

Figure 5: Xaver 100 Pre-Production Model Normal Mode Display
Photo by NLECTC SSBT CoE

Figure 6: Xaver 100 Production Model Normal Mode Display
Courtesy of Camero-Tech Ltd.

5.2.6 Multiple Target Detection

The normal mode of the Xaver 100 does not display multiple targets. However, High Penetration mode does have the ability to display information which the operator can use to identify multiple targets. High Penetration mode shows the distance and relative strength of the reflected signal along a single vertical line. In High Penetration mode, the previous readings are visible with the latest measurements inserted to the right of the screen. As additional scans are inserted, this gives a "historical" view of the previous scans and their strongest reflections. This ability is valuable for operator determination of targets and is especially true of moving targets. In addition to a "historical" view, High Penetration mode can allow for the identification of multiple targets.

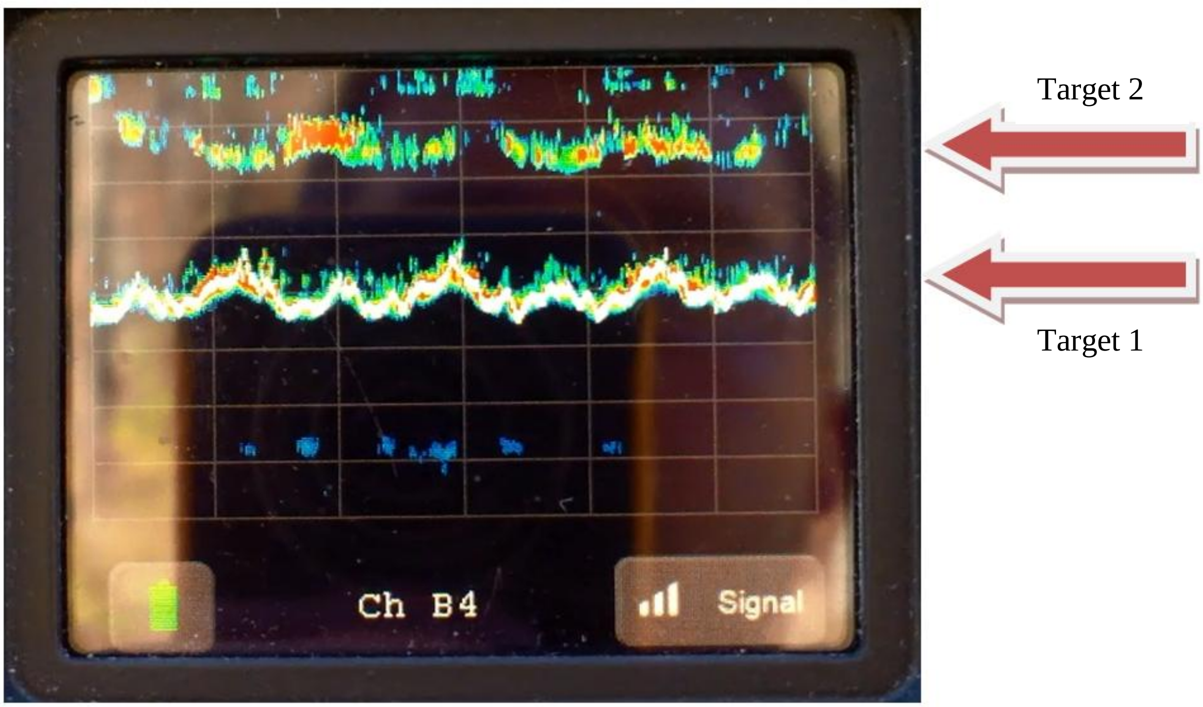

Figure 7: Xaver 100: Two moving targets observed in High Penetration mode
Both targets are walking perpendicular (side to side). Targets are indicated by the wavy lines between 3.5 m and 4.5 m, and between 6.0 m and 7.0 m. Each of the horizontal lines of the grey grid indicates 1.0 m; each vertical line indicates 5 seconds.
Photo by NLECTC SSBT CoE

5.3 Xaver 400

Table 6: Xaver 400 Usability Assessment Summary

Attribute	Value
Physical Properties	
Form Factor	Portable
Weight	7 lbs
Deployment Metrics	
Set-up Time	3 seconds
Power-up Complexity	Easy - Single button
Hands to Operate	Two
Battery Life	2.5 – 4.5, dependent on number of batteries installed
Operational Properties	
Instrument Capabilities	
Detection Range	20 m
Display Map	2D (Tracker and Expert modes only)
Multiple Target Detection	Yes
Data Display	
Level of Detail	Tracker and Expert modes 2D
Ease of Interpretation	Easy (Tracker), Moderate (Expert, High Penetration)
Screen Readability (in Sunlight)	Easy
Device Status	
Fault / Error Reporting	Yes – Screen message
Indication of Signal Strength	Yes – Total reflected strength/Expert and HP mode indication by colorimetric display
Battery Status Indicator	Yes
Miscellaneous	
Remote Viewing	Yes – With optionally viewer
Remote Control	No
IP Addressable	No
Record Session	No

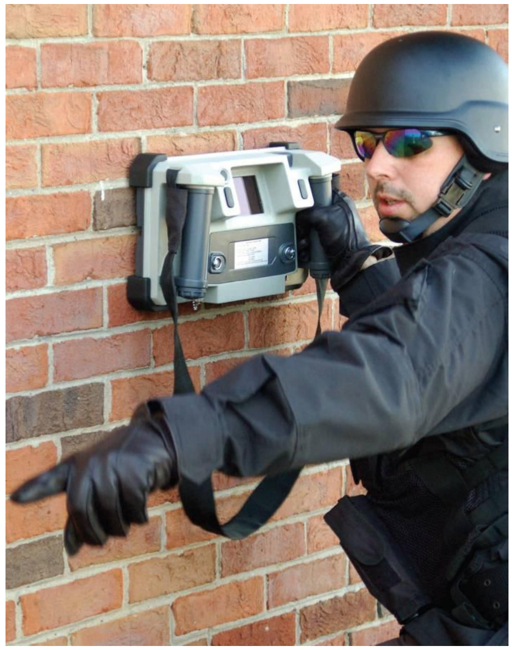

Figure 8: Xaver 400
Photo courtesy of Camero-Tech Ltd.

5.3.1 Portability and Handling

The Xaver 400 is transportable by an individual, although the bulk of the device may complicate movement through tight environments, especially with complex obstacles. The device has a neck strap that holds it at mid-torso height and is used to help protect the device from accidental dropping. Even without the strap, the handles of the device provide for a good solid grip on the device making it unlikely that the device would be accidently dropped.

The Xaver 400 appears to be a well constructed and rugged device. It appears that the device would be able to handle typical wear and tear that might be expected when used in the intended capacity.

For ATW operation, Xaver 400 has two handles used to hold in place against a barrier during operation (the handles also serve as auxiliary battery holders). While it is possible to operate the Xaver 400 with one hand, it is cumbersome and somewhat difficult to maintain in position for extended lengths of time with only one hand. The Xaver 400 is also capable of SO operation - it has a screw hole in the bottom for mounting to a tripod.

5.3.2 Storage and Transportation

A protective case supplied with the device appears to be protective enough to handle the drops and bumps that would be expected during normal handling, storage, and transportation to and from sites. The case also has cutouts for an extra rechargeable battery, the battery charger, and places to store the auxiliary (dry cell) batteries. With batteries installed, the device can be removed from the case and operational within a few seconds.

5.3.3 Power Requirements

Xaver 400 can be powered by rechargeable batteries or by non-rechargeable standard military grade cell batteries. The rechargeable batteries can be charged in a supplied charger, or they can be charged while still in the device. The rechargeable batteries are intended to be the main power source for the device, with the non-rechargeable batteries intended to be a backup power source in the event that the main battery fails or is completely discharged.

The batteries can be swapped out in the field. The rechargeable battery holder is released by two quarter turn fasteners that are readily accessible below the display of the device. An operator wearing gloves may have some difficulty manipulating the fasteners (pivoting the "wings" of the fastener so they can be turned), but should not have any difficulty with the remaining tasks, which include turning the fasteners, removing the battery holder, replacing the battery, and reassembling the holder to the device.

If the rechargeable batteries fail or are discharged in the field, military grade auxiliary batteries can be used. The handles of the Xaver 400 serve as battery compartments for these batteries. The auxiliary battery compartments are accessed by removing two screw caps on the ends of the handles. The caps are large enough and physically accessible enough to be removed and manipulated by a gloved hand.

Rechargeable batteries can be charged externally by the use of a supplied charger, or while the battery is still in the device. When charging a battery in the device, an external transformer plugs in to a standard wall socket and into a four pole socket on the Xaver 400, which is normally capped by a small screw cap. The small size of the cap and connector as well as the need for correct orientation of the plug would make manipulation difficult with a gloved hand, but this operation would not be expected to occur in the field.

5.3.4 Ease of Power-up and Device Operation

The Xaver 400 is easily powered on by the push of a single button, has the option of operating with three different ranges (4 m, 8 m, and 20 m), and can be cycled between three different detection modes (Tracker mode, Expert mode, and High Penetration mode). Selection of the range and mode are accomplished by easy to reach buttons when the device is being operated.

5.3.5 Information Display

The display has sufficient brightness and contrast to be visible in a variety of lighting conditions and different angles, although viewing from very wide angles may be difficult because the screen may be obstructed by the handles and other physical elements of the device.

Both Tracker mode and Expert mode present data in a 2D top-down view of the measured area. Targets and detected signal reflections are marked on the map so that distances as well as angular approximations are easily interpreted by the operator. High Penetration mode sacrifices the angular component for a time component, and therefore loses the 2D spatial aspect of the display but gains a historical view of the target movements locations and movements. This historical display can be beneficial for identifying a target when it may be difficult to identify in the other modes.

Tracker mode is the default mode and is the most intuitive to interpret, requiring only a minimal amount of training to understand the displayed data. When in tracker mode, the device attempts to detect and identify potential targets. Targets identified by the device are represented on the display by colored squares. The location of the squares on the display corresponds to the range and angles of detected targets. Because of the use of a tracking designation, there is a couple second delay from target movements to presentation of data (i.e., display lag).

Tracking mode appears to be susceptible to detecting reflections of the target ("false" targets or ghosts), making it appear that there may be multiple targets when there is only one. Sometimes (with a moving target) the targets will move in sync, giving a good indication that there is truly only one target. Other times the device indicates that one target is moving while the reflected "false target" is still. Sometimes, it appears that only a "false target" was identified. In this case it was still an identification of a target, just not in the position expected. This indicates that even though it may not be able to detect the actual target in this particular case, it was still able to indicate that a target was at least present. For many operators, this information will be sufficient for determining a course of action.

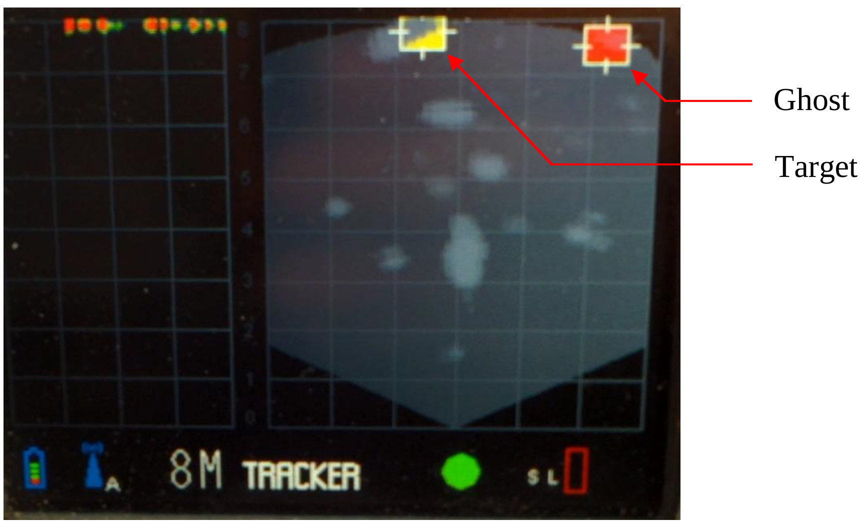

Figure 9: Xaver 400; "Real" target and "Ghost" target identified
Target was positioned at 8 m, slightly left of center (indicated by the yellow icon). The red icon indicates the presence of a second target; however there was no target at the second position.
Photo by NLECTC SSBT CoE

Expert mode indicates where movement is detected, but there is no attempt by the device to identify whether or not a reflected signal is from a target or an anomalous or false signal – the identification of a target is up to the judgment of the operator. There can be "flashes" of false detections made, which do not appear to have any apparent source, but these are typically weak signals and are appear intermittently and are disjointed. Because of their weak and sporadic characteristics, these signals can typically be dismissed by the operator as false targets. True targets can be identified by the signal strength, rhythmic pulsations of the signal (as in the case of breathing detection), and/or by the seeming purposeful movement of the reflected signal as seen on the display. Targets are indicated by green and yellow areas on the display with yellow indicating stronger signal. This mode may benefit by having a wider range of colors available for delineating signal strength.

Figure 10: Xaver 400 detecting Target at 4 m Through Office Cubicle Material
Grid spacing indicates a distance of 1 m. Grey dots indicate non-moving objects. Lighter green dots indicate possible multipath or reflections.
Photo by NLECTC SSBT CoE

High Penetration mode does not appear to make any attempt to filter or identify the data. Data about reflected signals (distance and strength; no left/right information) received by the device is presented to the operator on the display for operator judgment about the identification, location, and potential movements of a target.

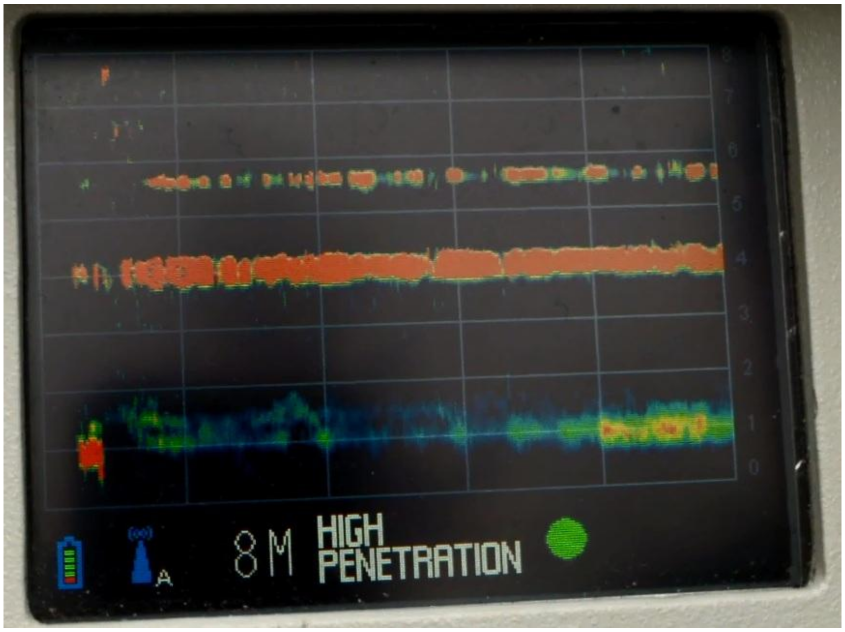

Figure 11: Xaver 400 detecting Target at 4 m Through a Brick Wall
Photo by NLECTC SSBT CoE

High Penetration only reports the distance from the device to the source of the reflected signal and the strength of the reflected signal. It thus loses the 2D aspect of the device, but may increase the overall signal strength which may make target identification easier. For example, during field tests, tactical officers with the Gwinnett County Sheriff's Department (Lawrenceville, GA) reported favoring the High Penetration mode for the increased information available to an operator without filtering or decisions made by the system.

5.3.6 Multiple Target Detection

All modes have the ability to detect multiple targets. Tracking mode and Expert mode have the ability to display multiple targets in 2D.

5.4 ASTIR

Table 7: ASTIR Usability Assessment Summary

Parameter	Rating
Physical Properties	
Form Factor	Fixed – Components portable, but device fixed upon setup
Weight	~ 5 lbs for device only (does not include computer and power supply)
Deployment Metrics	
Set-up Time	~ 3 minutes
Power-up Complexity	Complex
Hands to Operate	One
Battery Life	Variable – Dependent on power source used
Operational Properties	
Instrument Capabilities	
Detection Range	70 m
Display Map	1D – Map reduced to include historical time strip display
Multiple Target Detection	Yes
Data Display	
Level of Detail	Range, Still, Moving, recent range history (continuous time vs. distance display)
Ease of Interpretation	Moderate
Screen Readability (in Sunlight)	Variable - Dependent on computer used
Device Status	
Fault / Error Reporting	Yes – Computer generated error reporting; will also show error if signal saturates detector
Indication of Signal Strength	Yes – Colorimetric display on screen
Battery Status Indicator	No
Miscellaneous	
Remote Viewing	Yes, wired
Remote Control	Yes, wired
IP Addressable	Yes, wired
Record Session	Yes

5.4.1 Portability and Handling

The ASTIR is not easily moved from location to location on-site because of the required tripod, computer, power supply and electrical/communications cabling. Although not absolutely necessary, it is helpful to have a small portable surface to place the computer on while operating the device. At a minimum, the required equipment would require two individuals to transfer the components from a vehicle to the desired location on site (or two trips by a single individual).

5.4.2 Storage and Transportation

Since the device consists of an external battery supply, a computer, the transceiver portion, a mount for transceiver, and wiring to connect the various components, transportation to and from a site can be problematic. The operator has to take care that all the various components are available and quickly accessible during storage. At least two individuals would be required to transport the required components of the system from storage to the transportation vehicle in a single trip. The device takes up the most storage space of all the devices tested.

The transmitting and receiving portion is housed in a small suitcase sized Pelican case. It is not necessary to open the case even during operation. Ruggedness of the transceiver appears to be good. During a site visit to AKELA, AKELA personnel demonstrated the ruggedness of the transceiver by dropping the device from about chest high onto the floor. The device continued to operate normally. The ruggedness of the entire system is most dependent on the selected laptop computer.

5.4.3 Power Requirements

The current version of the prototype requires an external 12V power supply to operate the device. For testing, the CoE used a portable jump starter with a 12V output plug. The computer was the limiting factor as far as operational time was concerned (e.g., battery life tended to be around 2 hours).

5.4.4 Ease of Power-up and Device Operation

Setting the device up requires that the operator place the device on a suitable surface or mount it to a tripod, attach the power source, attach the computer, and then power up the electronics in the required sequence. After the electrical and communication cables have been connected, powering up the device requires only the push of a button, but since control, display and data storage are all performed by the computer, the computer must also be powered up, allowed to boot, and the control software started. This process can take a single operator close to 2 to 3 minutes to complete. One or even two additional personnel can assist with the setup of the equipment, which can significantly reduce setup time.

In its current state, it is important that the operator not activate the software (press the “Start” button in the software) before power is supplied to the transceiver; otherwise the software will display an error and configuration files will become corrupted. Closing and restarting the software will not result in fixing the issue; instead the configuration files must be copied from a good backup of the software.

5.4.5 Information Display

The ASTIR uses an external computer for controlling the device, data display, and for data storage. The computer used was a Windows 7 based high end graphics notebook computer. In addition to handling the control of the device, the computer also handles all data processing via the supplied software. The ASTIR is the only tested device that allows for data storage, which is useful for post viewing and processing, however this may not be beneficial in the field.

The main method for determination and identification of a target is a time-lapsed strip chart graphical display similar to the High Penetration modes of the Xaver 100 and the Xaver 400. There is a 2D display shown alongside the historical graphical display, but AKELA personnel indicated that the 2D display required additional work and that, at present, it would be best to monitor the historical display. SSBT CoE staff found the 2D map difficult to use for reliable identification and tracking of targets. This was primarily due to significant intermittent background signals from noise and/or extraneous sources. However, the strip chart was straightforward to use for locating and measuring targets distances.

Figure 12: ASTIR In Operation (Power Supply Not Shown)
Photo by NLECTC SSBT CoE

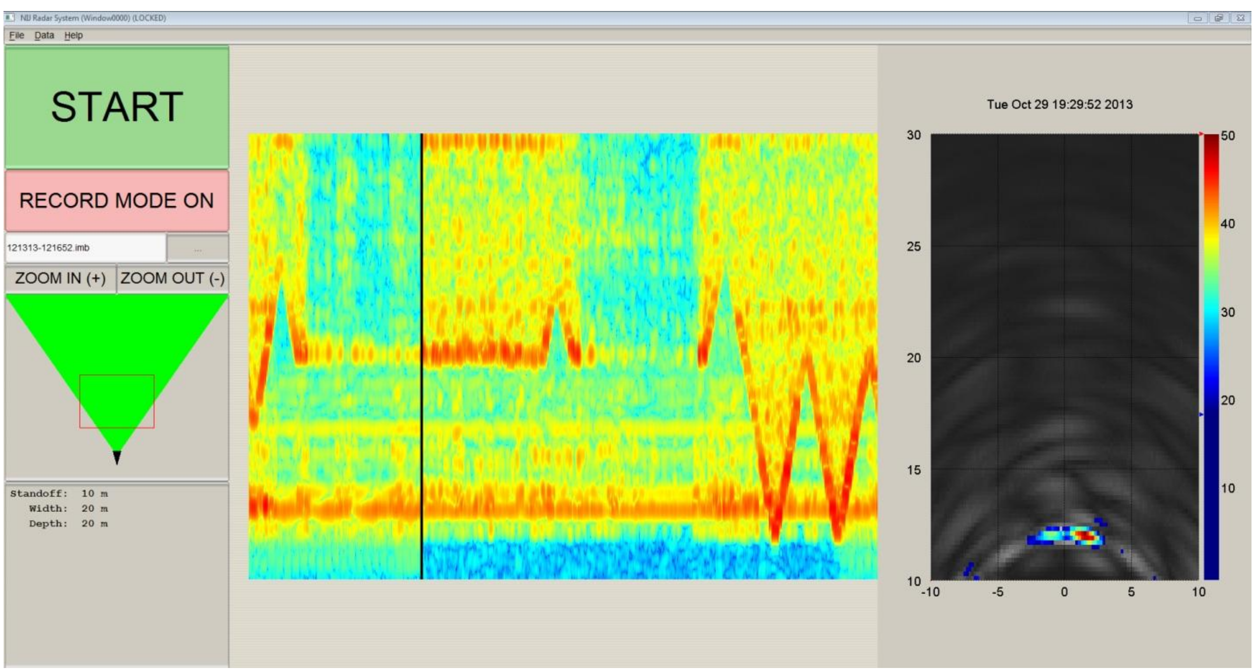

Figure 13: ASTIR display with target walking designated pattern

Display characteristics are dependent on the computer used. The HP EliteBook 8760w used by the Center did not provide sufficient brightness and contrast to easily make out the display in bright light, especially when viewed at wider angles. However, the computer selection was based on availability of pre-existing computer resources with sufficient processing power. It was not selected for field use. Alternative laptops specifically designed for mobile field operations by law enforcement or military personnel would improve the usability of the computer and therefore ASTIR.

5.4.6 Multiple Target Detection

The ASTIR is able to display the presence of multiple targets while operating in a similar manner as the Xaver 400 in High Penetration mode. The device does not attempt to identify the targets, but the strength of reflected signals is represented on the strip chart different colored plots. As the chart develops over time, the presence of multiple targets (at different ranges) is apparent.

6.0 TEST PROCEDURES

Testing incorporated different barriers, different target orientations and movements, and different operating modes of the devices if available. A significant distinction between the devices was whether the devices were intended to be mainly operated with the device stabilized ATW or if the device was intended to be operated at SO ranges with the device a significant distance from the barrier.

Devices which were intended to mainly be operated ATW are the Xaver 100 (pre-production), and the Range-R. The Xaver 400 is able to be mounted on a tripod and can be used either ATW or in SO operation. The ASTIR is intended to be operated in SO mode only.

