Phase-history data collection for synthetic scene modeling applications

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ABSTRACT

Development of phase history calibration techniques is important for improving Synthetic Aperture Radar (SAR) scene modeling capabilities. Image data of complex scene settings is used for clutter database construction, and the resulting databases are used in conjunction with synthetic radar predictions of complex targets to predict synthetic SAR imagery. The current method of trihedral calibration is typically performed after image formation, using a ratiometric technique, which is highly dependent on calibration target position and orientation and ground truth accuracy. As part of a recent SAR research data collection, measurements were made on a calibration-grade, 6-meter diameter top hat in both a homogeneous scene and with controlled obscuration and layover conditions. This paper will discuss phase-history calibration target design and scenario design to support obscuration and layover studies.

Keywords: Synthetic aperture radar, SAR, phase history, calibration

1. INTRODUCTION

To explore phase-history calibration prior to SAR image formation, and phemonology studies necessary for synthetic scene construction[1], a special calibration-grade target was designed, constructed, and tested. The results of this effort are summarized here. The target was a relatively large, aluminum, high-precision top hat reflector; data collection was done as part of a larger test for the Battle Damage Assessment program at Eglin AFB, Florida, during the first week of August 2000. The target is shown in Figure 1, with one of the authors included for scale.

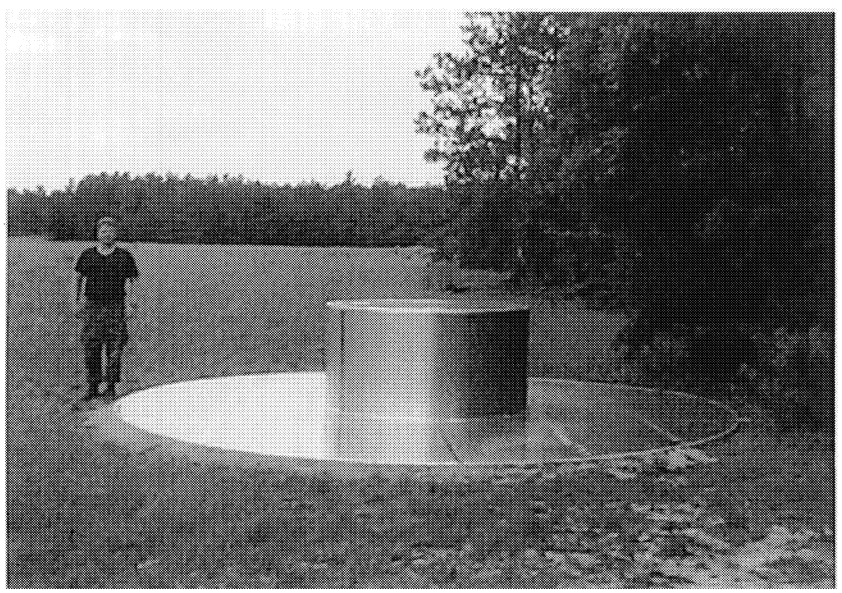

Figure 1: Top Hat Calibration Target with One of the Authors

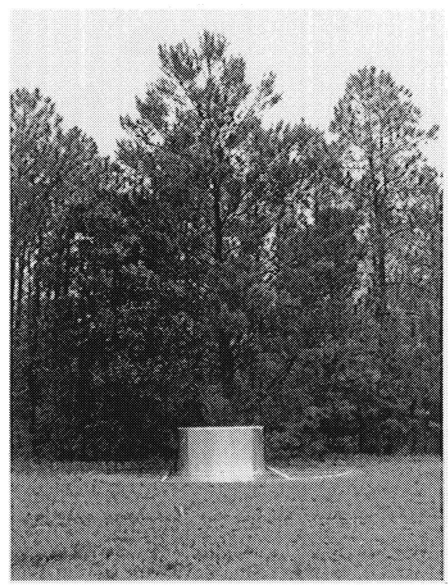

Figure 2: Tree Line Site

A previous data dynamic collection with the ERIM Data Collection Sensor provided complex SAR image data for clutter database development. Clutter database development was performed after complete image formation processing and image domain calibration methods were applied. The measured data from the collection was an excellent source of data for terrain segmentation and statistical distribution studies for clutter database development. Calibration issues prevented full use of the data for scene SAR image predictions.

Algorithms for Synthetic Aperture Radar Imagery VIII, Edmund G. Zelnio, Editor,
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The calibration targets used in the data collection were similar to calibration targets used in controlled measurement ranges, however the outdoor flight test environment is not as conducive as a controlled chamber measurement environment for insuring highly accurate position and orientation and ground truthing of calibration targets. Thus, a calibration target that is more robust to position and orientation errors expected in an outdoor environment and that has a uniform return over 360 degrees of azimuth angle coverage was built to support calibration of a dynamic SAR research data collection. A large top hat was the calibration target of choice because the uniform radar return over 360 azimuth aspect minimizes the impact of setup and ground truth errors in a field environment.

SAR data was collected on the top hat target in a grass environment for calibration analysis. The grass environment was also imaged with no top hat present. The top hat was also measured near a tree line to provide data for layover and obscuration analysis to improve full synthetic scene modeling techniques. The tree line scene was also imaged with no top hat present. The top hat also included a cavity that was either plugged for the collection passes intended for calibration analyisis. For other collection passes, the plug was replaced with one of three cylindrical cavities intended to model light to heavy damage to the top surface of the top hat to support Battle Damage Assessment (BDA) algorithm development.

2. TARGET DESIGN

The top hat target was designed such that it could be seen above a grass clutter background on a single pulse for the development of direct phase-history calibration techniques in addition to traditional post image formation calibration methods. The mean depression angle to the scene was 30 degrees. The mean radar cross section per unit area of the surrounding grass at a depression angle of 30 degrees was estimated as -15 dB.

The top hat dimensions were designed such that the RCS return was 10 dB above the grass clutter background and the cylinder would be uniformly illuminated for depression angles down to 26 degrees to allow for variations in the depression angle during the collection. The top hat return was computed using[2]:

$$\sigma = \frac{8\pi h^2 r\cos(\psi)}{\lambda} \tag{1}$$

This result assumes that the cylinder height and not the size of the ground plane limits the backscatter area of the reflector two bounce region.

Collecting measured data to support Battle Damage Assessment Algorithm (BDA) Development was the primary focus of the data collection. Thus, the top surface of the cylinder included a cavity that was plugged for the collection passes intended for calibration analysis. For other collection passess, the cavity was unplugged and replaced with cylindrical cavities of 3 different radii inended to model light to heavy damage.

3. TEST SETUP AND PREPARATION

Eglin AFB is located in the panhandle of Florida near Fort Walton Beach. Two collection sites were used, both located at test range C-72, an area about 20 miles inland of the Gulf of Mexico consisting of open fields and scattered forestation. One was along a tree line, as shown in Figures 1, 2, and 4. The actual placement of the target was on a mowed grass field nearby an abandoned runway and immediately adjacent to a relatively dense forested area. Data collected from this set-up is being used to study obscuration and layover issues. The other site was in a large, flat, open area, with sandy soil and ground cover consisting of scrub cut down to a height of three to four inches. This is shown in Figure 5. No topographic features, i.e. hills or ravines, or man made objects were located within the antenna footprint for most of the 360° orbit of the collection platforms. In this data set, the target is clearly discernable in the phase history basis, on a single-pulse basis from all azimuth angles, prior to SAR image formation.

The setup at both sites was the same. A smooth location, capable of supporting the target at a level orientation was chosen. Wooden shims were used to keep the entire 6-meter span of the lower plane as flat as possible. After the three pieces were set in place, lifting bolts were removed, the wings were attached to the center section, and all seams were covered with aluminum tape. Care was taken to keep sand, rainwater, and debris off of the target prior to all imaging events. At the tree line location, the height and distance of the immediately adjacent tree was measured for use in layover and obscuration studies.

Additionally, the top hat contained a cavity fitted with either a plug, or one of three differently sized annular rings. These are shown in Figure 8. From left to right in the photograph, they are the plug, 2-inch hole, 4-inch hole, and 6-inch hole. These were intended to simulate various levels of damage for BDA analysis. The actual tested configurations are shown in a table in the following section.