6.1 ATW Testing

Typically, ATW testing was performed with the target at 4 m (~13 ft) and 8 m (~26 ft) behind the barrier. The target would either stand still in various orientations or walk in predetermined patterns. Three measurements were taken of each target orientation and movement at different locations on the barrier to reduce the effect of potential variations in barrier composition.

6.1.1 Target Orientation

The target would take up a position or activity at a predetermined distance on the opposite side of the barrier before measurements began. Orientations and movements of the target during measurements were as follows and were typically performed in the following order:

- **Target standing still**
    - Target facing forward
    - Target facing sideways (to the right as viewed from the device)
    - Target facing away
- **Target moving**
    - Target walking perpendicular (side to side as viewed from the device)
    - Target walking parallel (closer and further from the device)

At the start of each measurement, the device would be placed in the appropriate mode (if needed) and positioned against the barrier. A stopwatch was used for timing purposes and started at the beginning of each measurement. At the end of each measurement the stopwatch was reset, and the device was readied for the next measurement. Three measurements were taken at different locations along the barrier before the target was asked to change orientation or movement.

6.1.2 Device Positioning on a Barrier

Because the composition of a barrier may vary from one test point to another, device placement can have a significant effect on the readings. Because of this, the position of the device on the barrier was varied for the tests. Typically, three measurements of each target position and orientation were taken in different locations of the same barrier. The locations of device placement were kept consistent across all measuring devices.

6.1.3 Measurement Duration

Initially two minutes were allowed for each reading, but it was quickly determined that if the device was going to detect the target, it would detect it within one minute. Therefore the time for detection of ATW testing was reduced to one minute for logistical reasons.

Devices and modes that did not rely on operator input to detect and identify a target were considered to have identified a target if there was a stable detection/identification for two seconds or more. In the field, this would have resulted in positive target identification, and additional time would not invalidate the initial identification of a target. Modes which required operator judgment were video recorded for later assessment of target determination.

6.2 SO Measurements

SO measurements were taken with the device positioned a predetermined distance from the wall. The device was stabilized on a tripod and the target was positioned a known distance from the device. Since the device is a significant amount of distance from the wall and therefore interrogating over a much larger area of the barrier, variances in barrier construction would be expected to "average out" during measurement. This would have the effect of "averaging" the differences in localized barrier properties. Therefore only one or two measurements were taken, as opposed to the standard three measurements taken with the ATW devices.

6.2.1 Target Orientation

A single measurement with the target moving to different orientations and taking different movements was adopted. The typical pattern that a target would use during a measurement was facing the device, walking perpendicular to the emission of the device, standing sideways, and finally walking parallel to the emission of the device. Movement is much easier to detect and this target movement pattern allows for alternating still/movement target actions. Since the target is continuously monitored, this pattern allows better distinction of transitions of target activity.

6.2.2 Device Positioning

As mentioned earlier in the introduction of this section, the device was positioned a known distance from the barrier, typically aimed at the center of the barrier. Device placement was typically at 7 m, 11 m, 12 m or 30 m from the barrier, depending on the device and physical limitations imposed by the surroundings. The target was typically positioned 4 m, 7 m, or 8 m behind the front of the barrier, again depending on testing conditions and physical geometry of the structure where testing was being performed.

7.0 DATA COLLECTION

Target detection and location are the most important data to capture and record. The nature of the TTWS user interfaces and the information presented to an operator required a conscious methodology to ensure consistent and reproducible data collection by testers. To this end, Center staff adopted the perspective of a non-technical operator with basic device training using the device in the field. This viewpoint improves the relevancy of the T&E with respect to the end user who would not know the intended targets location and activity.

TTWS devices used in testing either included internal algorithms to identify and mark targets, or removed software interpretation to show data in a more unfiltered manner to allow the user to interpret signals and make their own decisions regarding the presence of target(s) and their location. For devices and modes that attempted to internally detect a target (e.g., Range-R, Xaver 100 – Normal Mode, and Xaver 400 – Tracker Mode), a positive target detection was recorded when the device provided a stable target signal for two seconds or more. Devices and modes that did not utilize algorithms to identify targets relied on subjective interpretation of the displayed data by the operator. Evaluation of the data was done by adopting the viewpoint of a trained operator that did not have prior knowledge of the presence or activities of the target.

Blank measurements (measurements without targets) of each scenario were taken to ensure that there were no systematic sources of false positives; however false positive analysis was not performed. Although there were time and resource constraints, the main reasons for not performing a false positive analysis is that the devices were not under any constraints to eliminate detected motion that did not originate from the intended target, and that tests were performed in relevant environments to provide more value to the practitioner.

Any attempt to provide a false positive frequency would first require defining exactly what is to be considered a false positive. Since these devices were under no constraints to reject movement beyond certain boundaries or conditions, defining a false positive would have been limited to target detection by the device where there was no movement that the device would have been able to detect. This would include movements outside of the devices normal viewing area, which could have been detected because of multipath reflections or other mechanisms. While this may be achievable in a laboratory setting, the certainty of no movement in a relevant environment is more difficult to ensure because of environmental unknowns. In addition, labeling actual movements as false positives may have limited the utility of the investigation, and would have evaluated the devices beyond their current design criteria. In short, the devices were simply designed to detect motion through walls without any other performance requirements.

7.1 Accuracy and Precision in Measurements

Accuracy and precision are often used interchangeably in normal everyday discussions; however they describe different ways of measuring uncertainty. Accuracy describes how closely the average of multiple measurements is to the accepted or “real” value. Precision describes how close each individual measurement is to the average of all the measurements. A classic example is a bullet shot at a typical target. On one extreme, a weapon may be accurate but not precise. This weapon may never hit the actual center of the target but is still considered accurate as long as the average of all shots fired lies near the center of the target. A gun that is not accurate but precise would produce a small grouping of hits but the grouping would not be at the center of the target, probably due to some systematic error such as the sites being off. An accurate and precise gun would produce a small grouping at the center of the target (see Figure 14: Accuracy and Precision in Measurements). When calculating accuracy and distances for TTWS, only tests involving still targets were used for calculations because of the fluctuating nature of the true distance associated with moving targets.

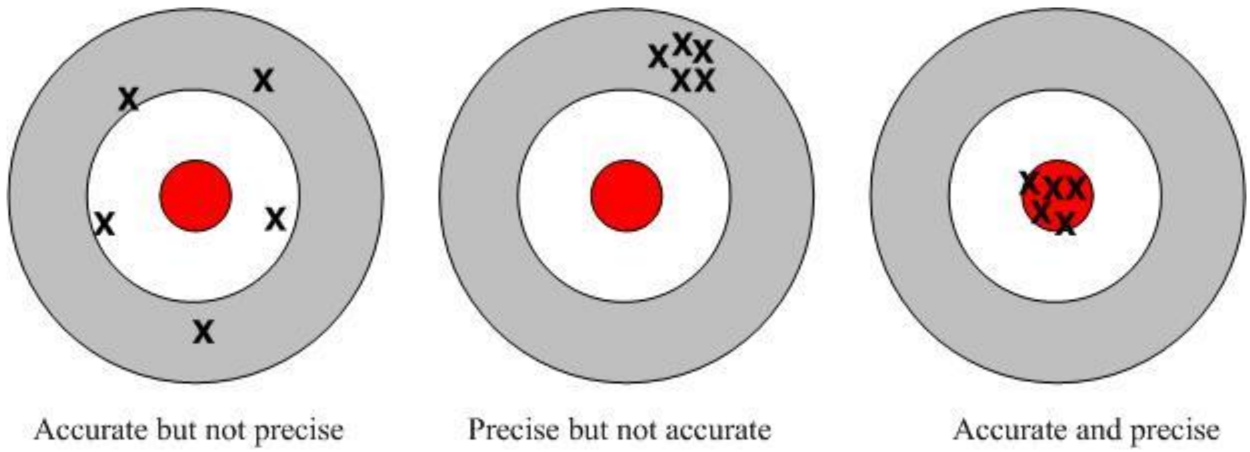

Figure 14: Accuracy and Precision in Measurements

7.2 Distance Measurement Accuracy

The distance accuracy of detected targets is one component of the TTWS performance. The accuracy represents how close the measured distance is to the actual target distance. This value was determined by calculating the error for each individual measurement and then calculating the average of those errors. The analyses and data summaries presented later on examine the performance metrics with respect to a fixed barrier composition and/or device position (i.e., ATW, SO). As a result, the accuracy must be described as an average percentage error from the actual range and not as a specific distance value. For example, a TTWS tested through concrete at 4 m, 8 m, and 20 m may have an average error of +5%. This would mean that, on the average, the target will be measured to be 5% further away than it actually is; 4 m would be reported (on average) to be at 4.2m and 20m would be reported (on average) to be at 21 m.

7.3 Distance Measurement Precision

The distance precision of detected targets is one component of the TTWS performance. The precision represents how reproducible measurements are for a target. This value was determined by calculating the average deviation from the mean for the individual measurement errors. This results in an uncertainty in the average error, or how much the error deviates. Similar to the accuracy value, the precision uncertainty is reported as a percentage error, but in this case a percentage of the accuracy and not a percentage of the actual distance. For example, a TTWS tested through concrete at 4 m, 8 m, and 20 m may have an error with uncertainty of +5% ± 12%. This measurement would mean that for a target at 4.0 m, on average, the distance measured would be 4.2 m ± 12% (or 0.7m); for a target at 20 m, on average, the distance measured would be 21 m ± 12% (or 2.5m). Thus the distance to a target at 4 m would most likely be reported to be between 3.5 m and 4.9 m (a difference of 1.4 m) and a target at 20 m would most likely be reported to be between 18.5 and 23.5 (a difference of 5 m).

7.4 Detection Time Uncertainty

The uncertainty in detection time provides an expected range of times for a given set of test parameters. This value was determined by calculating the average deviation from the mean for the individual measurement times. Average deviation was used instead of standard deviation because average deviation is more intuitive and because the data did not appear to be in a Gaussian distribution pattern, which is the preferred pattern when using standard deviation. This results in an uncertainty that is applied to an average time. For example, suppose three measurements were made at 4, 5, and 9 seconds. The average of the three measurements would be:

$$(4s + 5s + 9s)/3 = 6 \text{ seconds}$$

The deviation from the average (average = 6 seconds) of each measurement is calculated:
(Note that deviation is an absolute value and is therefore always positive)

$$|4s - 6s| = 2 \text{ seconds}$$
$$|5s - 6s| = 1 \text{ seconds}$$
$$|9s - 6s| = 3 \text{ seconds}$$

Then the average of the deviations is taken:

$$(2s + 1s + 3s)/3 = 2 \text{ seconds}$$

Then the uncertainty is reported as the average ± the average deviation:

$$6 \pm 2 \text{ seconds}$$

8.0 TEST RESULTS: OVERALL

A generic characterization of TTWS performance has been developed by compiling and averaging the results of all tests for each device. These results include all four testing locations, all barrier compositions, and any other test parameters. ATW testing was done with the Range-R, Xaver 100, and Xaver 400. SO testing was done with the Xaver 400 and the ASTIR. The Xaver 400 was the only device to be tested in both ATW and SO scenarios. This section distills the results from across all barriers tested and is intended as high-level look at the devices and their general overall performances. Later sections break down more specific parameters which may be more suitable for consideration based on potential use case scenarios.

8.1 All ATW

Table 8: ATW Results: Overall

Characteristic	Range-R	Xaver 100	Xaver 400
Total Number of Measurements Attempted	226	229	226
Percent Detection	74%	62%	93%
Moving Percent Detection	100%	91%	98%
Still Percent Detection	58%	44%	90%
Detection Time (Seconds) ± Average Deviation	13 ± 7	10 ± 6	8 ± 4
Average Distance Uncertainty	-1% ± 11%	-15% ± 23%	+3% ± 8%

Overall, the devices were able to detect targets more than 60% of the time, in 20 seconds or less, and with a typical accuracy of few meters. The Xaver 400 has the highest overall percent detection (93%) of the devices tested during ATW tests, followed by the Range-R (74%) and the Xaver 100 (62%). On average, the Xaver 400 detected the target fastest (8 seconds) followed by the Xaver 100 (10 seconds), and finally the Range-R (13 seconds). However, when the average deviations are taken into account there is considerable overlap. The Xaver 100 has the largest percent distance uncertainty. This was noted during testing in that the Xaver 100 seemed to have difficulty "zeroing in" on the specific distance to a target, often fluctuating between different distances during a reading.

Table 9: Xaver 100 – All: ATW

	Overall	Normal Mode	High Penetration Mode
Total Number of Measurements Attempted	229	162	67
Percent Detection	62%	53%	85%
Moving Percent Detection	91%	90%	93%
Still Percent Detection	44%	29%	80%
Detection Time (Seconds) ± Average Deviation	10 ± 6	11 ± 8	8 ± 4
Average Distance Uncertainty	-15% ± 23%	-29% ± 26%	-3% ± 14%

High Penetration mode appears to be superior to Normal mode in detection, time to detect, and distance accuracy. Since two measurements were taken with the normal mode and one measurement with high penetration mode, the number of normal mode measurements is roughly double the number of high penetration modes. Distance uncertainty in the Normal mode is larger than in the High Penetration mode because of the fluctuating distances often observed in the Normal Mode. High Penetration mode often seemed to have multiple reflections, and presumably, Normal mode would switch between the different reflections, making the error greater. It should be noted that the Xaver 100 model tested is a preproduction model, and since there are reported improvements in the range of the production model, improvements in target detection may have also been addressed in the production model.

Table 10: Xaver 400 – All: ATW

	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	226	76	75	75
Percent Detection	93%	97%	96%	85%
Moving Percent Detection	98%	100%	97%	97%
Still Percent Detection	90%	96%	96%	78%
Detection Time (Seconds) ± Average Deviation	8 ± 4	8 ± 5	9 ± 4	7 ± 2
Average Distance Uncertainty	+3% ± 8%	+1% ± 5%	+7% ± 13%	+3% ± 5%

Interestingly, the detection of a target in high penetration mode of the Xaver 400 by a trained operator appears to be less reliable than the detection of a target by the device itself; while the opposite is true of the Xaver 100. This may speak to the robustness of the target detection algorithm of the Xaver 400 and the ability of the algorithm to take advantage of data obtained from the four antennas in the Xaver 400 as opposed to the Xaver 100, which only has two antennas.

Another interesting note is that when Center personnel visited the Gwinnett County Sheriff's Department (Lawrenceville, GA), the officers indicated that they almost exclusively use the High Penetration mode of the Xaver 400.[10] The results from this task indicate that mainly using Tracker mode may be a better course of action. However, the familiarity and experience that the Sheriff's department has with this device may make using High Penetration mode a better option in view of their extensive experience with this device.

8.2 All SO

Table 11: SO Results: Overall

	ASTIR	Xaver 400 Overall	X400 Tracker Mode	X400 Expert Mode	X400 HP Mode
Total Number of Measurements Attempted	103	150	50	50	50
Percent Detection	68%	47%	56%	66%	18%
Moving Percent Detection	83%	55%	65%	75%	25%
Still Percent Detection	57%	41%	50%	60%	13%
Detection Time (Seconds) ± Average Deviation	14 ± 8	9 ± 5	9 ± 6	9 ± 4	12 ± 7
Average Distance Uncertainty	-11% ± 19%	-8% ± 11%	-13% ± 15%	-4% ± 5%	-13% ± 12%

Overall the ASTIR outperformed the Xaver 400 in SO testing (68% vs. 47%). However, the information display of the ASTIR most closely resembles the HP mode of the Xaver 400; it is a historical view (position vs. time) of the signal strength and target distance where operator judgment is used to identify targets. When considering all the measurements made, HP mode is the least reliable mode for the Xaver 400 in both ATW and SO operation. In SO operation, the Xaver 400 had a percent detection of 18% averaged across all measurements made in High Penetration mode. Although differences in the frequencies used for the signal may play a role in the differences, the most probable reason is that the Xaver 400 has a wider viewing angle than the ASTIR, resulting in a more diffuse transmitted radar energy density and opportunity for more interference reflections.

The Xaver 400 has a viewing angle of 120° as opposed to the narrower viewing angle of the AKELA ASTIR (44° as reported by the user's manual). This wider angle allows for better performance when ATW (by allowing a larger portion of the area beyond the barrier to be scanned) but it also dissipates the signal power more at larger distances. The less divergent signal of the ASTIR would allow for more power at the target at a distance, but this would be accomplished at the expense of viewing angle. The differences in target detection between the ASTIR and the Xaver 400 in SO operation may reflect this power dissipation phenomenon.

9.0 SITE 1 - URBAN TRAINING RANGE

The West Virginia Army National Guard's Camp Dawson (Kingwood, WV) is a Regional Training Institute for the US Army. The SSBT CoE utilized one of the urban training ranges located on the base to conduct field tests. The range has several structures made mainly of cinder block and lumber that are used for training purposes. These structures were good test barriers because of the uncluttered, uniform nature of the buildings. The structures are in an isolated area without utilities. The main structure used for this testing was a two story structure with a concrete slab base, four cinder block walls on the lower story, stairs leading to an upper story which was constructed with lumber and Oriented Strand Board (OSB).

9.1 Cinder Block Wall

Cinder block is a common building material utilized in structures of all types. It is not uncommon to have a barrier that would be constructed only of cinder block, but there may be other constituents of a cinder block barrier such as drywall, bricks, paneling, etc. The particular barrier used during testing was a painted cinder block wall with an open doorway on the left side. The interior of the structure was open with a stairway near the right side. The other walls are also constructed of cinder blocks, with window openings (no actual windows installed) on the walls perpendicular to the test wall. Another open doorway is on the right side of the rear wall. The ceiling of the lower level was constructed with 2" x 8" wooden joists. The floor of the second floor used OSB and is visible from inside the test area.

The openings in the barrier and other walls are not ideal, but by taking measurements from the same position, the relative performances of the devices should be unaffected. Openings in the barrier wall would not be expected to have a significant effect on ATW measurements, but for SO testing, the openings would provide an unobstructed view of the target if the target were directly in front of the opening. Efforts were made to minimize this effect during testing. The stairway in the interior would be expected to cause reflections when measuring both ATW and SO, and the window openings on the perpendicular walls might also be expected to cause some reflections off the edges of the openings.

Table 12: Barrier Summary – Cinder Block Wall

Barrier Feature	Details
Material Type(s)	Cinder Block
Thickness	Eight Inches
Metal Components	¼" horizontal steel support over doorway
Interior	Uncluttered with stairs along right side wall
Openings	Doorway
Wall Dimensions	8' x 16'
Other Features	Perpendicular walls have window openings, Rear wall has another doorway on the right side.

Figure 15: Cinder Block Barrier
Exterior of structure used for cinder block testing at Camp Dawson
Photo by NLECTC SSBT CoE

In preparation for testing, distances from the exterior of the test barrier were marked on the floor inside the structure with masking tape for target positioning. The standard testing procedure was followed for ATW and SO results shown below.

9.1.1 ATW – Cinder Block

The following tests were performed with TTWS devices in ATW mode against the cinder block wall:

- Target 4 m (~13 ft) from device (Range-R, Xaver-100, Xaver 400),
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 8 m (~26 ft) from device (Range-R, Xaver-100, Xaver 400),
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)

Table 13: Range-R – ATW – Cinder Block Results

Characteristic	Result
Total number of measurements attempted	33
Percent Detection	58%
Moving Percent Detection	100%
Still Percent Detection	33%
Detection time (Seconds) ± Average Deviation	15 ± 8
Average Distance Uncertainty	-3% ± 6%

Smaller percent detection, slightly longer detection times, and distance uncertainty (as compared to Table 8: ATW Results: Overall) indicate that the cinder block barrier is a more difficult barrier to penetrate than the average of other barriers for the Range-R. The distance uncertainty appears to be harder to determine for the cinder block barrier, however the precision does appear to have improved slightly over the average of all tests.

Table 14: Xaver 100 – Cinder Block: ATW

	Overall	Normal Mode	High Penetration Mode
Total Number of Measurements Attempted	36	26	10
Percent Detection	47%	35%	80%
Moving Percent Detection	92%	88%	100%
Still Percent Detection	25%	11%	67%
Detection Time (Seconds) ± Average Deviation	11 ± 7	12 ± 9	9 ± 5
Average Distance Uncertainty	-6% ± 10%	-18% ± 17%	-1% ± 4%

Comparing the above with Table 9: Xaver 100 – All: ATW indicates that cinder blocks are harder to penetrate than the average of all barriers tested. Percent detection was reduced for the cinder block barrier across all operational modes, and detection time was increased. Distance uncertainty appears to have improved through cinder blocks though. This may be an issue of mainly detecting the target at closer range, where the uncertainty could be expected to be less.

Table 15: Xaver 400 – Cinder Block: ATW

	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	30	10	10	10
Percent Detection	87%	100%	100%	60%
Moving Percent Detection	92%	100%	100%	75%
Still Percent Detection	83%	100%	100%	50%
Detection Time (Seconds) ± Average Deviation	9 ± 3	8 ± 2	12 ± 3	6 ± 2
Average Distance Uncertainty	14% ± 29%	14% ± 26%	+23% ± 43%	-3% ± 2%

Looking at the overall results of the Xaver 400 and comparing them to Table 10: Xaver 400 – All: ATW suggests that the performance through cinder block walls has been reduced. However, closer inspection of the different modes indicate that both Tracker and Expert mode have increased percent detection and that HP mode is pulling down the overall percent detection. Also, the average distance uncertainty of measurements taken through cinder blocks is significantly larger than the overall average.

9.1.2 SO – Cinder Block

The following tests were performed with TTWS devices in SO mode with a cinder block wall:

- Target 15 m from device, SO distance 7 m (Xaver 400, ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 15 m from device, SO distance 11 m (Xaver 400, ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 19 m from device, SO distance 11 m (Xaver 400, ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 20 m from device, SO distance 12 m (ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)

Table 16: Xaver 400 – Cinder Block: SO

	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	45	15	15	15
Percent Detection	38%	40%	60%	13%
Moving Percent Detection	56%	50%	83%	33%
Still Percent Detection	26%	33%	44%	0%
Detection Time (Seconds) ± Average Deviation	7 ± 4	5 ± 2	8 ± 4	13 ± 8
Average Distance Uncertainty	-3% ± 2%	-5% ± 0%	-2% ± 2%	N/A (No Still Detection)

The most noticeable item in the above table is that there was no detection of still targets in High penetration mode. As mentioned in Section 7.2 Distance Measurement Accuracy, only measurements taken with still targets were used for the determination of average distance uncertainty. Compared to Table 11: SO Results: Overall, the results indicate less detection than the overall SO results.

Table 17: ASTIR – Cinder Block: SO

Characteristic	Result
Total Number of Measurements Attempted	37
Percent Detection	84%
Moving Percent Detection	100%
Still Percent Detection	74%
Detection Time (Seconds) ± Average Deviation	18 ± 10
Average Distance Uncertainty	-26% ± 16%

There is a high detection rate as compared to the overall SO detection rate which seems to indicate that the cinder block wall was an easier barrier to penetrate than the average of all the barriers. The amount of time to detect a target, and the uncertainty in the distance are both higher than the overall results. This may indicate that a proportionally larger amount of still targets were detected through the cinder block wall as opposed to other barriers; again indicating that the cinder block wall is easier to penetrate than other SO barriers.

9.2 AKELA Long Range SO – Cinder Block

The following tests were performed with TTWS devices in long-range SO mode against the cinder block wall:

- Target 34 m from device, 30 m SO (ASTIR)
  - Target standing still (facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 38 m from device, 30 m SO (ASTIR)
  - Target walking parallel

Table 18: ASTIR – Cinder Block: Long Range SO

Characteristic	Result
Total Number of Measurements Attempted	11
Percent Detection	36%
Moving Percent Detection	50%
Still Percent Detection	20%
Detection Time (Seconds) ± Average Deviation	15 ± 7
Average Distance Uncertainty	-8% ± 0%

Although percent detection decreased as compared to the regular SO results (as would be expected at longer ranges), the detection time and average distance uncertainty appear to have improved over the shorter SO distances (Table 17: ASTIR – Cinder Block: SO). The improvement in the uncertainty may be due to only a small number of still detection being made (of the still detected made, they just happened to be more accurate and precise than average), and improvement in average detection time may be due to proportionally more movement detections being made (movements are typically detected faster than still detections).