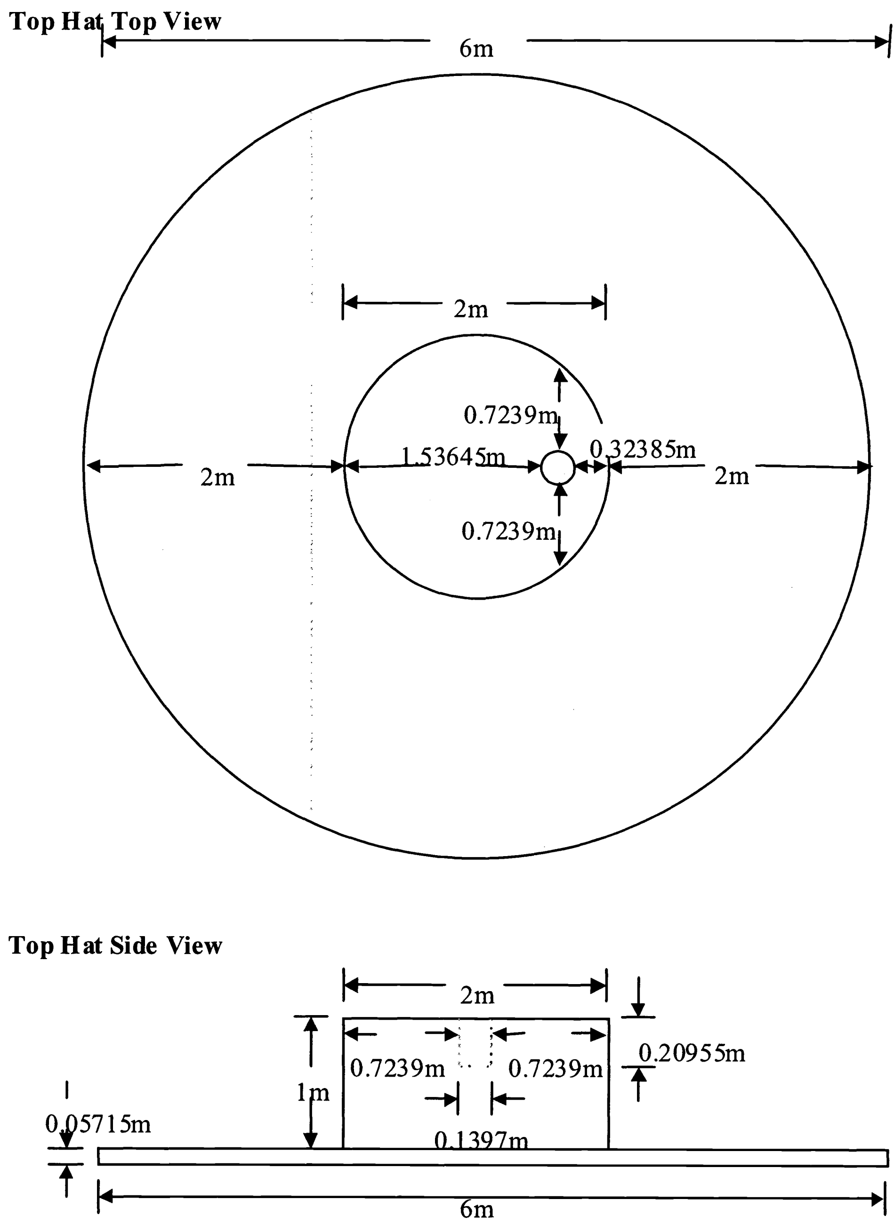

Figure 2: Top Hat Dimensions

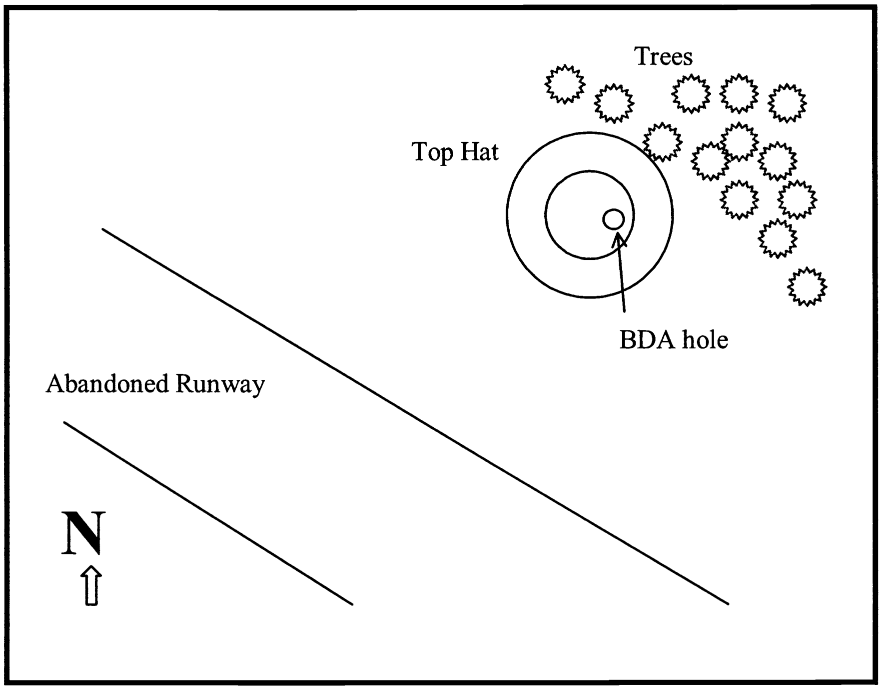

Figure 4: Tree Line Site Placement Map (not to scale)

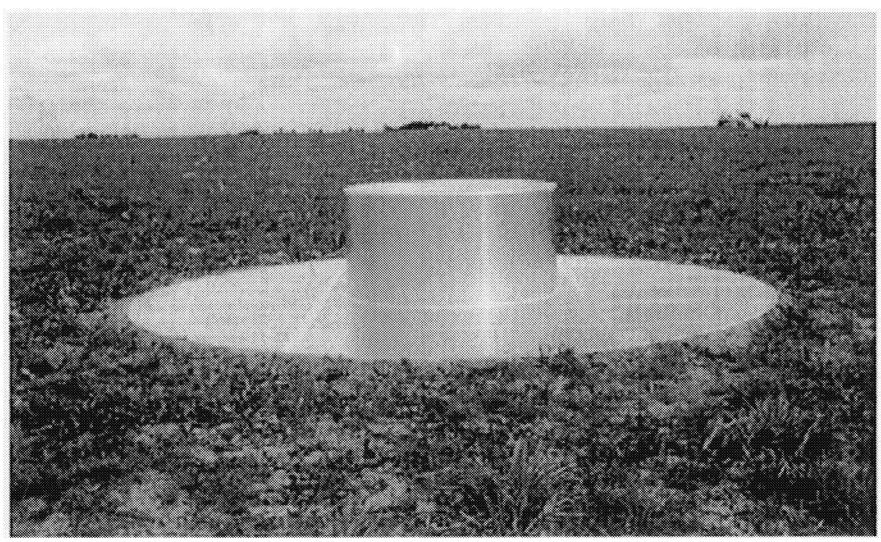

Figure 5: Open Area Test Site

4. TEST VARIABLES

The target was imaged under four distinctly different conditions: standing out alone surrounded by otherwise homogeneous clutter, obscured, with layover, and visible amongst non-homogeneous clutter. Figure 6 demonstrates the definitions of obscuration and layover, and Figure 7 shows the angular regions corresponding to the various conditions at the tree line. Layover occurs when another scatterer, such as the top of a nearby tree, occupies the same range cell as a target. Shadowing is more obvious, although given the tophat dimensions and the attenuation rate of the foliage, the target was still visible under the shadow conditions. The open area site contained only the homogeneous ground-cover clutter results.