9.3 OSB (Particle Board)

The second floors of the structures were constructed with wooden studs and OSB. The barriers had OSB on both sides, thus essentially the signal was required to go through two layers of OSB on a single barrier when traveling to the target (on return of the signal, the signal would again encounter two layers of OSB before reaching the device). The geometry of the structure was such that only 4 m measurements could be made by going through a single barrier. However, a smaller subset of tests were performed with the target at 8 m and the signal traveling through two OSB barriers to demonstrate the utility of these devices to detect targets through more than one barrier. In addition to the two barrier demonstration, a short SO measurement (3m SO) was made with the AKELA with the target walking throughout the structure. A third set of demonstrations tests were performed with the Xaver 100 and the Range-R attempting to detect a target sitting in a chair as well as lying down across multiple chairs to mimic someone lying down on a couch or a bed.

Table 19: Barrier Summary – OSB Particle Board

Barrier Feature	Details
Material Type(s)	OSB, 2" x 4" lumber
Thickness	½" thick OSB, 2" x 4" studs
Metal Components	Nails
Interior	Open area with stair railing on right
Openings	Doorway on the right
Wall Dimensions	8' x 12' (estimated)
Other Features	Ceiling OSB; Windows on outside walls, but not expected to be issues

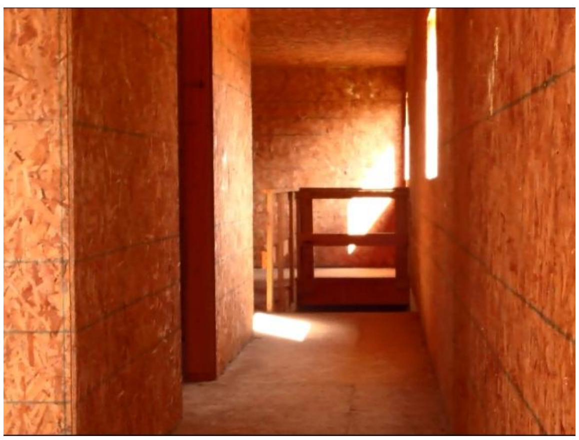

Figure 16: Interior of structure with OSB at Camp Dawson
Photo by NLECTC SSBT CoE

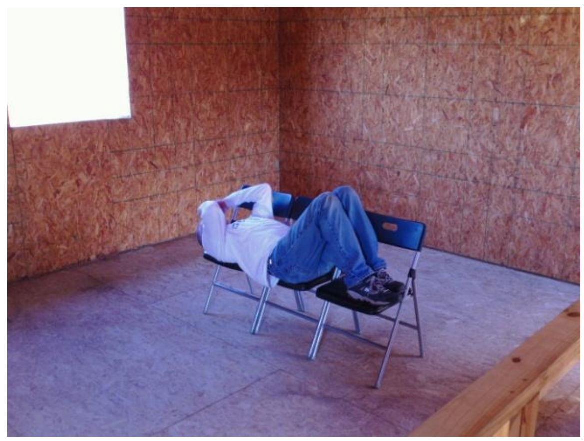

Figure 17: Target lying across multiple chairs
Photo by NLECTC SSBT CoE

9.3.1 ATW – OSB (Target at 4 m)

The following tests were performed with TTWS devices in ATW mode against the OSB barrier:

- Target 4 m from device (Range-R, Xaver-100, Xaver 400),
    - Target standing still (Facing toward, facing sideways, and facing away)
    - Target walking (parallel and perpendicular)

Table 20: Range-R – OSB: ATW: Target at 4m

Characteristic	Result
Total Number of Measurements Attempted	15
Percent Detection	80%
Moving Percent Detection	100%
Still Percent Detection	67%
Detection Time (Seconds) ± Average Deviation	16 ± 11
Average Distance Uncertainty	+4% ± 8%

On OSB, the Range-R had improved detection rates over the overall results (by 5%; Table 8: ATW Results: Overall), but decreased performance in detection time and distance uncertainty. The limitation of only having 4 m measurements probably played a role in the improved percent detection, which (presumably) included more still detections. Since still detections are more difficult, this may account for the apparent performance decrease in the detection time and distance uncertainty.

Table 21: Xaver 100 – OSB: ATW: Target at 4 m

	Overall	Normal Mode	High Penetration Mode
Total Number of Measurements Attempted	15	10	5
Percent Detection	53%	40%	80%
Moving Percent Detection	100%	100%	100%
Still Percent Detection	22%	0%	67%
Detection Time (Seconds) ± Average Deviation	11 ± 7	15 ± 8	7 ± 4
Average Distance Uncertainty	-6% ± 55%	No Still Detection	-6% ± 55%

"No Still Detection" in Normal Mode indicates that OSB is a significant barrier for the Xaver 100, especially considering that only targets at 4m were tested. Percent detection for OSB was lower for both modes than it was for Table 9: Xaver 100 – All: ATW. It was expected that OSB would be a relatively easy barrier to penetrate (see Figure 1: Attenuation properties of common building materials), but it appears that the Xaver 100 had some difficulty. It may be that since the OSB is exposed to the environment (there are no windows in the window openings), moisture may have collected in the OSB due to high relative humidity, which would make it more difficult to penetrate.

Table 22: Xaver 400 – OSB: ATW: Target at 4 m

	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	15	5	5	5
Percent Detection	100%	100%	100%	100%
Moving Percent Detection	100%	100%	100%	100%
Still Percent Detection	100%	100%	100%	100%
Detection Time (Seconds) ± Average Deviation	7 ± 3	6 ± 2	8 ± 2	7 ± 4
Average Distance Uncertainty	+3% ± 1%	+2% ± 0%	+3% ± 2%	+4% ± 1%

Improvements in performance of the Xaver 400 against OSB appear to have been made across the board over the aggregated results (Table 10: Xaver 400 – All: ATW). This is in contrast to the results of the Xaver 100 (above). Since the Xaver 100 uses the same technology (i.e., UWB), the difference may stem from the use of four antennas by the Xaver 400 instead of the two antenna of the Xaver 100, and the algorithms of the Xaver 400 that can take advantage of the additional antenna.

9.3.2 ATW – OSB (Target at 8 m – 2 OSB walls)

The upstairs structure did not allow testing at 8 m through only one OSB wall, but it did allow for testing at 8 m through two walls. Since it would be necessary for two barriers to be penetrated, a full complement of tests was not performed. Instead a smaller subset was used to demonstrate the abilities of the devices to penetrate more than one barrier.

The following tests were performed with TTWS devices in ATW mode against two OSB barriers:

- Target 8 m from device (Range-R, Xaver 100, Xaver 400)
    - Target standing still (Facing toward, facing sideways (Range-R only))
    - Target walking perpendicular (Range-R, Xaver 100, Xaver 400)

Table 23: Range-R – OSB: ATW: Target at 8 m (2 Walls)

Characteristic	Result
Total Number of Measurements Attempted	10
Percent Detection	90%
Moving Percent Detection	100%
Still Percent Detection	86%
Detection Time (Seconds) ± Average Deviation	16 ± 8
Average Distance Uncertainty	+2% ± 16%

The percent detection appears to be better than if only one barrier is used (Table 20: Range-R – OSB: ATW: Target at 4m). It is possible that longer distance allows for the opportunity for the signal to bounce around more and reach the target through a process known as multipath, but note that with 10 measurement attempts, 90% detection indicates that 9 measurements resulted in detections. Had the detections been decreased by just one, the percent detection would be the same as a single OSB barrier. This may be within the range of experimental error.

Table 24: Xaver 100 – OSB: ATW: Target at 8 m (2 Walls)

	Overall	Normal Mode	High Penetration Mode
Total Number of Measurements Attempted	7	5	2
Percent Detection	29%	0%	100%
Moving Percent Detection	33%	0%	100%
Still Percent Detection	25%	0%	100%
Detection Time (Seconds) ± Average Deviation	4 ± 1	No Detection	4 ± 1
Average Distance Uncertainty	-40% ± 0%	No Detection	-40% ± 0%

Detection performance decreased (to no detection) for the Normal mode of the Xaver 100 when two OSB barriers were used as opposed to just one barrier (40% detection). This indicates a significant attenuation of the signal by OSB. However, an increase to 100% detection in High Penetration Mode with two OSB barriers (as opposed to 80% detection with only one barrier) indicates that the signal was present, but for some unknown reason, the algorithm of the normal mode was unable to identify it as a target.

Table 25: Xaver 400 – OSB: ATW: Target at 8 m (2 Walls)

	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	6	2	2	2
Percent Detection	100%	100%	100%	100%
Moving Percent Detection	100%	100%	100%	100%
Still Percent Detection	100%	100%	100%	100%
Detection Time (Seconds) ± Average Deviation	8 ± 5	9 ± 6	4 ± 0	12 ± 9
Average Distance Uncertainty	+1% ± 1%	0% ± 0%	0% ± 0%	+2% ± 0%

Two OSB barriers did not seem to pose any more of an issue than a single OSB barrier. Average detection times and average distance uncertainty indicate some improvements; however taking the number of measurements made and the average deviations into consideration, it is difficult to say whether the improvements are real or within experimental error.

9.3.3 Demonstration – Target Sitting and Lying Down.

To test the ability of the devices to detect a person sitting or lying down, the Xaver 100 and the Range-R were tested with the target sitting in a metal chair and with the target lying across three metal chairs at 4 m from the OSB wall (see Figure 17: Target lying across multiple chairs). When sitting, the Xaver 100 did not detect a target in normal mode, but in high penetration mode, there was an identifiable signal at 4 m. The Range-R identified a target two out of three times when the target was sitting, although it did detect the target at a slightly further distance than the actual distance (~5.5 m measured as opposed to 4 m actual).

When lying down, two measurements were taken with the target lying on his back and one measurement taken with the target lying on his side. Again, with the Xaver 100 there was no detection of the target during normal operation, but there was an identifiable signal in High Penetration when the target was lying on his side. The Range-R did not detect the target when he was lying on his back, but was able to detect the target when he was lying on his side. The actual distance was 4 m and the measured distance was 4.3 m.

These tests were exploratory in nature and not comprehensive due to available time and resources. In addition, the metal chairs were not ideal given the possibility of reflections or interference, but were the resources available at the time of testing.

9.3.4 Demonstration - ATW Detection of Two Targets

As an exploratory demonstration, the Xaver 100 and the Range-R were tested ATW with two targets behind the OSB wall: one at 4 m and one at 8 m. The targets either stood still, facing the device or walked perpendicular (to the emission of the device).

9.3.4.1 Targets Still, Facing the Device

In the first attempt, the Xaver 100 quickly detected the 4 m target in normal mode when both targets were standing still, but did not detect the second target. The second attempt using normal mode did not detect any target. In High Penetration mode, there was a good signal for the 4 m target, but no real indication of a second target at 8m.

The Range-R detected the far (8m) target in the first two measurements, but didn’t detect the closer target. The targets changed places and two more measurements were taken. The first measurement did not detect any targets, but the second measurement did detect the 4 m target. It is possible that differences in body build and/or clothing contributed to the detection variations.

9.3.4.2 Targets Moving Perpendicular

In the first two measurements (normal mode), the Xaver 100 began to indicate that there was a target at 4 m, but didn’t stabilize until after about 30 seconds. The second target was never indicated or identified. However, in the third measurement (High Penetration mode) there were very strong indications that there were two targets (see Figure 18: Xaver 100 in High Penetration Mode Viewing Two Targets). Even with the 4 m target stationary and the 8 m target moving, the Xaver 100 did not provide a stable detection of the far target in normal mode until after 45 seconds in the second measurement with normal mode. However, similar to both targets moving perpendicular, it seems apparent in High Penetration mode that two targets are present.

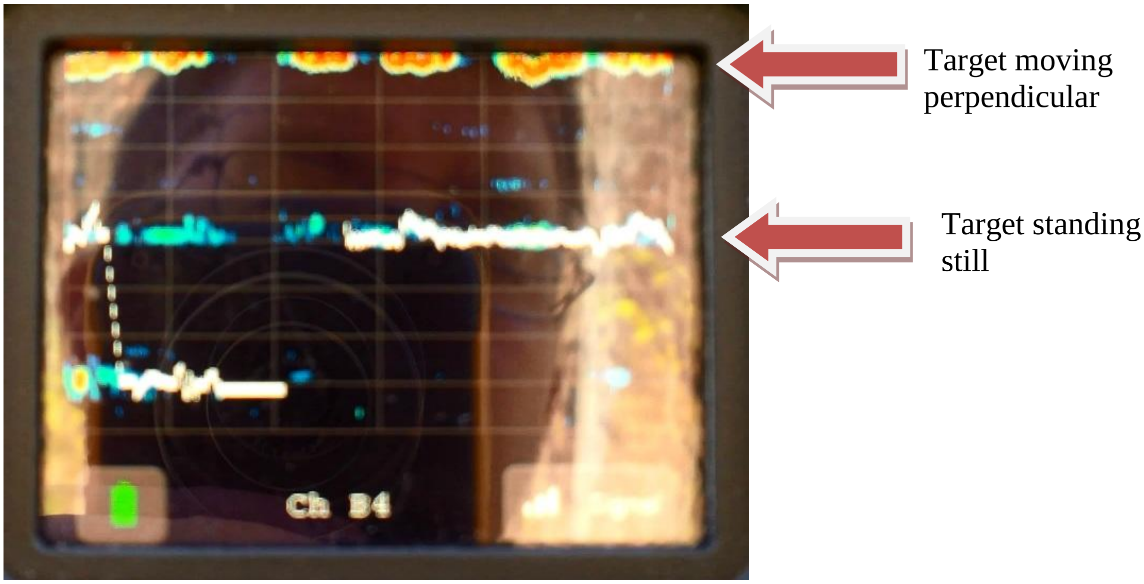

Figure 18: Xaver 100 in High Penetration Mode Viewing Two Targets
Farther target moving (8 m), close target still (4 m)
Photo by NLECTC SSBT CoE

In the first, third, and fourth measurements, the Range-R mainly detected the moving target at 8 m with little indication of the still, 4 m target (four measurements were taken with the targets switching places after the first two measurements). However in the second measurement, the Range-R gave strong indication of both targets, alternating measurements between the targets. With both targets moving the Range-R mainly indicated the closer target, but occasionally would stabilize on the farther target (approximately 1/5 of the time).

9.3.5 Demonstration – SO Detection of Two Targets

An exploratory demonstration was performed using SO measurements of multiple targets behind a cinder block wall. For the Xaver 400, the device was 11 m SO with 15 m to the close target and 19 m to the far target. Targets alternated between standing still and walking. There was no detection of still targets in any mode, but when targets walked perpendicular they would occasionally walk in front of an open doorway, which provided an unobstructed view of the target making it very easy to detect, however there was no detection when they were not in front of the doorway. When targets walked parallel (and not in view through the doorway), there was a slight indication in the Expert mode, but it was fleeting and it would be questionable whether someone without knowledge of the targets activities would be able to identify the movement.

Similar to the Xaver 400, the ASTIR was not able to detect perpendicular walking targets unless they passed in front of the open doorway (which was not considered to be a “hit”). The targets alternated walking parallel to the emission direction of the device. Although the targets were not in view of the device when walking parallel, only the target closer to the doorway was able to be determined and then only when walking.

10.0 SITE 2 – OFFICE BUILDING (TRADITIONAL)

The Alan B. Mollohan Innovation center is a traditional modern office building. It is a three-story structure built with a standard steel frame, a glass/stucco exterior and typical drywall with metal studs for the interior. The office building is occupied by several businesses and personnel. TTWS were tested against cubicle material and a glass door. Two additional measurements were performed that show the importance of building materials and how the signal interacts with the interior structure elements (e.g., metal studs) of the barrier.

10.1 Cubicle Material

For this test, available cubicle barriers were utilized that appear to be constructed with particle board overlaid with a medium weave fabric and framed with metal for protection and assembly. ATW measurements were taken with the Xaver 100, Xaver 400, and the Range-R; SO measurements were not performed. One caveat to this set of tests is that testing of the Xaver 400 and testing of both the Range-R and the Xaver 100 were performed at two different locations. During testing, the initial site became unsuitable because of pedestrian traffic. The cubicle panel was transported to a second site, and testing was completed at the second site. Even though the panel was the same, differences in the surrounding structure may have an effect on the detection ability of the devices due to reflections.

Table 26: Barrier Summary – Cubicle Material

Barrier Feature	Details
Material Type(s)	Wood, cloth
Thickness	1 3/4”
Metal Components	Metal border around edge
Interior	Site 1 (Xaver 400 tested): Open hallway with open doorways to the right (~4m) and left (~8m) Site 2 (Xaver 100 and Range-R tested: Open hallway with doorway to right (~8m)
Openings	None
Wall Dimensions	5’ 6” x 3’
Other Features	Somewhat unstable, too much pressure causes wall to move

10.1.1 ATW – Cubicle Material

The following tests were performed with TTWS devices in ATW mode against cubicle walls:

- Target 4 m (~13 feet) from device (Ranger-R, Xaver-100, Xaver 400),
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 8 m (~26 feet) from device (Ranger-R, Xaver-100, Xaver 400),
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)

Table 27: Range-R – Cubicle Material: ATW

Characteristic	Result
Total Number of Measurements Attempted	30
Percent Detection	100%
Moving Percent Detection	100%
Still Percent Detection	100%
Detection Time (Seconds) ± Average Deviation	10 ± 4
Average Distance Uncertainty	-10% ± 2%

Cubicle material appears to be an easily penetrated barrier for the Range-R. Percent detection and detection time improved compared to the overall results (Table 8: ATW Results: Overall). However, it is notable that the average distance uncertainty for the cubicle material was worse than the overall results.

Table 28: Xaver 100 – Cubicle Material: ATW

Characteristic	Overall	Normal Mode	High Penetration Mode
Total Number of Measurements Attempted	30	20	10
Percent Detection	93%	90%	100%
Moving Percent Detection	100%	100%	100%
Still Percent Detection	89%	83%	100%
Detection Time (Seconds) ± Average Deviation	6 ± 3	6 ± 3	6 ± 3
Average Distance Uncertainty	-18% ± 18%	-19% ± 19%	-17% ± 16%

The average percent detection improved significantly over the overall performance of the Xaver 100 (see Table 9: Xaver 100 – All: ATW). The cubicle material tested appears to be easily penetrated by the Xaver 100, with average detection times and average distance uncertainty improving overall ATW measurements taken with the Xaver 100. The only area where there was any decrease in performance was the average distance uncertainty of the High Penetration mode. This indicates that there were reflections that may have been mistaken for the “real” target; even though the distances would be affected, the reflections still indicate the presence of a target.

Table 29: Xaver 400 – Cubicle Material: ATW

Characteristic	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	30	10	10	10
Percent Detection	83%	80%	100%	70%
Moving Percent Detection	100%	100%	100%	100%
Still Percent Detection	72%	67%	100%	50%
Detection Time (Seconds) ± Average Deviation	6 ± 2	3 ± 2	8 ± 3	5 ± 1
Average Distance Uncertainty	0% ± 6%	-3% ± 1%	+2% ± 12%	-2% ± 2%

Although average detection time and distance uncertainty improved over the overall results (see Table 10: Xaver 400 – All: ATW), the detection percentage seems to indicate that the tested cubicle material was more difficult to penetrate than the average of all measurements taken. However, as mentioned above, the location of the testing site of the Xaver 400 was unavoidably different. This may contribute to the lower detection rate of the Xaver 400 when compared to the overall performance. This is especially apparent when compared to the Xaver 100, which uses the same technology to produce the signal as the Xaver 400. Also note that the performance of the Xaver 100, in every other test case, has been inferior to the Xaver 400. However it is still apparent from these results that detection of a target through a single layer of cubicle material tested in the effort is reasonable for all the devices.

10.2 Glass

At first pass, it may seem that testing through a glass window is pointless as one could simply visually observe if there's a target or not, but consider the case where the window is obstructed by curtains and/or blinds (vinyl or wood hopefully, not aluminum) or if the room is smoke filled; in these cases windows may provide a very good testing location for the operator. Note that on many office buildings, the glass is coated with a very thin metal layer. This layer is used to help keep the building cool in the summer by reflecting a large portion of sunlight. As a result, these windows may block or hinder through-wall detection.

The glass tested was in a door used as an emergency exit. The door was constructed with a large single pane of glass (6' x 2' approximately) with a metal frame. The glass appeared to have a tinted layer, but initial observations indicated that the signal from the devices was able to penetrate it, indicating that tinting was polymeric in nature and not due to a metalized, reflective layer.

Table 30: Barrier Summary – Glass

Barrier Feature	Details
Material Type(s)	Glass
Thickness	3/8”
Metal Components	Metal Frame, Metal panic bar
Interior	Open hallway with doorway to the right (~8m)
Openings	None
Wall Dimensions	2’ 3.5” x 6’ (glass); 3’ x 6’ 11” (Metal frame door)
Other Features	Slight tint added to glass

10.2.1 ATW – Glass

The following tests were performed with TTWS devices in ATW mode against the glass wall:

- Target 4 m (~13 feet) from device (Ranger-R, Xaver-100, Xaver 400),
    - Target standing still (Facing toward, facing sideways, and facing away)
    - Target walking (parallel and perpendicular)
- Target 8 m (~26 feet) from device (Ranger-R, Xaver-100, Xaver 400),
    - Target standing still (Facing toward, facing sideways, and facing away)
    - Target walking (parallel and perpendicular)

Table 31: Range-R – Glass: ATW

Characteristic	Result
Total Number of Measurements Attempted	30
Percent Detection	60%
Moving Percent Detection	100%
Still Percent Detection	33%
Detection Time (Seconds) ± Average Deviation	14 ± 9
Average Distance Uncertainty	-4% ± 2%

The glass tested in this effort appears to be a significant barrier for the Range-R. The performance results of all metrics have decreased when compared to the overall results (see Table 8: ATW Results: Overall). Because the glass appeared to have some form of tint, it is not known whether the glass itself, or the tinting material, or a combination of both is responsible for the reduced performance of the Range-R.

Table 32: Xaver 100 – Glass: ATW

	Overall	Normal Mode	High Penetration Mode
Total Number of Measurements Attempted	30	20	10
Percent Detection	73%	60%	100%
Moving Percent Detection	100%	100%	100%
Still Percent Detection	56%	33%	100%
Detection Time (Seconds) ± Average Deviation	7 ± 5	8 ± 8	5 ± 2
Average Distance Uncertainty	-6% ± 12%	-20% ± 17%	3% ± 8%

The results of the Xaver 100 show significant improvements over the performance of the overall measurements of the Xaver 100 (Table 9: Xaver 100 – All: ATW). This indicates that the glass door tested is able to be penetrated by the signal of the Xaver 100 easier than most barriers.

Although overall, the Xaver 100 has a higher detection rate than the Range-R, note that the Normal Mode (where the device attempts to identify a target) of the Xaver 100 has the same detection rate, and that the High Penetration mode of the Xaver 100 (that is dependent on the operator to make the judgment of a target or not) has a 100% detection rate. This is in contrast with the general trend of the devices (Range-R typically having higher detection rates), but this could be a function of the ultra wide band technology incorporated by the Xaver devices as opposed to the more narrow band "Step Continuous Wave" technology used by the Range-R and the barrier properties.

Table 33: Xaver 400 – Glass: ATW

	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	30	10	10	10
Percent Detection	100%	100%	100%	100%
Moving Percent Detection	100%	100%	100%	100%
Still Percent Detection	100%	100%	100%	100%
Detection Time (Seconds) ± Average Deviation	8 ± 3	8 ± 4	10 ± 3	6 ± 2
Average Distance Uncertainty	+4% ± 12%	-8% ± 13%	14% ± 19%	+7% ± 10%

Improvements over the overall performance of the Xaver 400 (Table 10: Xaver 400 – All: ATW) in several metrics are seen when tested against the glass door. This indicates that the glass is easily penetrated by the signal produced by the Xaver 400.

10.2.2 SO – Glass

The following tests were performed with TTWS devices in SO mode against the glass door:

- Target 16 m from device, SO distance 12 m (Xaver 400, ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 19 m from device, SO distance 12 m (Xaver 400, ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)

Table 34: Xaver 400 – Glass: SO

Characteristic	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	30	10	10	10
Percent Detection	80%	100%	100%	40%
Moving Percent Detection	75%	100%	100%	25%
Still Percent Detection	83%	100%	100%	50%
Detection Time (Seconds) ± Average Deviation	8 ± 3	10 ± 5	6 ± 1	8 ± 0
Average Distance Uncertainty	-8% ± 10%	-10% ± 12%	-2% ± 1%	-17% ± 11%

The SO results of the Xaver 400 against glass show a significant improvement over the detection of the overall SO results of the Xaver 400 (see Table 11: SO Results: Overall); indicating that glass is easily penetrated by the signal of the Xaver 400. The SO high penetration signal was very weak compared to the ATW high penetration signal. Many times the SO signal was lost in what appears to be random noise. The tracker and expert mode algorithms appear to be able to take advantage of Doppler effects which are unavailable in high penetration mode.

Table 35: AKELA – Glass: SO

Characteristic	Result
Total Number of Measurements Attempted	10
Percent Detection	70%
Moving Percent Detection	100%
Still Percent Detection	50%
Detection Time (Seconds) ± Average Deviation	10 ± 3
Average Distance Uncertainty	+9% ± 12%

The percent detection of the ASTIR at SO distances from glass seems to be similar to the detection of the overall SO results of the ASTIR (see Table 11: SO Results: Overall), indicating that glass tested in this effort is a medium barrier for the ASTIR.

In both ATW and SO, the Range-R and the ASTIR did not perform as well as the Xaver 100 and the Xaver 400 against glass in ATW and SO tests, respectively. This is a reversal of the typical pattern seen and may be a function of the barrier characteristics as indicated in Section 2.3 Technology Background; the ASTIR and the Range-R use similar frequencies for the signal, but the Xaver series uses an Ultra Wide Band signal which operates over a wider range of frequencies. It may be that this barrier is not able to transmit the frequencies used by the Range-R and the ASTR as well as the frequencies used by the Xaver series.

11.0 SITE 3 – OFFICE BUILDING (MODERN)

The Robert H. Mollohan Research Center is an office building with a glass exterior and interior walls constructed of drywall with metal studs. The building has larger, unused rooms that were able to be used for testing the devices against drywall barriers with metal studs for support. The open floor plan and more extensive use of metal and glass in its construction resulted in the CoE classifying the building as a modern office building as opposed to the more traditional office building (see Section 10.0 SITE 2 – OFFICE BUILDING (TRADITIONAL))

11.1 Dry Wall With Metal Studs (DWMS) Wall

Two large adjoining rooms were used for this set of tests. The wall between them (the test barrier) is constructed with metal studs that have drywall on either side off the metal studs. The metal studs are separated by 24”. Since there is drywall on both sides of the wall, the signal passes through two sheets of drywall before propagating to the target and back (where it, again, encounters two sheets of drywall).

Table 36: Barrier Summary – Drywall with Metal Support Studs

Barrier Feature	Details
Material Type(s)	Gypsum board
Thickness	5.5”
Metal Components	Metal studs on 24” centers
Interior	Large open room
Openings	Doorways to the left and right (~1 m from barrier wall) and one doorway to the right (~15m)
Wall Dimensions	8’ x 16’ (estimated)
Other Features	None

11.1.1 ATW – DWMS

Although metal is known to block the signal from the devices, no intentional effort was made to either avoid or incorporate the metal studs into the testing location (as a practitioner would not be expected to have knowledge of the construction details). Per standard testing procedure, three separate locations along the barrier were tested.

The following tests were performed with TTWS devices in ATW mode against DWMS:

- Target 4 m from device (Range-R, Xaver-100, Xaver 400),
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 5, 6, 7 m from device (Xaver – 100)
  - Target standing still (Facing toward)
  - Target walking (perpendicular)
- Target 8 m from device (Range-R, Xaver-100, Xaver 400),
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 15 m (~49 ft) from device (Range-R, Xaver 400

Table 37: Range-R – DWMS: ATW

Characteristic	Result
Total Number of Measurements Attempted	30
Percent Detection	80%
Moving Percent Detection	100%
Still Percent Detection	67%
Detection Time (Seconds) ± Average Deviation	14 ± 8
Average Distance Uncertainty	+4% ± 12%

Percent detection through drywall with metal studs is a little better than the overall (Table 8: ATW Results: Overall), but the average detection time is slightly longer (~1 second) than the overall average detection time.

Table 38: Xaver 100 – DWMS: ATW

Characteristic	Overall	Normal Mode	High Penetration Mode
Total Number of Measurements Attempted	51	41	10
Percent Detection	61%	56%	80%
Moving Percent Detection	95%	100%	75%
Still Percent Detection	37%	25%	83%
Detection Time (Seconds) ± Average Deviation	9 ± 5	9 ± 6	8 ± 3
Average Distance Uncertainty	-3% ± 19%	-11% ± 16%	+5% ± 24%

The results of the Xaver 100 against drywall with metal studs are slightly better than the overall with a few percentage better detection, and a second or two faster detection times. However the distance uncertainty is significantly improved over the overall.

Table 39: Xaver 400 – DWMS: ATW

Characteristic	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	39	13	13	13
Percent Detection	97%	100%	100%	92%
Moving Percent Detection	100%	100%	100%	100%
Still Percent Detection	96%	100%	100%	89%
Detection Time (Seconds) ± Average Deviation	5 ± 2	4 ± 1	5 ± 2	7 ± 2
Average Distance Uncertainty	+1% ± 3%	+1% ± 2%	+1% ± 2%	+3% ± 2%

The Xaver 400 detected a target in every instance of testing in using both the Tracker Mode and Expert Mode. High Penetration mode indicated that there were a lot of superfluous signals in the area making it difficult for an operator to identify a target. The fact that the detection algorithm of the Tracker mode was able to detect a target 100% of the time indicates that the Xaver 400 is efficient at picking out a target in an electronically noisy environment.

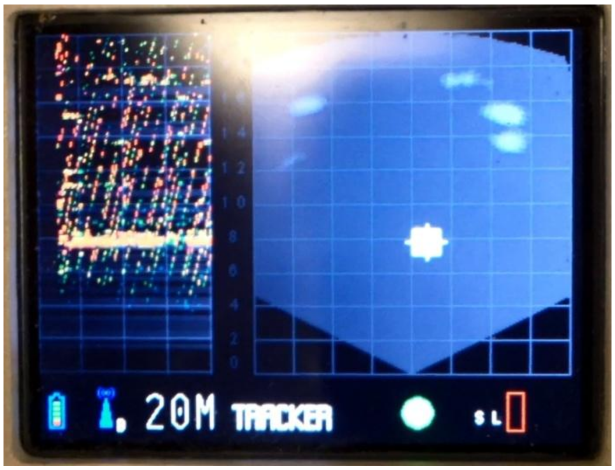

Figure 19: Xaver 400 – DWMS: ATW (Tracker)
Identified target standing sideways at 8 m within 4 seconds in Tracker Mode
Photo by NLECTC SSBT CoE

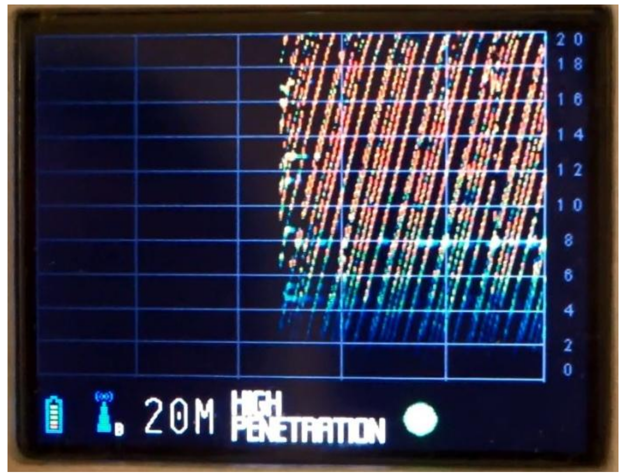

Figure 20: Xaver 400 – DWMS: ATW (HP)
Difficult to make out target standing sideways at 8 m in High Penetration mode
Photo by NLECTC SSBT CoE

11.1.2 ATW – DWMS (15 m)

The rooms were large enough to allow for longer ATW tests for devices that could detect beyond 8 m. This was performed at a distance of 15 m with the Range-R and the Xaver 400 (note that the preproduction model of the Xaver 100 has a range of 8 m and was not tested at this longer range).

The following tests were performed with TTWS devices in ATW mode against the drywall metal studs wall:

- Target 15 m from device (Xaver 400, ASTIR)
    - Target standing still (Facing toward, facing sideways, and facing away)
    - Target walking (parallel and perpendicular)

Table 40: Range-R – DWMS: ATW: 15 m

Characteristic	Result
Total Number of Measurements Attempted	15
Percent Detection	60%
Moving Percent Detection	100%
Still Percent Detection	33%
Detection Time (Seconds) ± Average Deviation	11 ± 7
Average Distance Uncertainty	-23% ± 28%

As would be expected, percent detection decreased with increased distance as did average distance uncertainty. Average detection time is slightly faster for 15 m, but this may be because a higher percentage of moving detections were made over still detections (moving detections are typically easier and faster to detect.)

At 15 m from the device, the target was very near the back wall. To check to see if the proximity of the wall had an effect, an additional test was performed. Three measurements were taken with the target standing facing at 14 m. The Range-R was used for this measurement, and the result was three out of three times the target was detected. This is in contrast at 15 m (very near the back wall) when only one out of three measurements detected the target. While the target being closer to the device will help increase the strength of the reflected signal, it is doubtful that a 7% decrease in the distance would result in a threefold increase in the detection of a target.

Table 41: Xaver 400 – DWMS: ATW: 15 m

	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	15	5	5	5
Percent Detection	87%	100%	100%	60%
Moving Percent Detection	100%	100%	100%	100%
Still Percent Detection	78%	100%	100%	33%
Detection Time (Seconds) ± Average Deviation	9 ± 5	7 ± 6	11 ± 5	7 ± 1
Average Distance Uncertainty	-3% ± 1%	-3% ± 0%	-3% ± 1%	-1% ± 0%

Tracker and expert modes were able to identify a target 100% of the time through drywall, but the longer range did increase the amount of time required to detect the target. High penetration mode performance decreased significantly, most likely due to the signal noise interfering with the operator’s ability to detect the target.

11.1.3 SO – DWMS

The larger size of the rooms in the office building allowed for SO measurements to be taken at a SO distance of 7 m.

The following tests were performed with TTWS devices in SO mode against the cinder block wall:

- Target 15 m from device, SO distance 7 m (Xaver 400, ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)

Table 42: Xaver 400 – DWMS: SO

Characteristic	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	15	5	5	5
Percent Detection	40%	60%	60%	0%
Moving Percent Detection	50%	50%	100%	0%
Still Percent Detection	33%	67%	33%	0%
Detection Time (Seconds) ± Average Deviation	6 ± 1	5 ± 1	8 ± 2	No Detection
Average Distance Uncertainty	-2% ± 1%	-2% ± 1%	-3% ± 0%	No Detection

Target percent detection in tracker and expert modes are similar to the overall SO results for the Xaver 400 (Table 11: SO Results: Overall), however there was no detection in High Penetration mode. This is most likely due to the electronic environment making it difficult for an operator to identify a target.

Table 43: ASTIR – DWMS: SO

Characteristic	Result
Total Number of Measurements Attempted	10
Percent Detection	80%
Moving Percent Detection	100%
Still Percent Detection	67%
Detection Time (Seconds) ± Average Deviation	9 ± 5
Average Distance Uncertainty	+1% ± 2%

The environment didn't appear to affect the AKELA during SO operation against drywall. Percent detection, average detection time, and distance uncertainty all were increased over the overall results for the ASTIR.

12.0 SITE 4 – RESIDENTIAL HOUSE

A house owned by the West Virginia High Technology Consortium (WVHTC) Foundation was utilized for several different barrier tests. The house is unoccupied and situated in a relatively isolated and wooded location. The house is of relatively recent construction (~20 years estimate) and still has electrical service, but not water. Barriers tested included exterior walls (one with vinyl siding and one with wooden siding) and a brick wall.

Figure 21: Foundation House – Exterior
Foundation House as seen from 30 m. First floor brick wall, lower left is the test barrier for the garage.
Photo by NLECTC SSBT CoE

Figure 22: Foundation House – Interior
Interior of room used for both vinyl siding and wood siding
Photo by NLECTC SSBT CoE

12.1 Vinyl Siding Exterior Wall

This barrier consisted of vinyl siding on the exterior, with plywood, insulation, wood studs and drywall on the interior. The interior room was less than the standard 8 m and therefore ATW measurements only consisted of the target positioned 4 m from the barrier.

Table 44: Barrier Summary – Exterior wall with vinyl siding

Barrier Feature	Details
Material Type(s)	Vinyl Siding, plywood, insulation, wood studs and drywall
Thickness	5.75" (estimated)
Metal Components	Metal components on door on left hand side of wall (hinges, door knob, etc.)
Interior	Open; fireplace to the left
Openings	Double Doorway
Wall Dimensions	8' x 12'
Other Features	*None*

Figure 23: Foundation House; Back Room; Exterior vinyl siding
Photo by NLECTC SSBT CoE

12.1.1 ATW – Vinyl Siding

The following tests were performed with TTWS devices in ATW mode against the vinyl siding wall:

- Target 4 m (~13 ft) from device (Range-R, Xaver-100, Xaver 400),
    - Target standing still (Facing toward, facing sideways, and facing away)
    - Target walking (parallel and perpendicular)

Table 45: Range-R – Exterior Wall with Vinyl Siding: ATW

Characteristic	Result
Total Number of Measurements Attempted	15
Percent Detection	67%
Moving Percent Detection	100%
Still Percent Detection	44%
Detection Time (Seconds) ± Average Deviation	11 ± 4
Average Distance Uncertainty	-3% ± 3%

The percent detection against this barrier was lower than the overall percent detection (Table 8: ATW Results: Overall). The decreased time for detection could be due to a larger fraction of moving targets being detected than still targets (moving targets are typically detected faster than still targets).

Table 46: Xaver 100 – Exterior Wall with Vinyl Siding: ATW

Characteristic	Overall	Normal Mode	High Penetration Mode
Total Number of Measurements Attempted	15	10	5
Percent Detection	73%	60%	100%
Moving Percent Detection	100%	100%	100%
Still Percent Detection	56%	33%	100%
Detection Time (Seconds) ± Average Deviation	9 ± 2	9 ± 2	10 ± 2
Average Distance Uncertainty	-25% ± 29%	-61% ± 19%	-1% ± 1%

Percent detection for both normal mode and High Penetration mode of the Xaver 100 were higher than the overall ATW results (Table 9: Xaver 100 – All: ATW). This indicates that the barrier was easier for the Xaver 100 to penetrate than the majority of barriers. However, the distance uncertainty for the vinyl siding was higher, indicating that the Xaver 100 had a difficult time locating the target.

Table 47: Xaver 400 – Exterior Wall with Vinyl Siding: ATW

Characteristic	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	15	5	5	5
Percent Detection	93%	100%	80%	100%
Moving Percent Detection	100%	100%	100%	100%
Still Percent Detection	89%	100%	67%	100%
Detection Time (Seconds) ± Average Deviation	13 ± 8	17 ± 14	12 ± 4	10 ± 4
Average Distance Uncertainty	+1% ± 2%	+1% ± 2%	+1% ± 1%	-3% ± 0%

Both Tracker and High Penetration modes were able to detect a target 100% of the time, with Expert mode detecting 80% of the time. Detection times were increased over the Overall results of ATW measurements for the Xaver 400 (Table 10: Xaver 400 – All: ATW).

12.1.2 SO – Vinyl Siding

The following tests were performed with TTWS devices in SO mode against the vinyl siding wall:

- Target 16 m (~52.5 ft) from device, SO distance 12 m (~39 ft) (Xaver 400, ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 19 m (~62 ft) from device, SO distance 12 m (~39 ft) (Xaver 400, ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)

Table 48: Xaver 400 – Exterior Wall with Vinyl Siding: SO

Characteristic	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	30	10	10	10
Percent Detection	47%	50%	60%	30%
Moving Percent Detection	58%	75%	50%	50%
Still Percent Detection	39%	33%	67%	17%
Detection Time (Seconds) ± Average Deviation	11 ± 5	11 ± 6	8 ± 3	15 ± 8
Average Distance Uncertainty	0% ± 1%	0% ± 0%	0% ± 0%	-1% ± 0%

Percent detection was slightly decreased when compared to the overall results of the Xaver 400 overall SO results (Table 11: SO Results: Overall), and detection time was also slightly increased. The distance uncertainty results indicate that once a target was detected, there was almost no question as to the location of the target.

Table 49: AKELA – Exterior Wall with Vinyl Siding: SO

Characteristic	Result
Total Number of Measurements Attempted	15
Percent Detection	60%
Moving Percent Detection	83%
Still Percent Detection	44%
Detection Time (Seconds) ± Average Deviation	13 ± 8
Average Distance Uncertainty	+22% ± 23%

Percent detection of the ASTIR decreased compared to the overall result of the ASTIR (Table 11: SO Results: Overall), and detection time was slightly improved over the overall results. However, the distance uncertainty was significantly larger than the overall results.

12.2 House Garage

The barrier is an external garage wall that has brick on the outside. Drywall on the inside of the garage, is supported by wood studs, and is filled with insulation in the void spaces between the wooden studs.

Figure 24: Garage – Interior
Interior view of Garage. Far wall was barrier tested (Brick, plywood, insulation, and dry wall); See Figure 21: Foundation House – Exterior
Photo by NLECTC SSBT CoE

The garage is a two car garage with two metal garage doors and an entry door to the left of the garage doors. The remainder of the house is to the left of the garage and to the rear of the garage. Testing was done on the right side wall of the garage, the wall is perpendicular to the wall with the two garage doors. Two windows are positioned on the test wall, and testing points for ATW measurements were between the two windows, to the left of the left window and to the right of the right window. ATW tests as well as stand-off tests were performed at this site.

Table 50: Barrier Summary – Brick Wall

Barrier Feature	Details
Material Type(s)	Brick, wooden studs, insulation, drywall
Thickness	8” (estimate)
Metal Components	Window frames
Interior	Open
Openings	Two windows
Wall Dimensions	8’ x 16’ (estimate)
Other Features	Metal garage doors on perpendicular wall may cause more reflections

12.2.1 ATW – House Garage

The following tests were performed with TTWS devices in ATW mode against the brick wall:

- Target 4 m from device (Ranger-R, Xaver-100, Xaver 400),
    - Target standing still (Facing toward, facing sideways, and facing away)
    - Target walking (parallel and perpendicular)
- Target 8 m from device (Ranger-R, Xaver-100, Xaver 400),
    - Target standing still (Facing toward, facing sideways, and facing away)
    - Target walking (parallel and perpendicular)

Table 51: Range-R – House Garage: ATW

Characteristic	Result
Total Number of Measurements Attempted	30
Percent Detection	70%
Moving Percent Detection	100%
Still Percent Detection	50%
Detection Time (Seconds) ± Average Deviation	14 ± 6
Average Distance Uncertainty	+16% ± 16%

Compared to the overall ATW results of the Range-R (Table 8: ATW Results: Overall), there was a slight decrease in percent detection and slight increase in detection time; however the difference was not large. The average uncertainty is higher for the brick wall, but this may be due to reflections coming from the metal garage doors on a perpendicular wall.

Table 52: Xaver 100 – House Garage: ATW

Characteristic	Overall	Normal Mode	High Penetration Mode
Total Number of Measurements Attempted	30	20	10
Percent Detection	53%	55%	50%
Moving Percent Detection	83%	88%	75%
Still Percent Detection	33%	33%	33%
Detection Time (Seconds) ± Average Deviation	21 ± 12	25 ± 13	13 ± 10
Average Distance Uncertainty	-47% ± 31%	-71% ± 16%	0% ± 0%

Percent detection for the Xaver 100 are similar to the overall performance of the Xaver 100 in ATW measurements for Normal Mode (Table 9: Xaver 100 – All: ATW), however High Penetration mode would have been significantly more difficult for an operator to make out a target than the overall results. The amount of time to detect a target is significantly increased (over double for Normal Mode). The low detection uncertainty in High Penetration mode could be due to a lower than normal detection of still targets who happened to be measured at just the right distance. A similar argument could be made for the large distance uncertainty of the normal mode where a small number of measurements happened to be significantly off. If a statically low number of still detections were made, the uncertainty may be skewed.

Table 53: Xaver 400 – House Garage: ATW

Characteristic	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	31	11	10	10
Percent Detection	90%	100%	80%	90%
Moving Percent Detection	92%	100%	75%	100%
Still Percent Detection	89%	100%	83%	83%
Detection Time (Seconds) ± Average Deviation	11 ± 6	14 ± 11	9 ± 4	8 ± 3
Average Distance Uncertainty	+6% ± 9%	0% ± 3%	+12% ± 12%	+9% ± 12%

Percent detection of the Xaver 400 against the brick wall improved for Tracker Mode and for High Penetration mode over the overall ATW (Table 10: Xaver 400 – All: ATW), however expert mode decreased overall. This decrease in the Expert Mode performance could be due to the garage doors on the wall perpendicular to the left side of the barrier. Expert mode measurements were typically taken at the far left of the barrier, which would be nearer to the metal garage doors. This could potentially cause more reflections of the main signal.

12.2.2 SO – House Garage

The following tests were performed with TTWS devices in SO mode against the cinder block wall:

- Target 16 m from device, SO distance 12 m (Xaver 400, ASTIR)
    - Target standing still (Facing toward, facing sideways, and facing away)
    - Target walking (parallel and perpendicular)
- Target 19 m from device, SO distance 12 m (Xaver 400, ASTIR)
    - Target standing still (Facing toward, facing sideways, and facing away)
    - Target walking (parallel and perpendicular)

Table 54: Xaver 400: House Garage – SO

Characteristic	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	30	10	10	10
Percent Detection	30%	40%	50%	0%
Moving Percent Detection	33%	50%	50%	0%
Still Percent Detection	28%	33%	50%	0%
Detection Time (Seconds) ± Average Deviation	15 ± 9	16 ± 9	14 ± 8	No Detection
Average Distance Uncertainty	-27% ± 20%	-55% ± 20%	-13% ± 15%	No Detection

The brick wall proved to be a difficult barrier for the Xaver 400 in SO operation when compared to the overall SO results of the Xaver 400 (Table 11: SO Results: Overall). Percent detection, average detection time, and distance uncertainty all showed decreased performance compared to the overall SO results for the Xaver 400.

Table 55: ASTIR: House Garage – SO

Characteristic	Result
Total Number of Measurements Attempted	10
Percent Detection	30%
Moving Percent Detection	50%
Still Percent Detection	17%
Detection Time (Seconds) ± Average Deviation	12 ± 4
Average Distance Uncertainty	0% ± 0%

Compared to the Overall SO results for the ASTIR (Table 11: SO Results: Overall), the brick wall was a very difficult barrier to penetrate and detect targets. Percent detection decreased by 38% and average detection time was slightly decreased as compared to the overall SO results for the ASTIR. The highly accurate and precise average distance uncertainty may be due to a statically low number of detections of still targets which may result in skewed averages.