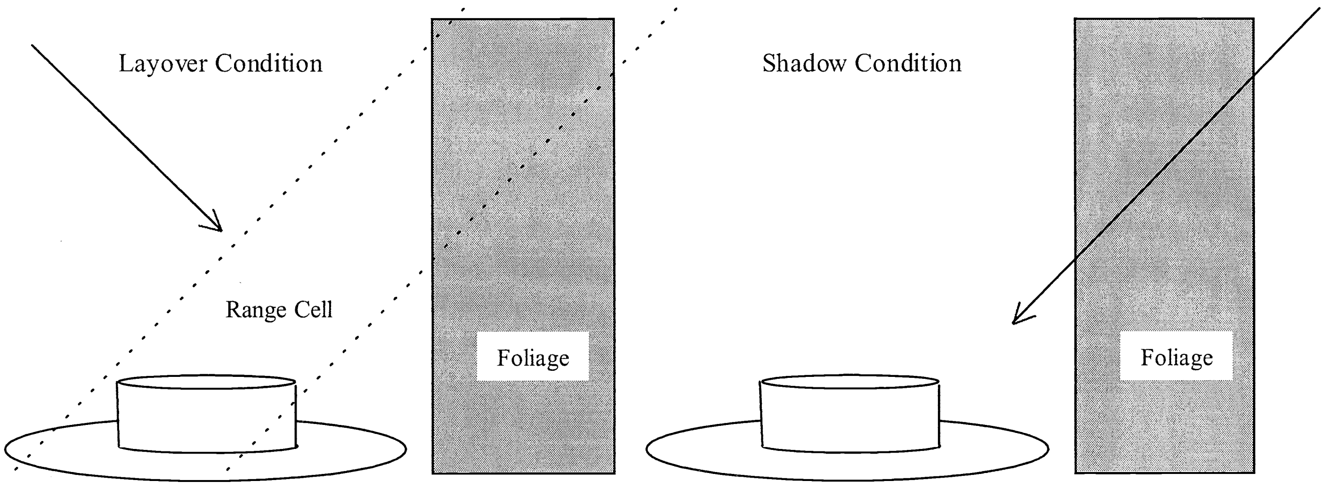

Figure 6: Layover and Shadow Definitions

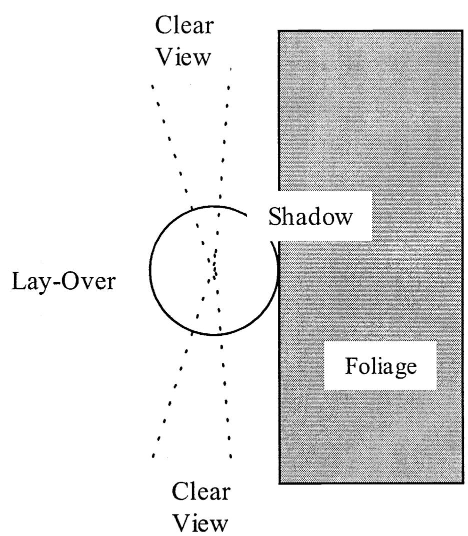

Figure 7: Layover and Shadow Regions

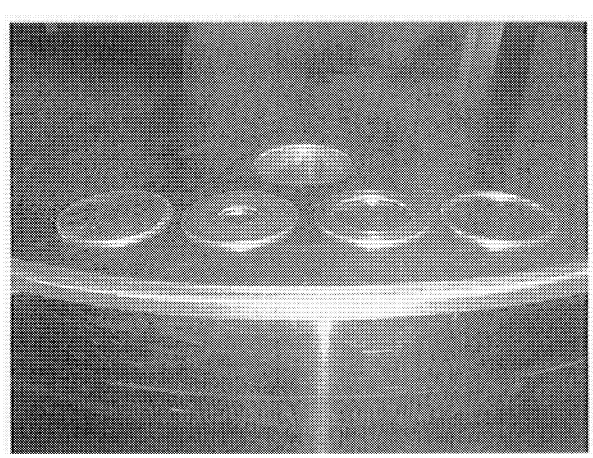

Figure 8: Fitted Rings for BDA Cavity

5. DATA COLLECTION

Two different airborne SAR systems were used to collect data, the LYNX radar, built and operated by General Atomics and the Data Collection System (DCS) radar built and operated by ERIM International. The LYNX radar operates at a center frequency of 15 GHz (Ku band), and its data product was a complex valued SAR image with 4-inch resolution. At the time of collection, the LYNX radar did not provide raw video phase history (VPH) data.

The ERIM DCS radar (http://www.erim-int.com/SDAG/sdag.html) has a center frequency of 9.66 GHz (X band) and a range resolution of one foot. It records raw VPH and various auxiliary files that contain aircraft location and antenna pointing information to allow motion compensation and processing to create SAR images at a later time. The transmitted waveform is a 600 MHz bandwidth linear frequency modulation (LFM a.k.a. chirp) pulse with a duration of 25 μs. The pulse repetition frequency (PRF) is 1953 pulses/second. DCS is fully polarimetric, meaning that it transmits both horizontal and vertical linear polarization (on alternating pulses) and has two receive channels, vertical and horizontal. This results in four channels of recorded data, VV, HH, VH, and HV, where the first letter describes the transmitted polarization and the second letter represents the received polarization. Other noteworthy parameters are a peak transmitter power approximately 1 kW and an antenna gain of 29 dB.

The raw VPH contains partially processed range data. The recorded data consists of 2048 range samples of the deramped* radar return. Samples are from a 6 bit A/D operating at 90 MHz sampling rate. When fully processed, the sampled, deramped return data corresponds to a range swath of about 500 m.

Data was collected between 31 July 2000 and 4 August 2000. All measurements were made at a nominal 30° depression angle; depression is defined as the angle between the line of site from the airborne sensor to the target and a line parallel with the ground. The DCS collection orbits were circles of radius 26,000' at an altitude of 15,000'. VPH was recorded over the entire 360° orbit for later processing on the ground. The Lynx orbits were also circular with a radius of 22,500' and an altitude of 13,000'. Unlike the DCS, the Lynx formed an image during the orbit every 30 degrees of Azimuth.

At both sites, data was collected with no simulated damage, i.e. the BDA cavity was plugged, and the "bare" scene was also imaged with the top hat removed. Some additional data was taken with the cavity cover plate removed and replaced with the annular rings mentioned above. Not all combinations were tested. Tables 1 and 2 summarize the collections that were completed.

Table I: Imaging orbits completed from tree line scene, 30° depression angle

	Clean Tophat (plug)	2" hole	4" hole	6" hole	Target removed
DCS	1	1	1	1	1
LYNX	½ orbit, 180°	0	0	½ orbit, 180°	1

Table 2: Imaging orbits completed from open area scene, 30° depression angle

	Clean Tophat (plug)	2" hole	4" hole	6" hole	Target removed
DCS	1	0	0	1	1
LYNX	1	0	0	1	1

* Deramping is a process where the received signal is multiplied with a linear FM signal with equal but opposite slope as the transmitted LFM waveform. The deramp signal is timed so that its instantaneous frequency passes through the center frequency at the exact moment that a pulse returning from a scatterer located at a reference range (usually the range to the center of the image region) passes through the center frequency. Such a pulse would have its LFM chirp completely removed leaving a DC signal. Similarly, returns from other ranges are mixed down to returns with constant non-zero frequencies. The conversion of a deramped signal to a high range resolution profile requires only a Fourier transform.

6. RESULTS

Figures 9 and 10 show the VPH for the open field site first without and then with the tophat target. The target is clearly visible on a single pulse basis, forming the long horizontal line across the entire phase history matrix. No other single object in the scene returns such a high level, indicating that the design requirements for the target were satisfied.

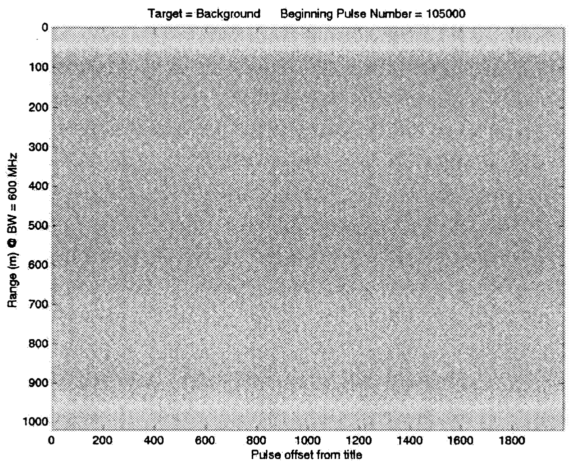

Figure 9: VPH for Open Field Site, No Target

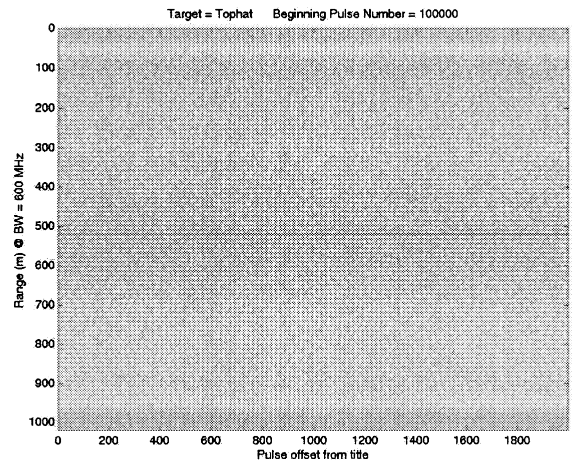

Figure 10: VPH for Tophat in Open Field Site

Figure 11 shows the tophat target near the tree line under all observation conditions indicated from. The top row is a clear view, showing the no-return zone from the brim and upper disk of the tophat. All the return energy is focused at a single point, resulting in spatial sidelobes. The second row if the figure shows the layover condition, where the target is still bright enough to be distinguished, despite the interference from the trees behind it. The final row shows the tophat through the tree shadows, indicating that although the foliage attenuates the radar energy, it still does pass enough through to allow location of the target.