12.2.3 ASTIR Long Range SO (30 m) – House Garage

The surrounding terrain allowed for testing long range SO of the ASTIR, although there was a small amount of potential environmental interference from trees, shrubs and tall grass. (see Figure 21: Foundation House – Exterior)

The following tests were performed with the ASTIR against the brick wall at long range SO:

- Target 34 m from device, SO distance 30 m (ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)
- Target 38 m from device, SO distance 30 m (ASTIR)
  - Target standing still (Facing toward, facing sideways, and facing away)
  - Target walking (parallel and perpendicular)

Table 56: AKELA: House Garage – 30 m SO

Characteristic	Result
Total Number of Measurements Attempted	10
Percent Detection	80%
Moving Percent Detection	75%
Still Percent Detection	83%
Detection Time (Seconds) ± Average Deviation	13 ± 7
Average Distance Uncertainty	-9% ± 7%

It is interesting that the AKELAs percent detection improved significantly at longer range. One possible reason is that the angle of the signal passing through the windows is less when the ASTIR is placed at longer ranges. This may allow a more direct path for the signal to travel into the garage instead of passing through or reflecting off of the floor, ceiling, and perpendicular walls and allowing a higher percentage of multipath reflected signals to reach the target.

12.3 Wood Siding Exterior Wall (House Porch)

This barrier consisted of wood siding on the exterior, with plywood, insulation, wood studs and drywall on the interior. The interior room was less than the standard 8 m and therefore ATW measurements only consisted of the target positioned 4 m from the barrier. The external measuring locations were accessible by a covered porch which was approximately seven feet off the ground. The porch was only a couple of meters wide which made standard SO measurements impossible.

Table 57: Barrier Summary – Exterior wall with wood siding

Barrier Feature	Details
Material Type(s)	Wood Siding, plywood, insulation, wood studs and drywall
Thickness	5.75” (estimate)
Metal Components	Door and window hardware, frames
Interior	Insulation, wood studs
Openings	Doorway and two windows
Wall Dimensions	8’ x 12’
Other Features	*None*

Figure 25: Interior view of wall with wood siding.
Photo by NLECTC SSBT CoE

Figure 26: Exterior view of wall with wood siding
Photo by NLECTC SSBT CoE

12.3.1 ATW – Wood Siding

The following tests were performed with TTWS devices in ATW mode against the exterior wall with wood siding:

- Target 4 m (~13 ft) from device (Range-R, Xaver-100, Xaver 400),
    - Target standing still (Facing toward, facing sideways, and facing away)
    - Target walking (parallel and perpendicular)

Table 58: Range-R – House Porch: ATW

Characteristic	Result
Total Number of Measurements Attempted	15
Percent Detection	80%
Moving Percent Detection	100%
Still Percent Detection	67%
Detection Time (Seconds) ± Average Deviation	9 ± 4
Average Distance Uncertainty	+2% ± 25%

Compared to the overall ATW results for the Range-R (Table 8: ATW Results: Overall), this barrier did not seem as difficult to penetrate as the average of all barriers. Percent detection is higher than the overall, and the average detection time is slightly shorter. Compared to the vinyl siding (which was the opposite wall of the same room of the wood siding) the results show a marked increase in percent detection and decrease in average detection time.

Table 59: Xaver 100 – House Porch: ATW

Characteristic	Overall	Normal Mode	High Penetration Mode
Total Number of Measurements Attempted	15	10	5
Percent Detection	53%	30%	100%
Moving Percent Detection	67%	50%	100%
Still Percent Detection	44%	17%	100%
Detection Time (Seconds) ± Average Deviation	7 ± 3	7 ± 2	7 ± 3
Average Distance Uncertainty	-13% ± 33%	-78% ± 0%	+9% ± 5%

Normal mode percent detection is significantly lower than the overall average for ATW measurements of the Xaver 100 (Table 9: Xaver 100 – All: ATW), however high penetration mode shows a significant increase in percent detection over the overall results. The high distance uncertainty may indicate that the device had difficulty isolating a target, which may be easier for an operator when presented with the HP mode data. Compared with the vinyl siding wall, the Normal mode had a significantly harder time identifying a target through wood, although HP mode was identical (100% in both cases).

Table 60: Xaver 400 – House Porch: ATW

Characteristic	Overall	Tracker Mode	Expert Mode	High Penetration Mode
Total Number of Measurements Attempted	15	5	5	5
Percent Detection	100%	100%	100%	100%
Moving Percent Detection	100%	100%	100%	100%
Still Percent Detection	100%	100%	100%	100%
Detection Time (Seconds) ± Average Deviation	7 ± 2	8 ± 2	9 ± 2	5 ± 1
Average Distance Uncertainty	+1% ± 2%	0% ± 0%	-2% ± 2%	+5% ± 2%

The Xaver 400 had an easy time detecting and indentifying a target through the barrier. Percent detection was 100% in all cases, the times are comparable to the average of the overall detection times (Table 10: Xaver 400 – All: ATW), and the average uncertainty is also better in all modes except HP. Percent detections through vinyl siding (

Table 47: Xaver 400 – Exterior Wall with Vinyl Siding: ATW) were also high (Expert mode did miss one detection out of five), but on the average it took longer to identify the target through the vinyl barrier.

13.0 ANGULAR DEPENDENCE OF DETECTION

The ability of the devices to detect targets as a function of azimuth angle was investigated; measurements were taken at various angles using a moving target. Two sets of tests were performed. In the Linear Angular tests (LAT), the target walked directly away from the device to the maximum detection range then straight back to the device at various angles. In the Angular Arc Tests (AAT), the target walked from 0° to 90° and back in an equidistant arc with a radius of approximately half the detection range. Barriers were not used in either of testing methodologies. The Xaver 400 and the ASTIR were tested by mounting the device on a tripod, and the Xaver 100 and the Range-R-Link were stabilized by placing them on a small table. The Range-R-Link was used instead of the Range-R (these are identical except for the addition of the wireless communication of the Range-R-Link) so that the device could be operated hands free and not have to be stabilized against a barrier.

Two sites were used for these measurements. The first site was directly behind the Allen Mollohan Office Building (Site 1). The ASTIR and the Xaver 400 were tested in this location. After testing these devices, pedestrian traffic increased at this location, and further testing of the Xaver 100 and the Range-R were done at a second location (Site 2); an empty parking area further behind the initial testing site.

Figure 27: Site 1 (ASTIR and Xaver 400)
Photo by NLECTC SSBT CoE

Figure 28: Site 2 (Xaver 100 and Range-R)
Photo by NLECTC SSBT CoE

13.1 Linear Angular Tests (LAT)

In preparation of the measurements, the device was positioned at a predetermined location and markers were placed along the target's intended path at 1m intervals for the first 20 m, 5 m intervals from 20 m to 50 m and at 10 m intervals thereafter up to 70 m as aides to determine distance during measurement. The target would walk to the maximum range of the device being tested. Measurements were initiated with the target at 5m. After the device detected the target at 5 m (or several seconds had elapsed in the case there were no detection), the target would then walk stepwise (pausing ~2 seconds between steps) to the maximum range of the device. To change the angle of the target's path relative to the device, the device being tested would be rotated to the left (away from the office building) to the specified angle. Angles tested were 0°, 30°, 45°, 60°, and 90° (0° being straight in front of the device).

In the sections below, the graphics indicate the angle of the target path and whether the target would be detected or not by the device. The angle of the target path is indicated by lines radiating out from 5 m to the maximum detection distance of the device. the color of the line indicates whether the target was detected, not detected, or may be detected along the path of the line (green = target detected, red = no target detected, orange = target detection uncertain).

13.1.1 Range-R-Link LAT Testing

The target walked from 5 m to 15 m during testing. Note that the maximum reported detection range of the Range-R is 50 ft (~15 m) (see Table 4: Range-R Usability Assessment Summary). Target path is indicated by the angles of the lines, and the detection is indicated by colors (green = detection, red = no detection, and orange = target detection uncertain).

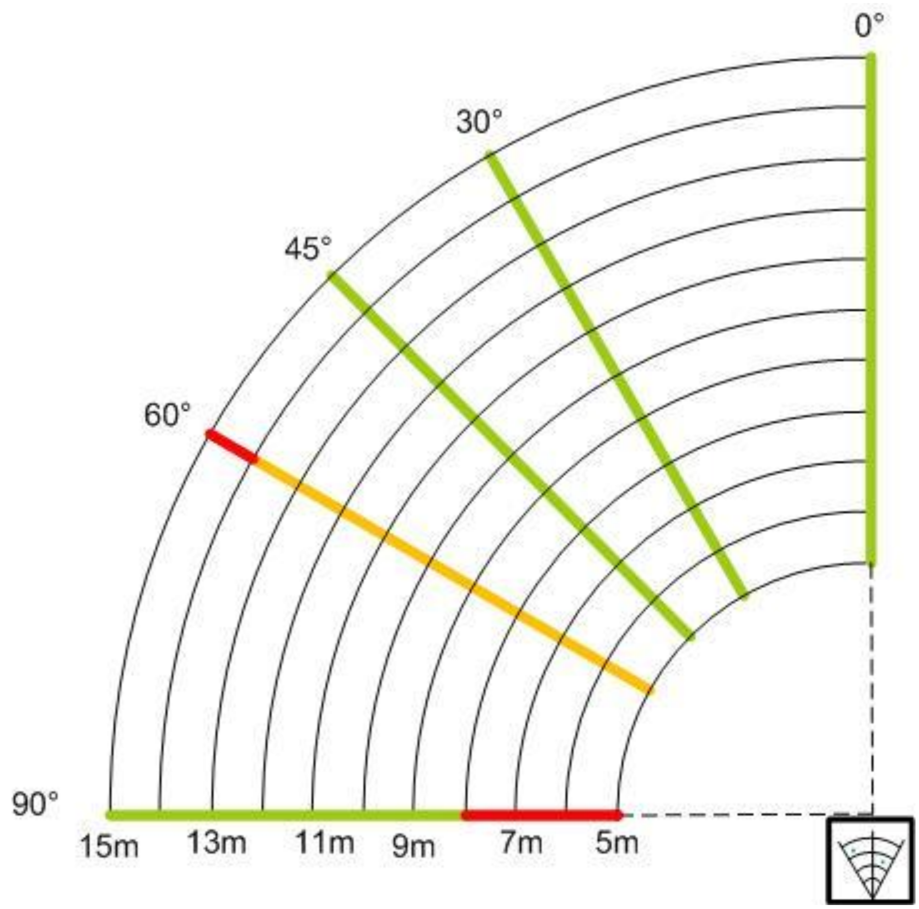

Figure 29: Angular Performance of the Range-R

Table 61: Range-R: LAT: SW: Away

Range-R Link: Target walking Stepwise (SW) away from device (5 m to 15 m)	
0°	Able to track all the way out to 15 m
30°	Able to track all the way out to 15 m
45°	Able to track all the way out to 15 m
60°	Readings were on and off several times, but able to detect to 14m
90°	Picked target up at 8 m and good out to 15m

The Range-R was able to detect the target all the way to 90°, although it began to detect/lose/redetect the target at 45°. Interestingly, the detection at 90° seemed to be more stable than either 45° or 60°.

13.1.2 Xaver 100 LAT Testing

The target walked from 5 m to 8 m during testing. Note that the maximum reported detection range of the Xaver 100 is 8 m (see Table 5: Xaver 100 Usability Assessment Summary). Measurements were taken with the device operating in both Normal mode and High Penetration mode.

13.1.2.1 Xaver 100 - Normal Mode

Target path is indicated by the angles of the lines, and the detection is indicated by colors (green = detection, red = no detection, and orange = target detection uncertain).

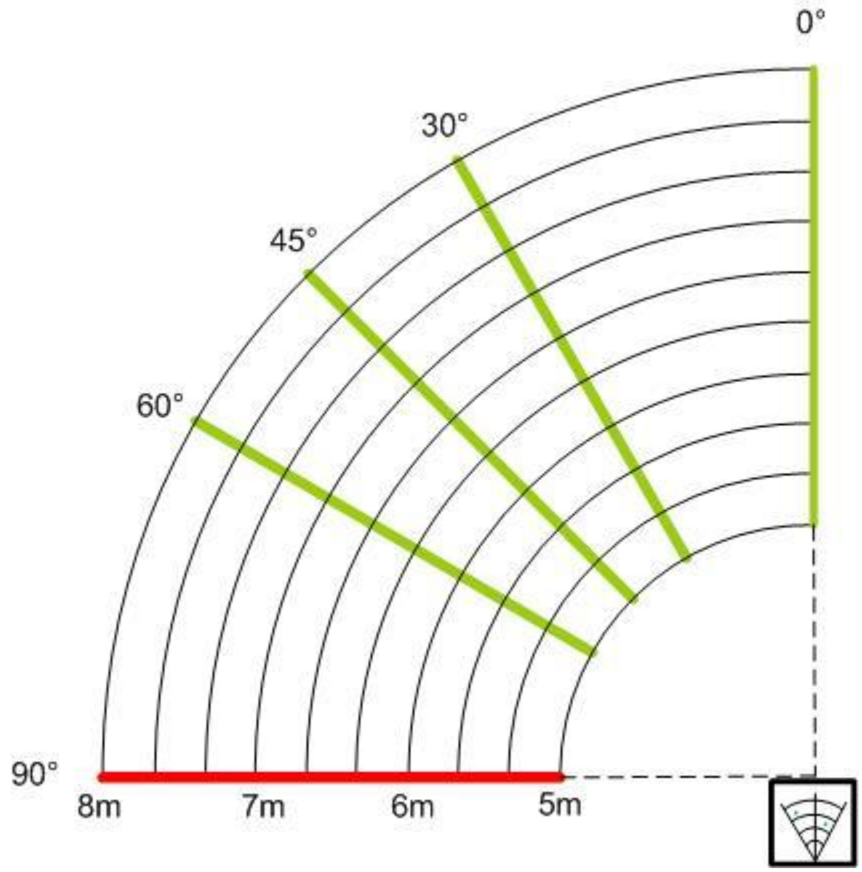

Figure 30: Angular Performance of the Xaver 100 - Normal Mode

Table 62: Xaver 100: Normal Mode: LAT: SW: Away

Xaver 100: Normal Mode: Target walking Stepwise (SW) away from device (5 m to 8 m)	
0°	Started at about 3.5 m *(5 m actual)* and fluctuated around 3.0 m to 4.0 m rest of the way out
30°	Detection was made all the way out, but measurements stayed between 3.8 m and 5.0 m most of the way (display showed 7.0 m toward the end).
45°	Detection was made all the way out, but reading fluctuated between 0.5 m and 1.8 m until target was at 7 m, then reading fluctuated between 5 m and 4.3 m to end
60°	Detection was made all the way out; reading showed 4.7 m for most of the time
90°	No Detection

Normal mode was able to detect that a target was present up to 60° from center when the target was moving stepwise; this would indicate a nominal viewing angle of 120° without a barrier. However, the distance measurements became unreliable almost immediately. At 0° when the target walked up and back at a normal pace, the Xaver 100 indicated a target was present, but it fluctuated between 1 and 3.8 m for most of the time.

13.1.2.2 Xaver 100 - High Penetration Mode

Target path is indicated by the angles of the lines, and the detection is indicated by colors (green = detection, red = no detection, and orange = target detection uncertain).

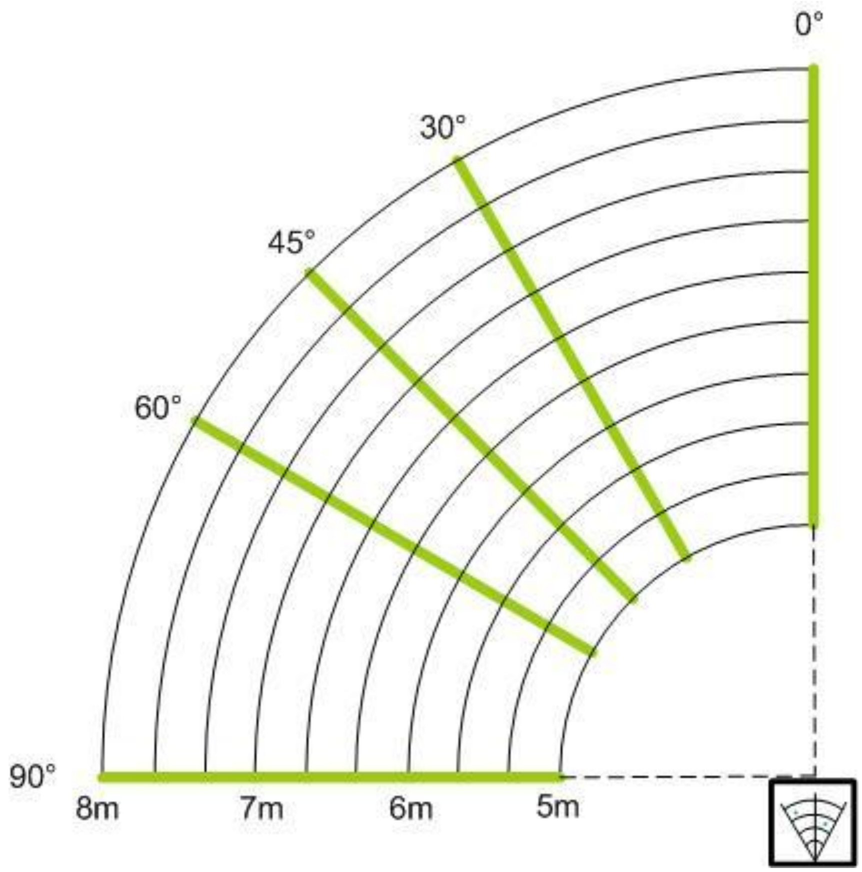

Figure 31: Angular Performance of the Xaver 100 - High Penetration Mode

At all angles, the Xaver 100 produced identifiable graphs of the moving target. The 90° angle measurement was a little more difficult to make out, but a trained operator would almost certainly conclude that a target was present, but the range may be off because of reflections.

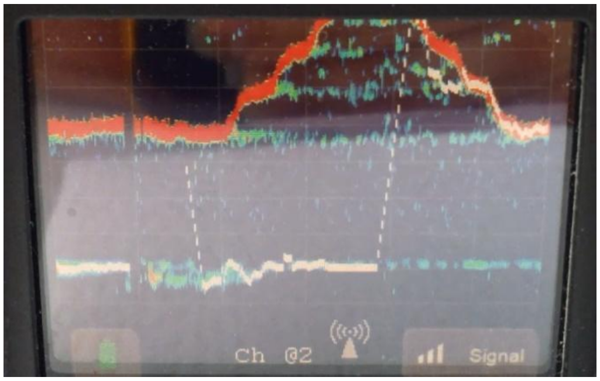

Figure 32: X100 in High Penetration mode 60° to target; target walking stepwise Photo by NLECTC SSBT CoE

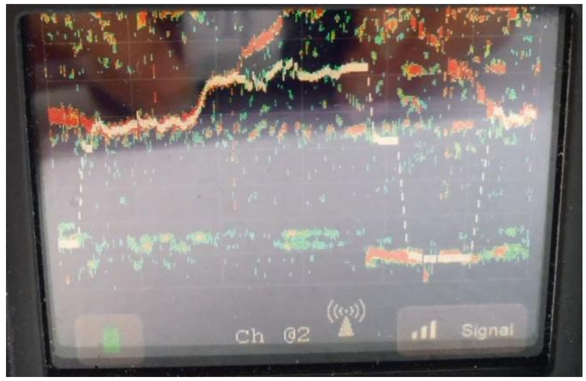

Figure 33: X100 in High Penetration mode 90° to target; target walking stepwise. Photo by NLECTC SSBT CoE

When viewed in High penetration mode, the display indicates that a target is present at every angle, however the Xaver 100 had some difficulty identifying the target in normal mode at 60° (see Table 62: Xaver 100: Normal Mode: LAT: SW: Away). Even at 90° (see Figure 31: Angular Performance of the Xaver 100 - High Penetration Mode), the CoE operators would conclude that a target was present. Normal mode did not show any detection at 90°.

13.1.3 Xaver 400 LAT Testing

The target walked from 5 m to 20 m during testing. Note that the maximum reported detection range of the Xaver 400 is 20 m (see Table 6: Xaver 400 Usability Assessment Summary). Measurements were taken with the device operating in Tracker mode, Expert mode, and High Penetration mode. Note that the performance of the Xaver 400 was exceptionally poor for this series of tests for some unknown reason. Barrier tests showed the Xaver 400 excelled in target detection in every mode and typically was the best performer of the ATW devices (e.g., Sections 10.1.1 ATW – Cubicle Material, 10.2.1 ATW – Glass, and 10.2.2 SO – Glass). However, during this series of tests (which did not include a barrier), the Xaver 400 underperformed for some unknown reason.

This was a series of tests carried out over the course of several hours with no change in the performance noted. The Xaver 400 performed well in other (barrier based) tests which were performed both before and after the angular tests. The batteries were well charged, and there were no performance issues previously noted while using low batteries until the device automatically shuts off. One possibility for the poor performance of the Xaver 400 is that the physical layout of the device and/or that the signal processing have been fine tuned to require a barrier to be present and that targets that are not behind a barrier are less likely to be detected. However this is pure speculation and the true reason for the poor performance for these tests is not known.

13.1.3.1 Xaver 400 - Tracker Mode

Target path is indicated by the angles of the lines, and the detection is indicated by colors (green = detection, red = no detection, and orange = target detection uncertain).

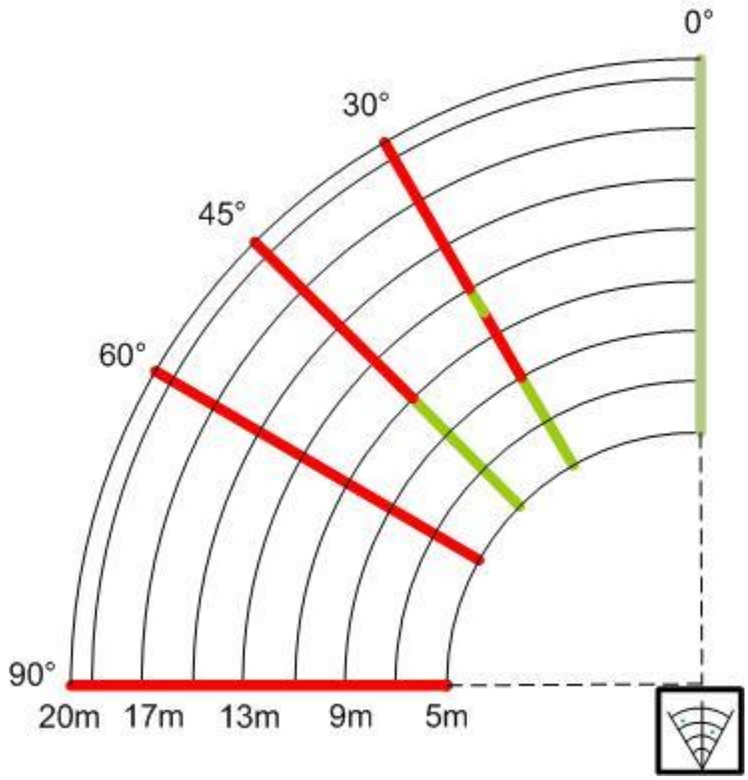

Figure 34: Angular Performance of the Xaver 400 – Tracker Mode

Table 63: Xaver 400: Tracker Mode: LAT: SW: Away

Xaver 400: Tracker Mode: Target walking Stepwise (SW) away from device (5 m to 20 m)	
0°	Tracked all the way
30°	Tracked initially to 9 m then lost; picked up at 12 m and lost again at 13m. No further detection
45°	Tracked initially to 9 m then lost. No further detection
60°	No Detection
90°	No Detection

Tracking mode was not able to detect the target beyond 45°, but even at lesser angles the device seemed to have difficulty detecting the target beyond 19m.

13.1.3.2 Xaver 400 - Expert Mode

Target path is indicated by the angles of the lines, and the detection is indicated by colors (green = detection, red = no detection, and orange = target detection uncertain).

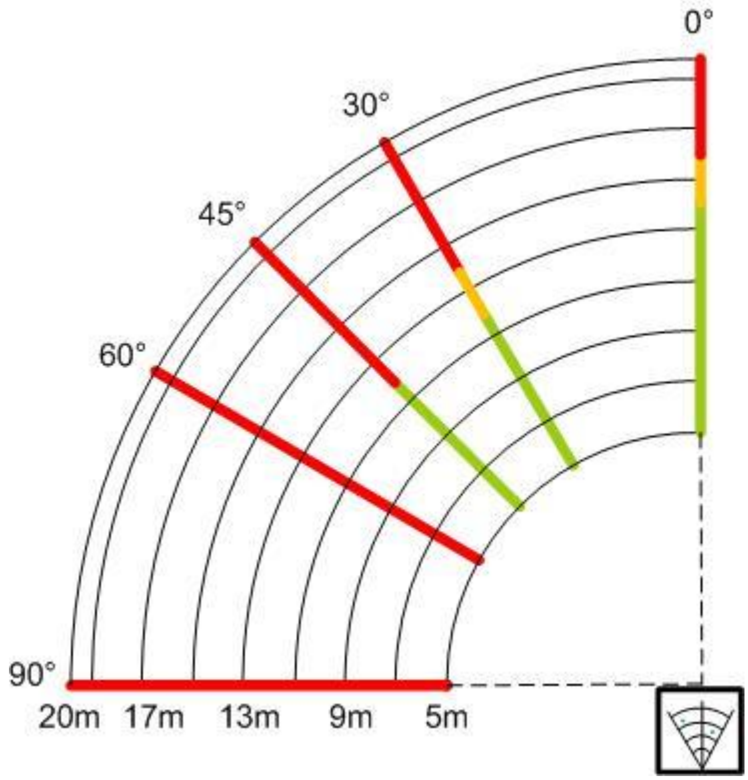

Figure 35: Angular Performance of the Xaver 400 – Expert Mode

Table 64: Xaver 400: Expert Mode: LAT: SW: Away

Xaver 400: Expert Mode: Target walking Stepwise (SW) away from device (5 m to 20 m)	
0°	Tracking initially; target signal is hard to make out around 14 m to 16 m
30°	Tracking initially; target signal is hard to make out around 12 m to 14 m
45°	Tracking initially; target signal is hard to make out around 12 m
60°	No Detection
90°	No Detection

Expert mode is similar to Tracker mode in that there was no detection at angles larger than 45°. Even then, there was no measurement that was able to detect the target at the full range of 20 m.

13.1.3.3 Xaver 400 - High Penetration Mode

Target path is indicated by the angles of the lines, and the detection is indicated by colors (green = detection, red = no detection, and orange = target detection uncertain).

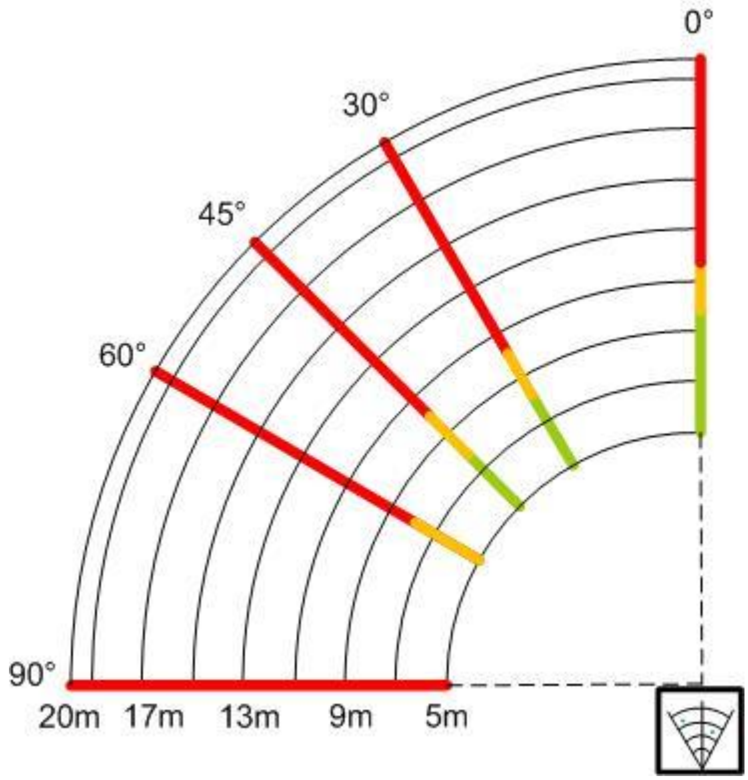

Figure 36: Angular Performance of the Xaver 400 - High Penetration Mode

Table 65: Xaver 400: High Penetration Mode: LAT: SW: Away

Xaver 400: High Penetration Mode: Target walking Stepwise away from device (5 m to 20 m)	
0°	Difficult to make out beyond 10 m – 12 m
30°	Difficult to make out beyond 8 m – 10 m
45°	Difficult to make out beyond 8 m – 10 m
60°	Seen at 5 m, No Detection beyond 8 m
90°	No Detection

While the target was able to be detected at 60° in High Penetration mode, detection was at shorter distances (about 8 m); there was no detection at 90°. In general, the detection range was shorter than the 20 m detection range of the Xaver 400; maximum distances tended to be in the 10 - 12 m range.

13.1.4 ASTIR LAT Testing

The target walked from 5 m to 70 m. Note that the maximum reported detection range of the ASTIR is 70 m (see Section 5.4 ASTIR). Device was angled at 0°, 30°, 45°, 60°, and 90°. Target path is indicated by the angles of the lines, and the detection is indicated by colors (green = detection, red = no detection, and orange = target detection uncertain).

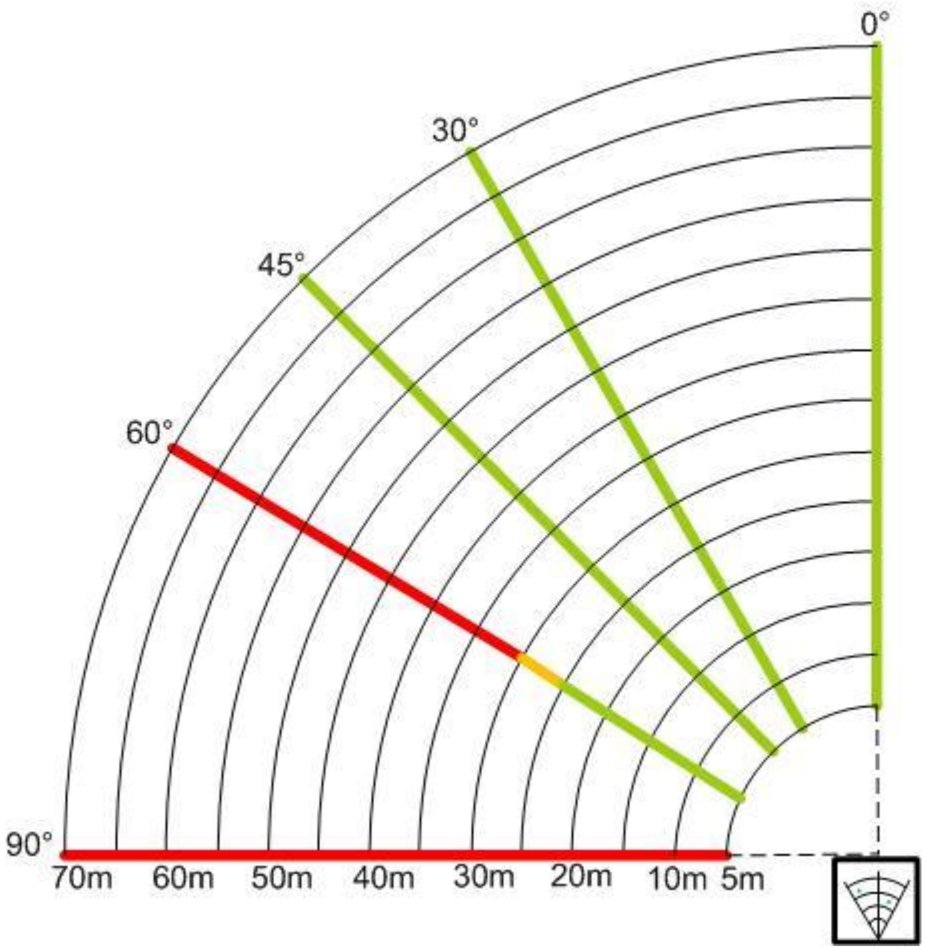

Figure 37: Angular performance of ASTIR

Table 66: ASTIR: LAT: SW: Away

ASTIR: Target walking Stepwise away from device (5 m to 70 m)	
0°	Target identifiable entire range
30°	Target identifiable entire range
45°	Target identifiable entire range
60°	Target identifiable up to approximately 25 m to 30 m
90°	No Detection

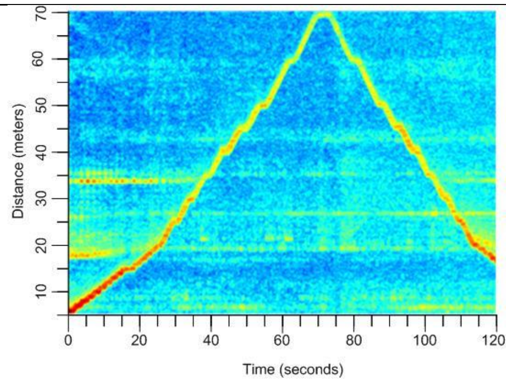

Figure 38: Target walking stepwise at 0°

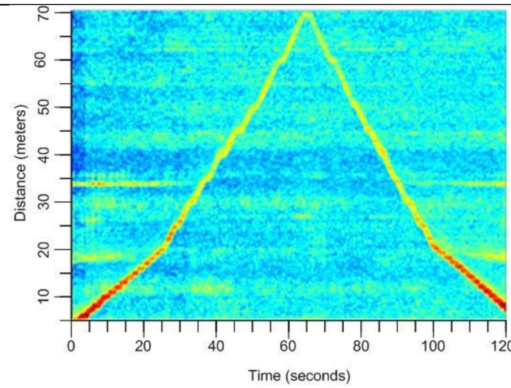

Figure 39: Target walking stepwise at 30°

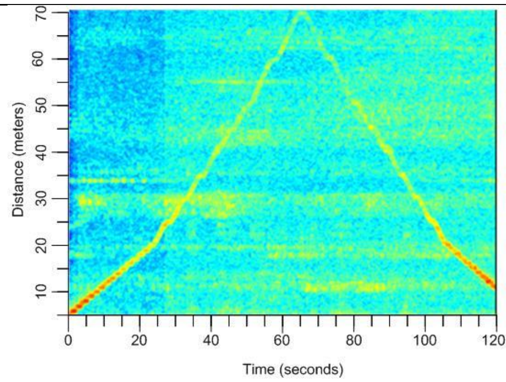

Figure 40: Target walking stepwise at 45°

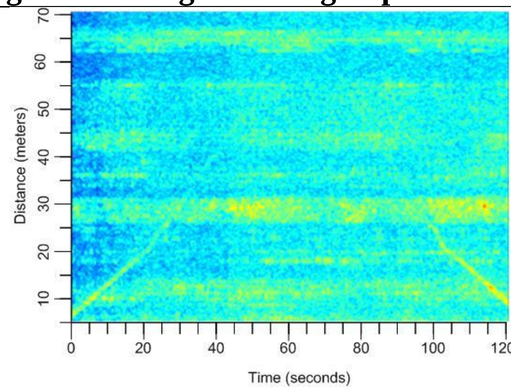

Figure 41: Target walking stepwise at 60°

The ASTIR was able to detect the target throughout the entire 5 to 70m range up to 45° without barriers. At 60° the target began to be difficult to pick out from the background at about 25 m to 30 m, and at 90° there was no indication that a target was present.

13.2 Angular Arc Test (AAT)

The angular arc test (AAT) was performed to check the ability of the devices to detect targets that were not necessarily directly in front of them but were at equal distance throughout their movements. The test consisted of the target walking in an arc (with the device at the center) at a predetermined distance. For the Xaver 100, Xaver 400, and the Range-R the distance was half the stated detection range of the device. For the ASTIR the range was less than half the detection range (20 m as opposed to 35 m) because of geographical limitations (target would have had to climb a small hillside if measurements were taken at 35 m).

13.2.1 Range-R Link Angular Arc Test

The Range-R Link measurements were taken with the target walking at a distance of 7.5 m from the device. The Range-R Link was used to provide hands free operation instead of the Range-R. The Range-R Link is identical to the Range-R with the added feature of being able to communicate to an iPod running a customized communication application. During testing, the

Range-R Link was able to detect the target throughout the arc from 0° to 90° in both directions. The reading was stable and varied from 21 ft to 22 ft during the measurement period.

13.2.2 Xaver 100 Angular Arc Test

The Xaver 100 measurements were taken with the target walking at a distance of 4 m from the device. Both Normal mode and High Penetration modes were tested. Normal mode was able to detect the target throughout the angular range 0° to 90° in both directions. The reported target distance fluctuated between 1.9 m to 4.3 m with most of the readings between 3 m – 4 m. High Penetration mode showed the target throughout the angular range in both directions, although the signal started to get noticeably weaker at angles larger than 60°, and reported distances were higher than actual distances as the angles increased to 90°. In addition, there seems to be some type of systematic distance error associated with the higher angles (when walking on an arc, the distances should be equal throughout the entire measurement).

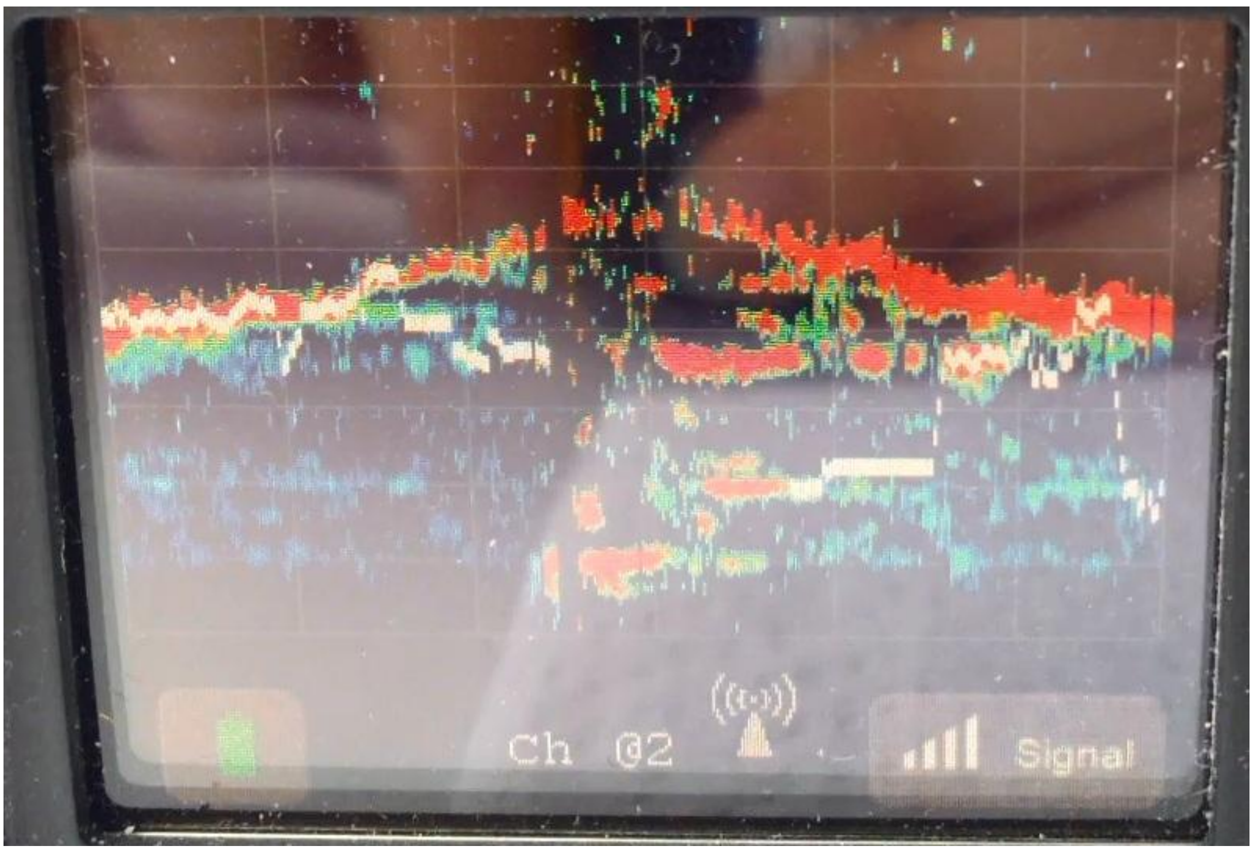

Figure 42: Target walking from 0° to 90° and back to 0° (90° in center of display)
Photo by NLECTC SSBT CoE

13.2.3 Xaver 400 Angular Arc Test

The Xaver 100 measurements were taken with the target walking at a distance of 10 m from the device. Tracker, Expert, and High Penetration modes were tested. With the target walking from 90° to 0°, Tracker mode was not able to identify the target at any angle. When the target reversed and walked back from 0° to 90° Tracker mode was able to track the target at angles less than 45°. Expert mode was able to detect the target at angles less than 30° with the target walking from 90° to 0°. When the target walked from 0° to 90° the target was identifiable up to 45°. High Penetration mode did not show that any target was present throughout the range.

Similar to the results of the LAT (see Section 13.1.3 Xaver 400 LAT Testing), these tests produced unexpectedly poor results for the Xaver 400 operating in an open environment without barriers. An explanation could not be easily determined.

13.2.3 ASTIR Angular Arc Test

Measurements were taken at 20 m instead of half the maximum detection distance because of geographical constraints. In the image below, the target starts behind the ASTIR and walks to position (diagonal line on left of image); walks along an arc to 90° and then back to 0°. The device is able to track the target strongly to about 20°, although the target can still be made out up to about 45°.

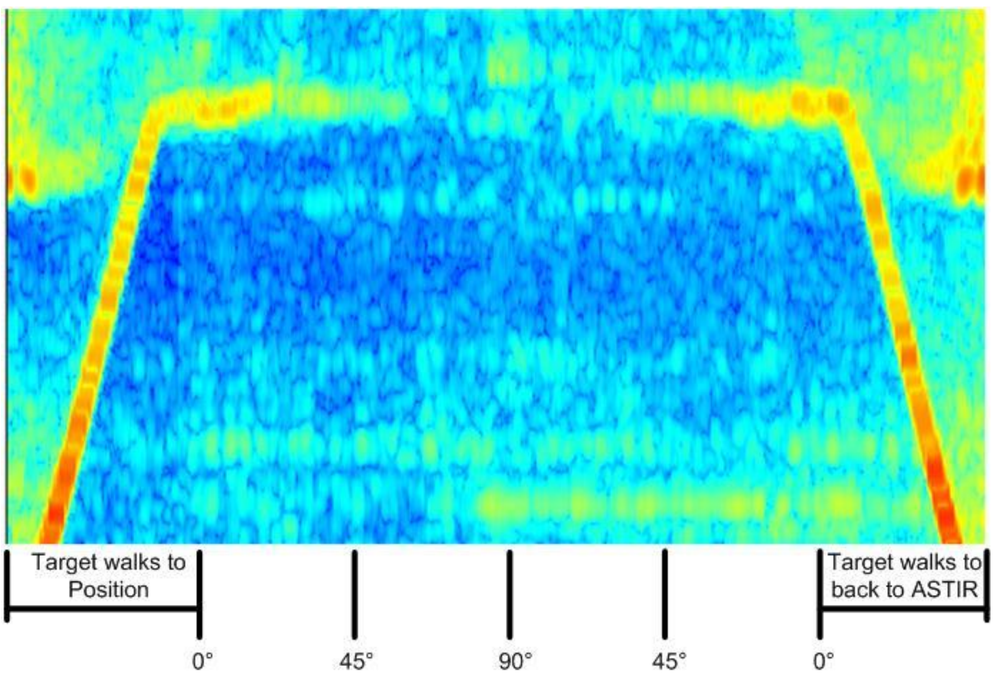

Figure 43: AKELA Angular Arc Test

13.3 Conclusions of Angular Testing

In general, the abilities of the devices to detect targets that are not directly in front of the device diminish as the angle increases – detections can be intermittent or not present and the accuracy of the distance measurements may suffer. Also, at wide angles, it is possible for a target to be missed when close to the device, but be detected when the target is further from the device. This is most likely due to what are known as lobes in the transmitted signal. Lobes are a natural consequence of antenna arrays and can create higher transmitted signal strength in areas outside the main transmitted signal. The devices generally are able to detect targets near the manufacturers' stated operational window, but keep in mind that these tests were done without barriers. The addition of barriers would presumably decrease the ability of the devices to detect targets at larger angles. The poor performance of the Xaver 400 during this series of tests is surprising, even when the target was directly in front of the device it seemed that the Xaver 400 had more difficulty detecting the target than it did when placed against a barrier.

14.0 TARGET WALKING THROUGHT STRUCTURE

The ASTIR by AKELA is listed as having a SO operation range of 30 m and has a 70 m detection range. This indicates the possibility of perhaps detecting a target throughout a small structure, such as a house. Tests such as this were performed on both the cinder block/OSB structures at the Camp Dawson Urban Training range, and at the Residential House.

14.1 Target Walking Throughout Upstairs of Building 1 at Urban Training Range

The building at Camp Dawson was constructed with cinder block, lumber and OSB. The first floor was an open room with outer walls constructed with cinder block and a wooden stairway to a second floor. The second floor was an open room with outer walls constructed of 2 x 4 lumber and OSB. To mimic a typical walking scenario in a building, the target walked into the first floor, went upstairs and walked a predetermined pattern. The target's activities were monitored at a SO distance of 30 m from the front of the structure. Once upstairs, the target walked to the wall closest to the ASTIR and stood for ~ 10 seconds, then repeated standing at the center of the room and the back of the room. Target then walked parallel to the front and back walls at three distances in the room. Target then walked from the front of the room to back of the room and returned to the front of the room before walking down the stairway and out the front of the building.