7. CONCLUSION

The tophat design fulfilled its intended function. It allowed detection in the VPH domain and formed a valuable data set for obscuration and layover effects studies. Further collections are planned for not only this target, but also similar designs, with some parameters varied to enable calibration algorithm development for VPH data prior to image formation.

REFERENCES

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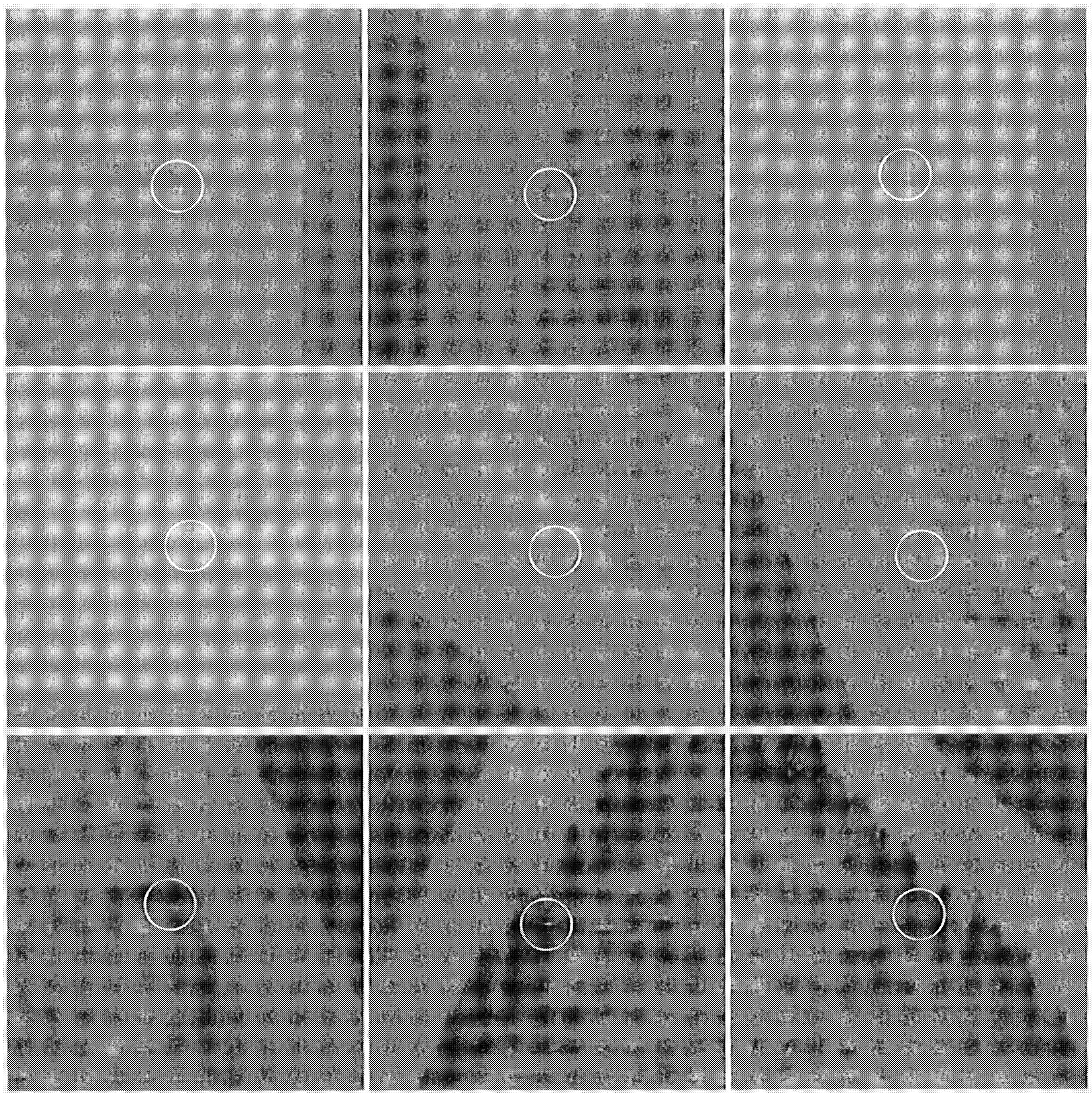

Figure 11: SAR Imagery of Tophat Near Treeline. Top row is clear view, second row is layover, bottom row is shadowed