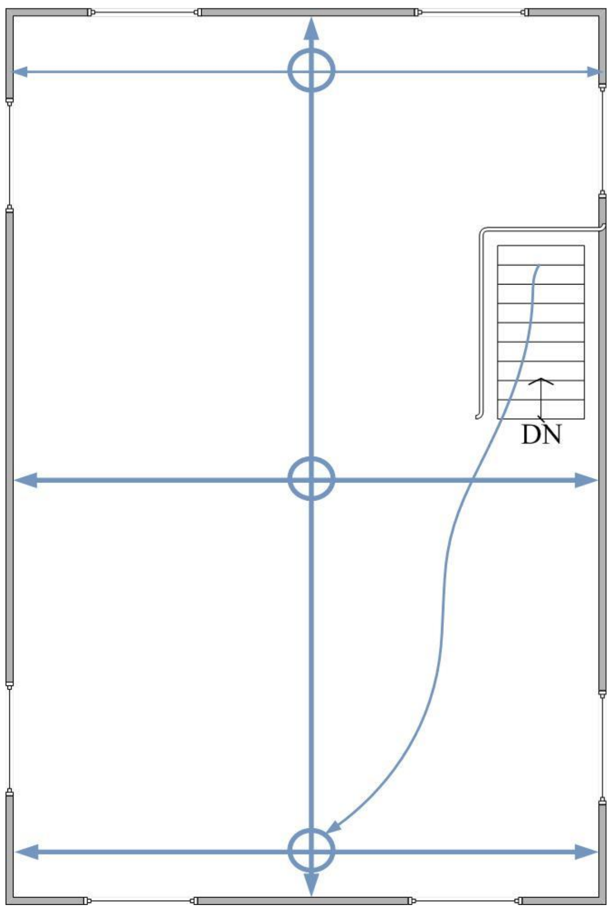

Figure 44: Building 1 second floor and target path

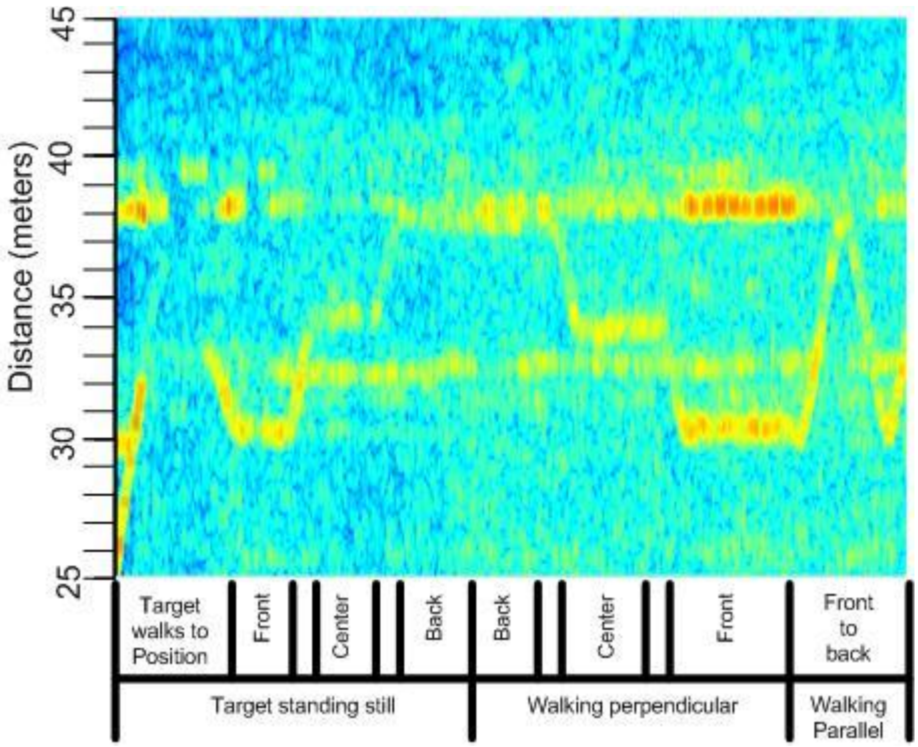

Figure 45: ASTIR 30 Meter SO
One OSB wall: Target Walking Perpendicular at Front, Center, and Back of Room

Figure 45: ASTIR 30 Meter SO shows the target entering the building (lower left) and moving toward the stairs. The target signal becomes faint as he gets behind the stairs and is not discernable as he climbs up the stairs to the second floor. The stairs are made of thick lumber and appear to be efficient at blocking most of the signal. Once on the second floor the target is seen walking to and standing against the front wall. The signal is fainter, but still visible when the target is standing in the center of the room. When the target is at the back of the room, the signal is hard to distinguish from the back wall. The transitions between each position can be seen with a slightly angled line (Approximately 10° right of vertical) with the intensity of the line decreasing as the target approaches the back of the room. When the target walked perpendicular, the signals were visible and generally more intense at each position (back, center, and front of the room) than they were when the target was standing still.

Note that when the target was at the front wall walking perpendicular, there was a strong signal on the back wall as well, in fact a stronger signal. This is due to the radar "shadow" of the target moving along the back wall. If there had been no "historical" indication that the target was along the front wall, the CoE operator would determine that the signal on the back wall was a true target, either thinking that there may be two targets in the room, or that the front target is a reflection of some type. The general unevenness of the front signal would indicate that it was not simply a wall or other reflective object.

Finally the target walked parallel (from the front to the back of the room) several times. The target's motion is indicated by the diagonal "zigzag" lines on right of the displayed image. Only one and a half cycles are shown in the image, otherwise information on the left side of the display would not be visible.

14.2 Target Walking Throughout Upstairs of Building 2 at Urban Training Range

The upstairs of building 2 was also constructed of lumber and OSB as building 1, however there was a small room in the center of the upstairs. This allowed measurements through one or two OSB walls. The ASTIR was set up 3 m from the interior wall of the upstairs room. Three meters was chosen simply because this was the farthest that the device could be placed away from the first wall. The target walked perpendicular in the room, then parallel. The target then left the interior room and went to the other side of the structure. In this location, there were two OSB/lumber walls between the target and the ASTIR. The target repeated the perpendicular/parallel walking pattern. The ASTIR was able to distinguish the target in all cases.

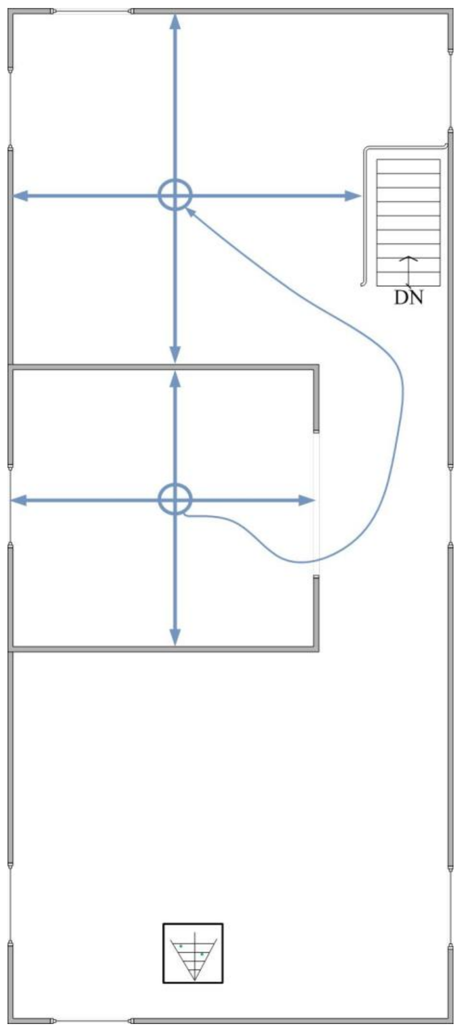

Figure 46: Building 2 upstairs and target path

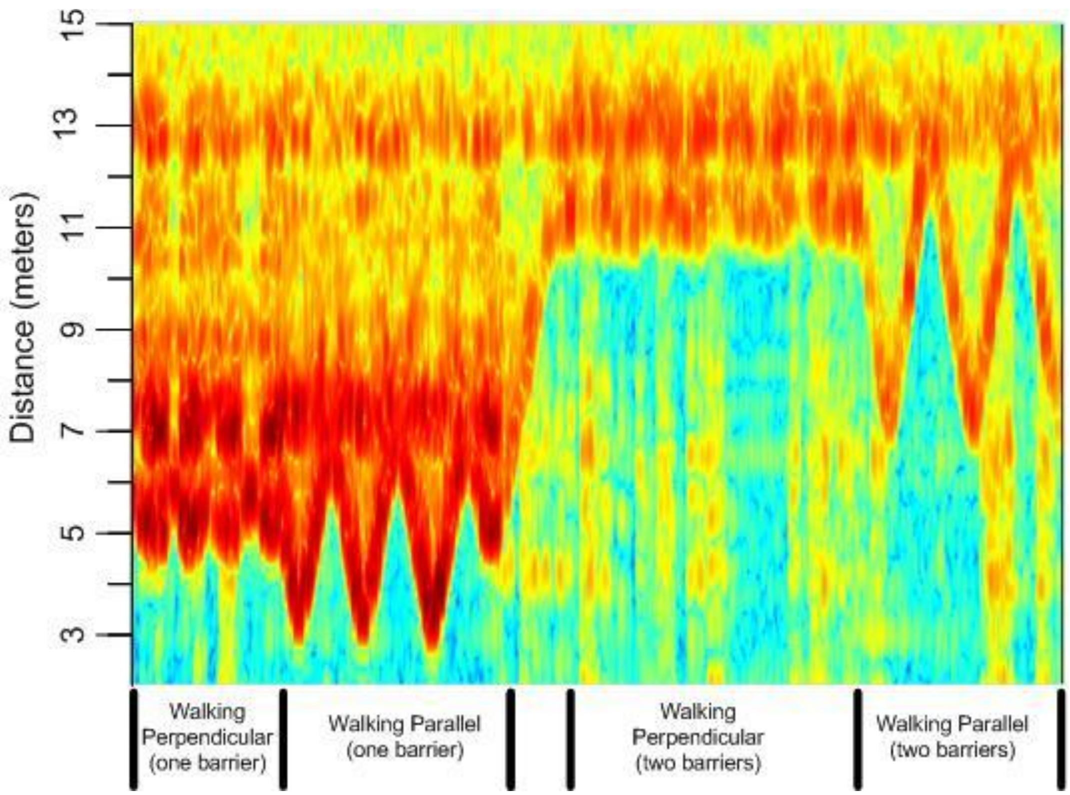

Figure 47: ASTIR 3 m SO
One and Two OSB walls: Target Walking Perpendicular and Parallel

In Figure 47: ASTIR 3 m SO, the target is walking perpendicular in the center of the room behind one OSB wall then walks parallel. Target then walks out of the room and to the center of the second room, now behind two OSB walls. The target walks perpendicular initially, then parallel. The target is clearly seen through two OSB walls; although the excess signal from shadows against the walls and even the ceiling and floors have the effect of appearing to “smear out” the signal. 3 m SO is pretty close for SO operations, and therefore the system may not be optimized for receiving the large amount of signal that would be received at this close distance.

14.3 Target Walking Throughout Residential House

At the residential house, the target started in the garage, walked through a door in the back of the garage and then walked throughout living areas of the house. The target video recorded his movements during the measurement so it would be easier to correlate his movements with the measurements. The target walked throughout the first floor and through two bedrooms on the second floor. Throughout the measurement, the target was not detected behind more than one barrier. The target was also not detected through the dining room window, but was detected through the bedroom window. In positions where there were more than one barrier between the target and the device, the signal faded beyond recognition. Descriptions of the ASTIR signal and the associated target movements are captured in the figures below for easier interpretation.

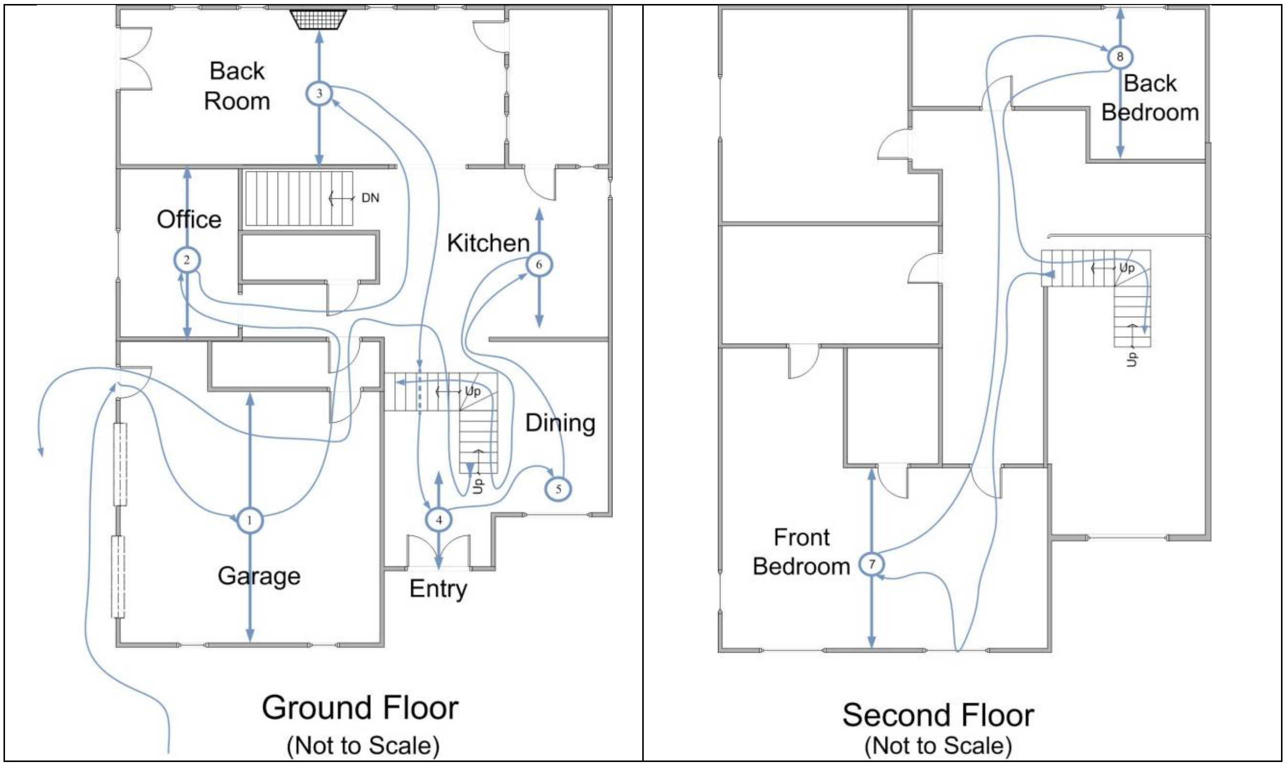

Figure 48: Schematic of Foundation House and target walking path

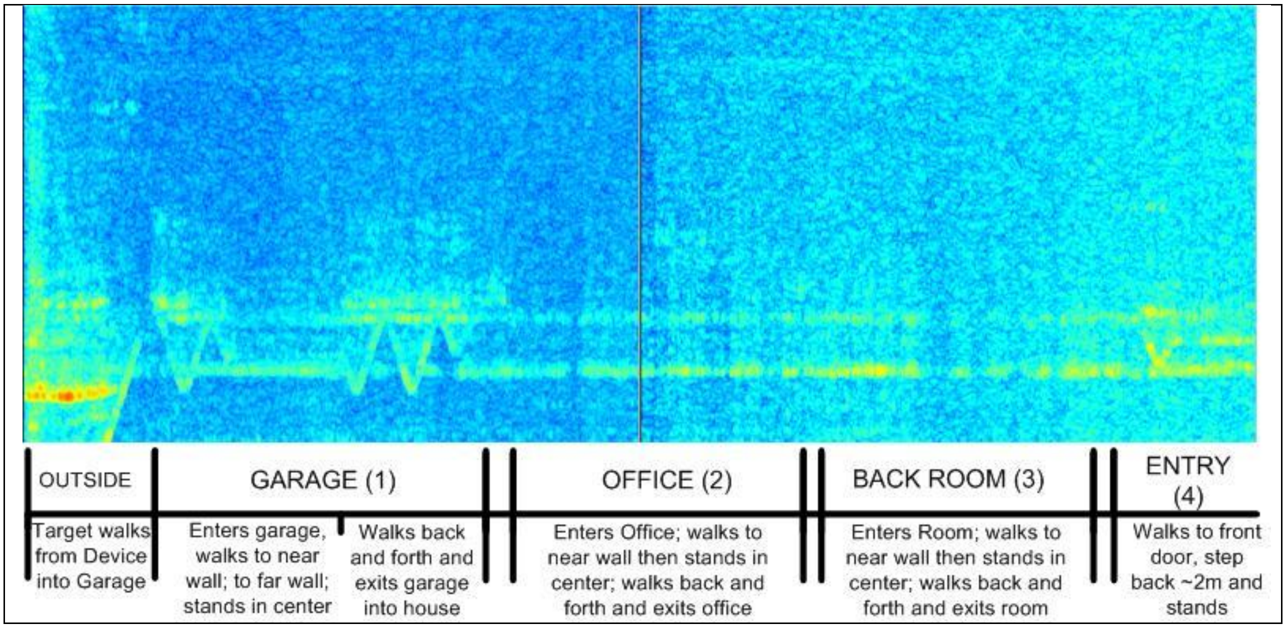

Figure 49: AKELA output during house walk through (part 1/2)

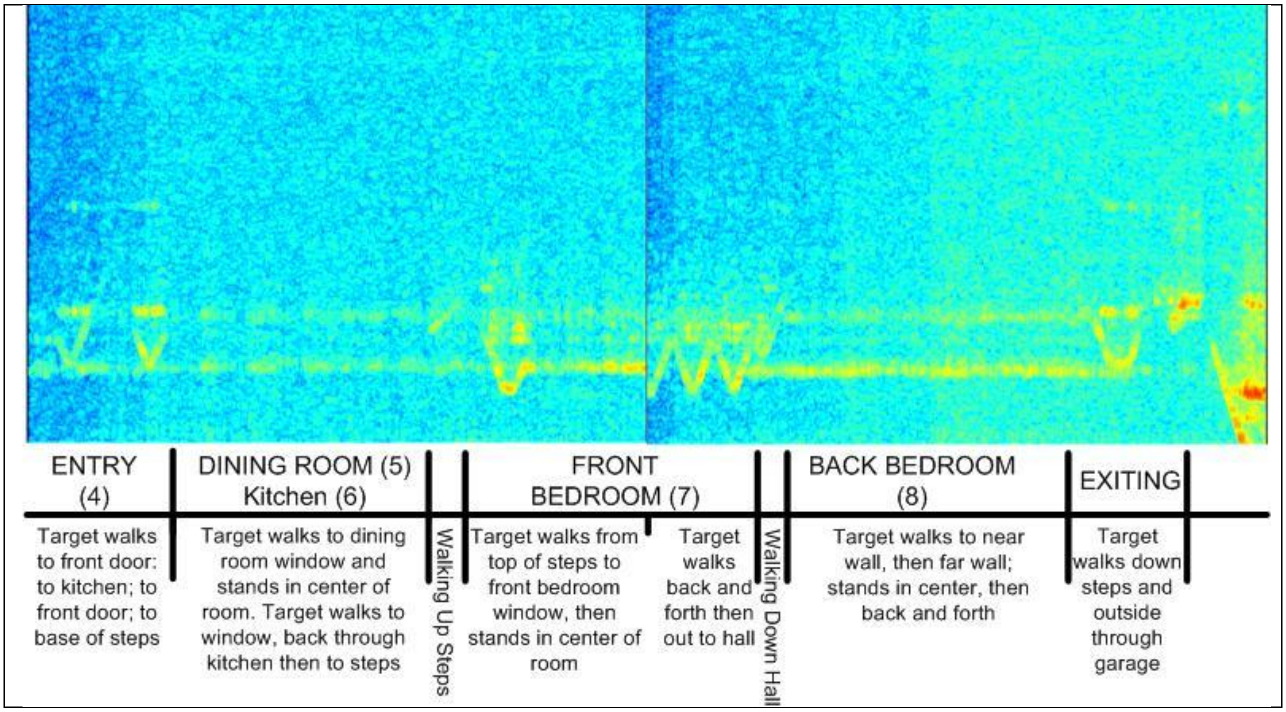

Figure 50: AKELA output during house walk through (part 2/2)

15.0 ANALYSIS

As indicated earlier, the choice of device will be strongly dependent on its intended use. The ATW hand-held devices would be most suitable for occasions where mobility is key and a minimal amount of time is available. Other situations may require extended observation and/or observation at SO distances. In these situations it may be worth the extra time to set up a device or the extra effort to maneuver a more bulky device into place so that the situation can be monitored over time at a safer distance.

Between the three ATW devices, the Xaver 400 has the highest overall percent detection, followed by the Range-R and then the Xaver 100; however the different modes of the Xaver 100 can give it an advantage over the Range-R in certain intended uses. The detection times of the devices are essentially equal when experimental error is taken into account.

The SO devices are situated further from the barrier and typically further from the target than ATW devices. They are also less maneuverable and require a support making the entire setup more bulky. During SO testing, the ASTIR was able to detect targets more often and at longer distances than the Xaver 400. The result is not surprising since the ASTIR is a dedicated SO device (and therefore specifically designed for SO operation), while the Xaver 400 is intended to operate both as an ATW device and a SO device (and not specifically designed for SO operation).

15.1 ATW Analysis

Overall, the Xaver 400 has the best ATW percent detection, the lowest average detection time, and a good distance uncertainty (+2% ± 9%). However, the Xaver is bulkier and heavier than the other ATW devices tested (The Range-R and the Xaver 100). Mobility and the performance of other operational tasks by the operator would be more hindered with this device than with a smaller device, such as the Xaver 100 or the Range-R. The larger size of the Xaver 400 is used to house additional antenna, which are able to provide better reflected signal reception and potentially better triangulation for target location. This, along with an algorithm that is able to take advantage of the additional information, is probably the main reason that the Xaver 400 has the overall highest percent detection of all ATW devices tested. This device would be best suited for instances where there is a real need for the additional information that a 2D device can provide, such as hostage or barricade situations. While it could be implemented in other situations (such as warrant serving or building clearing) the bulk and cumbersomeness of the device would be a disadvantage if fast movement through obstacles and close quarters were required.

The Range-R has the second highest overall percent detection for ATW measurements, the longest time for detection, and a low average distance error, but a medium distance precision measurement. While the Range-R is not able to directly indicate the presence of more than one target, the Range-R will cycle different distances when targets' activities change so that the reflected strength of the signal strength is changed from one target to the other. There is the potential of identifying more than one target, but the Range-R cannot detect two or more targets simultaneously. The Range-R is small and easily carried by one hand, although it seems just a little too bulky to have truly good grip on the device with one hand. With a better overall percent detection, but less ability to distinguish more than one target, the Range-R would probably be of most benefit in operations where the main question is "Is there anyone there?"

The Xaver 100 (preproduction model) had the lowest overall percent detection, the largest distance uncertainty, and a medium average detection time. The Xaver 100 preproduction model is a 1D device and does not have the performance, range, or additional operational modes of the Xaver 400. However, it is compact, easily carried, and has some ability to display movements of multiple targets. The two operational modes are Normal mode (the default mode) and High Penetration mode. Normal mode will attempt to identify a target and display the distance to the target. Normal mode will not detect multiple targets simultaneously. The ability of the Xaver 100 to switch to High Penetration mode is an advantage because during testing there were several occasions where the operator would probably identify a signal as a target from the data displayed in High Penetration mode, but the algorithm of the Normal mode did not. In addition to having better percent detection, High Penetration mode also has the potential of being able to simultaneously detect more than one target.

Different scenarios will have a greater priority on detection time. However, there does not seem to be a lot of difference in the detection times of these devices measured during testing. Table 8: ATW Results: Overall shows the average detection times of the devices to range from 8 seconds to 13 seconds, but the average deviation of the times are large and allow for significant overlap. This means that between the three tested devices, the average detection times are essentially equivalent within measured uncertainties.

Below is a table that summarizes the information presented earlier in the report for ATW devices for easy comparison across all barriers tested:

Table 67: Summary of ATW Measurements: Various Barriers

Percent Detection of ATW Measurements						
Barrier	**Range-R**	**Xaver 100**		**Xaver 400**		
	Average	**Average**		**Average**		
		Normal	**HP**	**Tracker**	**Expert**	**HP**
Cinder block	**58%**	**47.00%**		**87%**		
		35%	80%	100%	100%	60%
OSB	**80%**	**53.00%**		**100.00%**		
		40%	80%	100%	100%	100%
Cubicle	**100%**	**93.00%**		**83.00%**		
		90%	100%	80%	100%	70%
Glass	**60%**	**73.00%**		**100.00%**		
		60%	100%	100%	100%	100%
DWMS	**80%**	**61.00%**		**97.00%**		
		56%	80%	100%	100%	92%
Vinyl Siding	**67%**	**73.00%**		**93.00%**		
		60%	100%	100%	80%	100%
Brick wall	**70%**	**53.00%**		**90.00%**		
		55%	50%	100%	80%	90%
Wood siding	**80%**	**53.00%**		**100.00%**		
		30%	100%	100%	100%	100%

Comparison of the overall performances of the devices shows some interesting properties about the devices and even the barriers. The barrier that seemed to be the most difficult for the devices to penetrate is the cinder block wall. This is most likely due to the high density of cinder blocks, relative thickness, and potential moisture content (from exposure to the outside environment). The easiest barrier was the Cubicle material. The cubicle material is lightweight (not very dense), thin, and unlikely to have a high moisture content (the cubicle material is in a controlled environment).

There are significant differences between the different modes of individual devices. Typically, High Penetration mode of the Xaver 100 had a better detection than the Normal mode of the same device. This is in direct contrast with the Xaver 400, which typically had better detection in Tracker mode (the mode that most closely resembling the Normal mode of the Xaver 100) than it did in High Penetration mode. This may indicate that there is information available to Xaver 100 that could be used to improve the percent detection of the device, although it’s doubtful that the algorithm of the Xaver 100 (with two antennas) would ever be able to fully match the performance of the Xaver 400, which has four antennas.

Comparison of the modes where the device attempts to detect and identify a target (Normal mode of the Xaver 100, Tracker mode of the Xaver 400, and the Range-R) show that the Xaver 400 had nearly a perfect percent detection across all barriers, the only exception being the cubicle material. The Range-R had higher percent detection than the Xaver 100 in Normal mode in all cases except through glass where the percent detection was equal. While this gives a good indication of how well the devices are able to detect and identify a target when operated in these particular modes, a practitioner may use more than just one mode of a device (if it has more than one mode is available) to obtain as much information as possible, if time allows.

In the case that an operator has the time and training to read multiple available modes of the devices, it may be best to compare the devices based on the highest percent detection across all operational modes of an individual device. Viewed in this manner, the Xaver 400 still has the highest percent detection overall, but the Xaver 100 has higher detection than the Range-R in four cases, equal detection in three cases, and less detection in one case. This is mainly due to the high penetration mode of the Xaver 100.

In light of this, the Xaver 100 may be best utilized in HP mode and in situations where there is some length of time to allow the chart to fully develop to increase confidence in target detection and identification by the operator. Also, situations where the target would be expected to make translational movements would be the ideal scenario for the Xaver 100 operated in this manner as moving targets are more easily identifiable in HP mode. Normal mode could be used as a “second opinion” if there are any questions about the identification of a target in HP mode.

In situations where the target would not be expected to be moving (target intentionally remaining still, sleeping, unconscious, etc…) the Range-R may be a better choice since reflective clutter in a room would show up as a horizontal line on the High Penetration graph of the Xaver 100 and may mask the signal of a true (still) target. Another advantage of the Range-R over the Xaver 100 is that there is little (if any) training needed to understand the numeric display of the Range-R. The display of the HP mode of the Xaver 100 does require more thought and judgment (perhaps tempting an operator to spend more time cycling between modes and letting the chart develop more fully before coming to a decision).

15.2 SO Analysis

The Xaver 400 and the ASTIR were tested in SO operation. For comparison, the results of the percent detection are presented in the table below:

Table 68: Summary of SO Measurements: Various Barriers

Percent Detection of SO Measurements				
Barrier	**ASTIR**	**Xaver 400**		
	Average	**Average**		
		Tracker	**Expert**	**HP**
Cinder block	**84%**	**44%**		
		40%	60%	33%
Glass	**70%**	**80%**		
		100%	100%	40%
DWMS	**80%**	**40%**		
		60%	60%	0%
Vinyl Siding	**60%**	**47%**		
		50%	60%	30%
Brick wall	**50%**	**30%**		
		40%	50%	0%

The High Penetration mode of the Xaver 400 most closely resembles the evaluated display (historical chart) of the ASTIR. Even when comparing across all modes of the Xaver, the ASTIR was able to detect a significantly larger percentage of targets during SO operations than the Xaver 400 against all barriers with the exception of the glass barrier.

It is interesting to note the Xaver 100 also performed relatively better than the Range-R in ATW measurements against glass (see Section 10.2.1 ATW – Glass and Table 67: Summary of ATW Measurements: Various Barriers). Because the Range-R and the ASTIR use similar frequencies for their signals, and the Xaver series use ultra wide band technology for signal generation, this could indicate that the glass door tested (in both SO and ATW) was more efficient at blocking the signals from the ASTIR and the Range-R than it was at blocking signals from the Xaver series. If this is true, this would be an example of how barrier properties may cause a disproportionate absorption of signals of different frequencies (see Section 2.3 Technology Background).

The Xaver 400 is more flexible and mobile than the ASTIR and would be better suited for SO operations that would require a faster setup, and be able to be more quickly moveable to different locations at the site, or in cases where operation could benefit from a combination of SO and ATW. The ASTIR would be the better choice if there was little reason of having to move the devices once the device had been setup on site or in the case where a SO detection range of more than 20 m would be desirable.

The ASTIR by AKELA is a dedicated SO device and is able to detect targets as far as 70 m away. The device is not yet commercially available; however it shows promise for having good detection ability from long SO distances (30 m or more).

16.0 ASTIR PROTOTYPE EVALUATION

The ASTIR by AKELA is a SO motion detection device that uses an external computer to process and display data. In addition to an external computer, the prototype also requires an external power supply. The computer and power supply are required to be hard wired to the device. Once the ASTIR is up and running, control and operation are handled through a graphical user interface on the computer. The data display consists of a graphical representation of the integrated area, a historical display, and a 2D display. The historical display is easily read and interpreted and the 2D display is also set up to be easily interpreted, although AKELA personnel said that the 2D display requires more work, and their suggestion was to use the historical window for analysis. The device is able to detect movement easily, although still targets may be challenging. This is especially true if the target is close to a barrier or other strong reflector. The performance of the device is good, and it is the only device tested that is able to detect beyond 20 m (up to 70 m).

While control and operation is easy, the initial setup can be time consuming. The ASTIR prototype requires connections to an external power supply and a computer. Because it is a SO device, the ASTIR requires a stable mount or mounting surface. Although not absolutely necessary, placing the computer on a stable surface is advised. Storage, transportation, and setup can be cumbersome with all these separate components. When getting the device out of storage, it may be easy to forget something. During transportation, the device and different components required a significant amount of space in the vehicle. The time required for placing, connecting, and initializing the components was not insignificant. In addition, if the software is accidently run before the device is turned on, some system files for the software appear to be overwritten with bad parameters. Once this happens, the files had to be copied from a good copy of the software before the system could be operated.

16.1 Physical

The ASTIR requires a large number of individual components to be stored, transported, and wired together. Setup requires that the ASTIR be mounted on a stable surface, connected to a power supply, and connected to a computer. During testing, a tripod was used as a stable mount, and a 12V automotive emergency jump starter was used as the power supply. Additional pieces of equipment that are not technically required but were helpful included a small table to place the computer on and a sun shield for viewing the computer display in bright sunlight.

Having a smaller power supply within the case would reduce the number of parts that have to be transported and connected together. AKELA personnel indicated that the device could be run for about two hours with AA batteries. If AA batteries could be used as the main power source and inserted within the device, then this would reduce the weight, bulk, and number of components of the entire system. If desired, there could be an external connection that would be able to connect to a 12V external power source.

The computer used by the Center (based on AKELA's requirements) was a high end graphics notebook computer and is larger and heavier than typical laptops. In terms of logistics, setup, and physical handling, the computer was the "weak link" of the system due to it being a separate component and designed for normal mobile office use. However, the computer to be used with the ASTIR is to be furnished by the user and it would be up to the user to decide if a ruggedized computer was purchased or not. If some of the data processing could be transferred to the device itself, then a smaller, lighter, and more dedicated display device could be used (e.g., a tablet). This would help reduce the weight and bulk of the system. Of course, additional processing on the device would increase power consumption.

Having a small, foldable, and detachable stand may also be of benefit. This would reduce the number of separate components and potentially decreasing setup time. The option to be able to remove the attached stand could still be available so that the ASTIR could potentially be mounted on a more traditional stand (such as a tripod).

16.2 Software

One particular issue noted is that the software ran by the computer requires that the ASTIR device be powered up before the "Start" button be pressed. If the ASTIR is not powered up, an error occurs that shuts down the software. It also appears that some of the files used by the software are overwritten with bad parameters, which cause future operation of the software (even if the device is powered up) to not operate the ASTIR. To fix the issue, the corrupt files have to be replaced with non-corrupt files from a "good" copy of the software. The software should check the power-on status of the ASTIR before doing anything else and alert the user if a power off status was detected. At minimum a "restore defaults" or "restore last known good parameters" button or menu choice could be made available. It should be noted that AKELA personnel did say that the device must be powered on before running the software, but did not go into detail about what would occur if it did happen.

The color scheme of the charts and graphs is well suited for this application, and works well with both the historical display and the 2D image display. The 2D display seems to show the target position as more of an arc or what looks like multiple targets along a larger arc. The color scheme in the 2D window seems to be to show Doppler activity in color and non-Doppler reflections in gray shades. The additional target "blips" appear to be located at positions where the lobes of the antenna array might be expected to be stronger. An algorithm that would be able to look at the intensity changes between two "targets" displayed in the 2D might be able to help determine whether one signal is a ghost of the other or not (or perhaps give an indication of the possibility). It may also be of benefit to have an additional algorithm that would attempt to identify and track a target without the user having to interoperate whether they believe the reflected signal is a target or not.

Some improvements in data analysis by the system would be beneficial. In its current form, the 2D image display was not tremendously helpful during operation due to reasons listed in the previous paragraph. Test operators tended to focus almost exclusively on information presented in the historical display. As mentioned previously, AKELA personnel indicated that the 2D display required more work. In the historical display, the shadows of a target on walls can sometimes be used to indicate that a target is present. This is especially beneficial if the target is not able to be directly detected. Currently it is difficult to tell whether the signal is from a shadow or a target. It would be beneficial to be able to graphically view whether the displayed signal is from an increase in reflected signal (as in the case of a target) or from a decrease in reflected signal (as from a shadow).

Improvements in data display and display control would also be beneficial. Zoom options, color scheme options, and scrolling for the historical view on the front screen would help the operator focus on the analysis instead of operating the device. While there are "Zoom In" and "Zoom Out" options, the buttons only provide incremental changes. Adding buttons with preset ranges would allow the operator to more quickly adjust to required parameters. The color scheme indicates the strength of the reflected signal, but there is no easy method to change or modify the scaling factors immediately available on the user interface. The ability to easily change the scaling factors may allow the operator to bring out or highlight weaker signals. Finally, Center personnel felt that a scrolling screen for the historical view would be more intuitive and useful than the current wrap around method used for data display.

16.3 Operational

Wireless communication between the device and the computer would be beneficial. This would eliminate having to hardwire the device to the computer, and would allow for easier mobility. Of course, data security, decreased operational time (because of the extra power drain), and potential interference are issues that would have to be addressed before implementing any changes of this nature.

During operation, movements of the operator(s) are sometimes seen as "ghosts" in the display of the device (appears as a potential target). One potential solution would be to place a single rear facing antenna that would be able to detect any movement behind the device and try to compensate for this movement if a similar signal pattern is detected elsewhere.

16.4 Data Review

Data review is performed by loading the original data and reprocessing the data with the desired parameters. The ASTIR saves the raw data during a scan, therefore it is possible to change processing parameters for review. One improvement would simply to have the default file to open as the last data collected/saved. Other beneficial options would to have a "fast forward", "pause", and "reverse" options readily available.

16.5 ASTIR Evaluation Conclusion

The ASTIR is a promising technology that would need some more developmental improvements to be fully functional for use by LE and other first responder, even as a demonstration unit. The main thing would be to reduce the overall bulk and number of components of the system and to reduce the setup time and improve storage and transportation. The current 2D display has a lot of erratic and errant signals that does not really reflect the position (especially angular) of the target well. Improvements in the 2D signal processing would increase the functionality of the device beyond the historical graphical view. Improving the software so that the device attempts to identify a target would be a good addition, but not strictly necessary given the current display characteristics. Reduction of reflections or "ghosts" would also be beneficial. While improvements in data review would have been helpful during this evaluation, data review is probably not needed often in the field. Note that of all the devices tested, the ASTIR was the only one that had the capability to directly save and review the data at a later time.

16.5.1 Recommendations

The ASTIR seems to be able to detect targets well, but there are some issues with the number of components needed to operate the device and some software and signal processing that could be improved upon. Some of the main recommendations are:

- Reduce number of components needed for system support;
- Improve signal processing to remove or reduce erratic and errant signals, especially for the 2D graphical display;
- Incorporation of a target identification algorithm to specifically point out and track targets in the 2D display;
- Allow for the compensation of operator and other movement behind the device (such as using a backward facing antenna);
- Use different color schemes to indicate an increase or decrease in reflected signal (to tell the difference between a target (increased) and a shadow on a wall behind the target (decreased);
- Do not allow software to overwrite configuration file if ASTIR is not turned on;
- Incorporate wireless communication capability between device and display device;
- Allow easy real time manual scaling of signal strength;
- Allow for “on board” processing so the computer could be replaced with a smaller display (such as a tablet);
- Use scrolling display on historical chart instead of wrapping; and
- Improve data review to incorporate fast forward, pause, stop, and restart at current point.

17.0 CONCLUSIONS

TTWS have the capability to increase situational awareness in scenarios pertinent to law enforcement and other emergency responders. Like any technology, they have general limitations because of the base technologies incorporated, and specific limitations because of individual system designs. The manufacturers of the devices tested in this study have obtained certification by the FCC for operation by emergency responders and law enforcement. The devices met the manufacturer's specifications and were able to detect and locate targets behind most barriers with at least a reasonable level of probability and accuracy. Moving targets were more easily detected than still targets. The Xaver 400 was able to detect a significantly higher percentage of targets than the other ATW devices (Xaver 100, and the Range-R), but was not able to detect targets as well as the ASTIR during SO testing; nor did the Xaver 400 have the range of the ASTIR.

Overall, the Range-R was able to detect a higher percentage of targets than the Xaver 100, however when the individual modes of the Xaver 100 are examined, we notice that the High Penetration mode was able to detect more targets than the Range-R. Because of the display characteristics of the historical chart method, it is easier for an operator to detect movement than a still target, thus it appears that if a target is expected to be moving, the Xaver 100 may be the better choice, however if the target is expected to be still, the Range-R would be the device of choice.

17.1 Overall

The Xaver 400 had the highest overall performance of the ATW devices, and the ASTIR was the highest performance of the SO devices. There were some specific points noted with the devices and the technologies.

- The Xaver 400 has the highest percent detection of the ATW devices, can detect multiple targets, and has three different display options for increased confidence. The Xaver 400 is also larger than the Xaver 100 or the Range-R, not as easily stored, transported, or maneuvered on site.
- The ASTIR has the highest detection probability of the SO devices, and it has a significantly longer detection range (70 m as opposed to 20 m).
- The AKELA has the largest range of all devices, but is the largest, bulkiest, and takes the longest time to set up. It would most likely be best suited for longer term observations and/or for operations requiring larger monitoring distances.
- During testing the Xaver 100 readings seemed to jump around a lot during testing, reducing the usefulness of the distance reading, but still indicating that a target was present. (Note: this may be addressed in the final production model.)
- The UWB devices (Xaver series) seemed to show an increased amount of noise when tested in an office environment. This seemed to mainly affect the historical graph of the device, making it harder for an operator to identify a target. Detection of a target by the device (Normal mode for the Xaver 100 and Tracker mode for the Xaver 400) did not seem to suffer (at least not that it was noticeable) from the electronic environment of the

office. The ASTIR did not appear to suffer from the noise in the office environment. Nor were there any effects noted with the Range-R operated in the same environment.

17.2 Operation

Display characteristics, device setup, and ease of use are important considerations to take into account when evaluating how useful a device would be to an organization.

- Having different data display modes can helpful (e.g., Xaver 100 detecting more than 1 target in HP), but it does take additional time to cycle through and analyze the different modes.
- The Xaver 400 has three modes of operation (Tracker, Expert, and High Penetration modes). All three modes can detect multiple targets simultaneously.
- The Xaver 100 has two modes of operation (Normal and High Penetration). High Penetration mode has the ability to detect multiple targets simultaneously.
- The Range-R has one mode of operation (distance to detected target) and cannot detect multiple targets simultaneously.
- The ASTIR displays a historical chart similar to High Penetration mode of the Xaver series. It has the ability to simultaneously display a 2D chart as well, but the 2D chart requires more development. Both modes can or would have the ability to detect multiple targets simultaneously once fully developed.
- Interference was not specifically tested, however cell phones and two-way radios were in operation during testing and no interference issues were encountered.
- SO operations take longer to set up than ATW because of the necessity of a secure mount.
- Once setup, the devices require minimal manipulation to operate; usually 1-2 buttons.
- The ASTIR is the only device with direct recording capability.

17.3 Detection

In general, the devices had strengths and weaknesses that should be taken into account and evaluated in view for their intended end use.

- The Xaver 400 performed very well during ATW measurements and was the highest rated in nearly every situation; detecting a higher percentage of targets than the other ATW devices.
- The Range-R was able to identify targets better than the Normal mode of the Xaver 100.
- High Penetration mode of the Xaver 100 is able to detect targets better than the Range-R.
- The Range-R is better at detecting still targets than the Xaver 100.
- Smaller devices have fewer antennas which:
    - Allows them to be smaller and lighter.

  - Can make them less accurate at distance reporting.
  - Can make them less likely to detect a target.
- The Xaver 100 is sensitive to operator and observer movements which tend to indicate a target around the 1 m area. This could mask a true target at this distance on the other side of a barrier.
- The Range-R has a rear facing antenna that helps compensate for operator and observer movements behind the device.
- Average detection times across the devices are about equal.

17.4 Storage, Transportation, and Setup

During storage and transportation the device should be able to survive typical bumps and even accidental drops that may occur. Most devices have a protective storage case for this purpose. Setup times for ATW devices are typically very fast, but for SO devices times can increase because of the need to mount the device to a stable surface.

- The ASTIR takes the longest time to set up and it has multiple components that need to be assembled on site.
- The Xaver 400 operated in SO mode takes additional time to setup (as compared to ATW operation) as SO mode requires a stable mount.
- Devices operated in ATW mode take about the same amount of time to setup.
- Devices operated in ATW operation do not require multiple components.
- The ASTIR takes up the largest amount of space during storage and transportation.
- The Range-R and the Xaver 100 take about the same amount of space (small).
- The Xaver 400 takes up about four times the space as the smaller devices.

17.5 For Consideration

Companies and suppliers of TTWS may be willing to provide a demonstration of their devices and may even be willing to loan a device to an organization for evaluation purposes. Potential customers should try to take advantage of any offers available to better evaluate a device for their specific purposes and in typical environmental in their geographic location.

- Before purchasing a device, an organization should try to arrange for a demonstration of the devices and have them tested on a variety of barriers that are common in their locale.
- An organization considering obtaining one of these devices should compare the requirements for their intended use to the features available at a price that is within budget. For example, some questions an organization may consider are:
  - Is the typical intended target expected to be moving or still?
  - Is necessary to track a target over time, or is just an indication of whether someone is on the other side of the barrier needed?

  - Is monitoring activity in an area for extended times required or would the device have to be quickly located at different barriers and locations at a site?
  - Is it is expected that the typical sites would have a lot of obstacles (e.g., dense underbrush) that the operator would need to navigate before operation?
- Would typical situations include structures that hamper this technology (such as metal shipping containers, trailers, or recreational vehicles)?It is advisable to take multiple measurements at multiple locations on a barrier. This is especially true for ATW operations when localized barrier variations will have the largest effect.
- High moisture content in a barrier may hamper detection.
- Building codes and materials can change over time and can vary between different locales.
- The Xaver 400 (a 2D device) is significantly more expensive than the other (1D) commercial devices.
- The production model of the Xaver 100 was not tested during this evaluation, but company literature reports that the production model has increased the maximum range to 20 m (as opposed to 8 m for pre-production model).

17.6 Considerations for Future T&E

The testing conducted by the CoE was performed to establish a foundational evaluation of TTWS in operationally-relevant law enforcement settings. Because of the constrained resources and schedule, there are some activities that would be modified or added given an opportunity to conduct similar TTWS T&E in a more robust project environment. Below are two considerations for future T&E of TTWS in support of criminal justice or homeland security applications.

It is recognized that the operator of the device was aware of the presence of targets and their orientation and movements during testing. This is not an issue for device that automatically detects targets (i.e., Range-R, Xaver 100 Normal Mode, and Xaver 400 Tracker Mode). However, for devices and modes that rely on operator judgment, operator bias may be an issue. The ideal testing methodology would be to institute a double-blind with randomized test scenarios. This would allow the operator to be ignorant of the target(s) or lack thereof and their movements. A second approach would be conduct data collection and analysis independently, with the analyst unaware of the test conditions. Both approaches would necessity duplicate tests (including additional blanks in each wall type) and additional logistical personnel, something that the CoE testing was unable to support.

A more in depth study of potential interferences may also be worth exploring in future evaluations. Potential sources of motion such as oscillating fans, ceiling fans, and perhaps even small animals could be targets for false positive tests. Additional testing of common window coverings and coatings, including metalized coatings and aluminum foil over windows, could provide valuable information for the practitioner. Systematic investigation into potential electronic interference such as wireless networks, GPS receivers, cell phones, and other transceivers that may interfere with the operation of the TTWS or that may indicate the presence of a TTWS would be of value.

Future evaluations may also consider constructing custom barriers. This would provide barriers with exactly known materials and composition for testing. The barriers could even be varied to match local building codes or even to match historical codes. Custom barriers would also allow different thicknesses of barriers and their components to be tested. Tests of this type were considered early on in CoE test planning, but discarded due to the prohibitive level of manual labor and time required for this effort.

APPENDIX A: ACRONYMS, ABBREVIATIONS, AND REFERENCES

A.1 Acronyms and Abbreviations

ACRONYM	DESCRIPTION
2D	Two Dimensional
3D	Three Dimensional
AAT	Angular Arc Test
ASTIR	AKELA Standoff Through-wall Imaging Radar
ATW	Against the Wall
CFR	Code of Federal Regulations
CoE	Center of Excellence
DOJ	Department of Justice
DWMS	Drywall Metal Studs
FCC	Federal Communications Commission
FCCID	Federal Communications Commission Identification
FPSPA	Facing, Perpendicular, Side, Parallel, Away
HP	High Penetration
IP	Internet Protocol
LAT	Linear Angular Test
LED	Light Emitting Diode
MAX/MIN	Maximum/Minimum
NIJ	National Institute of Justice
NLECTC	National Law Enforcement and Corrections Technology Center
OSB	Oriented Strand Board
RADAR	Radio Detection And Ranging
RFI	Request for Information
SFCW	Stepped Frequency Continuous Wave
SO	Standoff
SSBT	Sensor, Surveillance, and Biometric Technologies
SW	Step Wise
TTWS	Through-the-Wall Sensors

ACRONYM	DESCRIPTION
TWG	Technology Working Group
US	United States
UWB	Ultra-Wide Band
WVHTC	West Virginia High Technology Consortium

A.2 References

[1] Frazier, L.M. Feb. 18, 1997. *Radar Surveillance through Solid Materials*. Bellingham, WA: SPIE, 2938: pp. 139-146
[2] MiCOM Labs, *Grant of Equipment Authorization Certification for ZZM-ASTIR3300* (January 9, 2013)
[3] Federal Register; "NIJ Evaluation of Through-Wall Sensor Devices, Notice of NIJ Evaluation of Through Wall Sensor Devices;" 77 FR 59667, p. 59667; https://federalregister.gov/a/2012-23873 (September 28, 2012)
[4] L-3 Communications CyTerra Corporation, *"Range-R Through the Wall Radar,"* http://www.range-r.com/ (Accessed October 31, 2013)
[5] Camero-Tech Ltd., *Xaver 100*, http://www.camero-tech.com/product.php?ID=38 (Accessed October 31, 2013)
[6] Mistral Security, *Early Adopter Program Brochure (2012)*
[7] Camero-Tech Ltd., *Xaver 400*, http://www.camero-tech.com/product.php?ID=39 (Accessed October 31, 2013)
[8] Taylor, Paula, AKELA; *"RE: ASTIR Output Power & Freq."* Personal e-mail to Lars Ericson, (July 11, 2012)
[9] AKELA; *AKELA Standoff Sense-Through-the-Wall Imaging System*, *Product Information Sheet* (2011)
[10] Gwinnett County Sheriff's Department, *Atlanta TTWS Field Testing Event* (January 15-16, 2013; Lawrenceville, GA)