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Signatures Directorate
Technical Data Measurement Report

SCI-1000 Evaluation

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SCI-1000 Evaluation Report

1. EXECUTIVE SUMMARY

A miniature, high speed radar system has been developed by Sensor Concepts, Inc. This system is a variant of the system developed at China Lake, California, and the model is called the SCI-1000. The DSMS team was tasked with evaluating the SCI-1000 to see if this miniature radar system could be an appropriate system for both static, high resolution, short range RCS measurements and large boat or small ship scale (target under 200' long) dynamic RCS measurements. The SCI-1000 was evaluated in a side-by-side manner with the Deployable Signature Measurement System (DSMS) at the Chesapeake Beach Detachment (CBD) of the Naval Research Laboratory (NRL) during the week of 15 December 1997. Tests were designed to evaluate fundamental RCS measurement characteristics, as opposed to testing a complete measurement system solution. This was necessary because the SCI-1000 has been designed primarily as a static near range RCS measurement system. The outdoor, dynamic RCS measurement needs are significantly different, but share many fundamental system requirements.

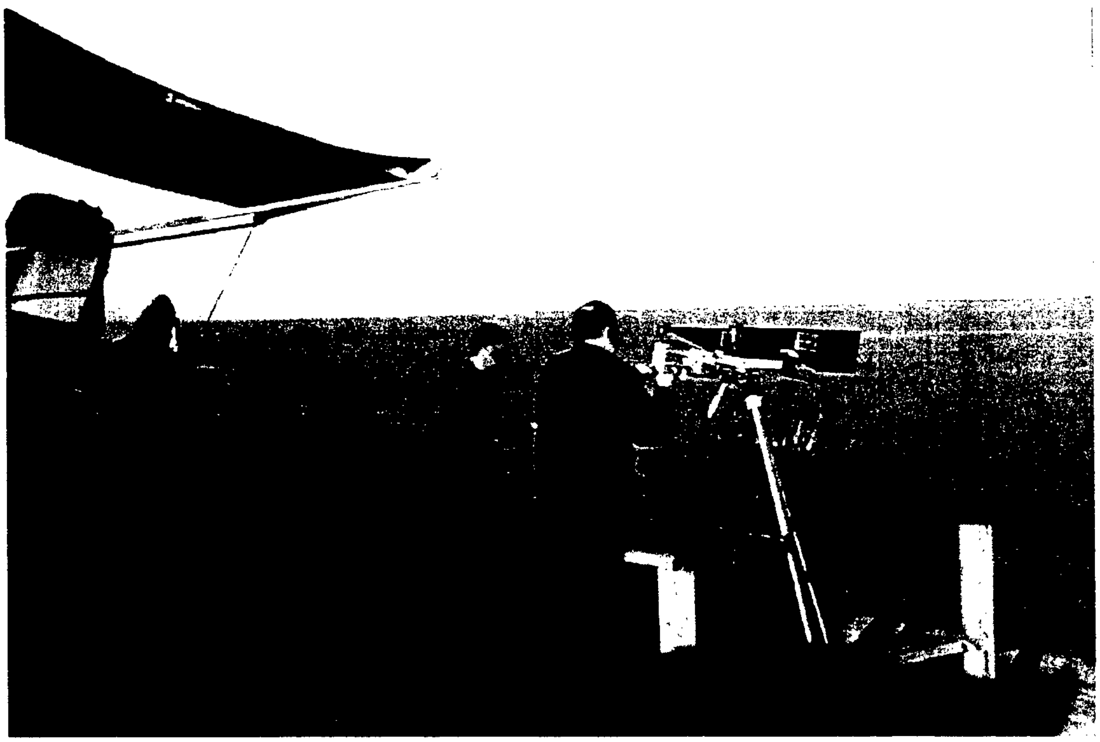

Figure 1. Setting up SCI-1000 in front of DSMS Antennas

The SCI-1000 performed above expectations throughout the entire battery of tests. Data were collected at 'near' distance (500 to 800 feet) and 'far' distance (1 nautical mile) conditions on targets with a wide variety of cross-sections. All SCI-1000 data compared well with DSMS data in both level and character. The SCI-1000 collected data at burst rates fast enough to capture the dynamic data scene. Data were processed quickly enough for on-site comparison, and were archived for more detailed data processing later.

The SCI-1000 is a linear sweep FM homodyne radar system. This is fundamentally different from the stepped pulsed DSMS radar system. Because of this difference, DSMS has 1000 watt transmitters, while the SCI-1000 has 0.4 watt transmitters. In addition, DSMS uses three $85,000 Comstron frequency generators with three $100,000 Travelling Wave Tube Amplifiers (TWTA's), while the SCI-1000 uses low-cost, custom designed frequency sweep circuitry which produces the full required output power. One drawback of the linear sweep system is that it must have two antennas to allow simultaneous transmit and receive. Another drawback is that objects between the radar and target can saturate the radar, making RCS measurements impossible (This problem was not evident during any tests). Stepped pulsed systems can more easily tolerate objects between the radar and target, by range gating and the use of expensive limiters. However, because the SCI-1000 is designed to measure at short range as well as at long range, short range calibrations can be performed. This is a very significant advantage because it is much easier to prepare a "clean" calibration (no multipath and adequate signal-to-clutter) at 10-foot range than at the 150-foot typical calibration ranges of stepped pulsed systems.

While current technology would allow linear sweep FM homodyne radar systems to function at long range (1 nautical mile and longer), the SCI-1000 is the only commercially available radar system known that has actually implemented the hardware and algorithm improvements needed for long range operation.

Some significant performance and system characteristics are:

- SCI-1000 was able to detect a 5 dBsm target at 1 nautical mile (-16 dBsm range resolved) - DSMS also detected a 5 dBsm target. Both systems used comparable antennas; but, DSMS transmitted 2500 times the power (1 kW vs. 0.4 W).
- SCI-1000 was calibrated with a simple calibration target placed 10 feet from the radar - DSMS required that a much larger calibration target be placed a minimum of 150 feet away (much more difficult to avoid multipath and reduce clutter).
- SCI-1000 covers radar frequencies from 0.2 - 18 Ghz (we only tested 8 - 18 Ghz), DSMS covers 2 – 4 Ghz, 8 – 18 Ghz.
- SCI-1000 does not need frequency allocation coordination because of low transmitted power. DSMS must obtain temporary frequency allocations for each operating location.

The small size of the SCI-1000 produces significant cost savings, while at the same time providing more measurement flexibility:

- Easier (cheaper) to ship -- SCI-1000 weighs a total of 100 lb. - DSMS weighs 4500 lb.
- Easier to set up (no trucks, fork lifts, generators, scissors lifts).
- Cheaper to maintain spares (less expensive parts, fewer parts to stock, smaller parts to store).
- Lower electrical power requirements -- SCI-1000 requires 250 watts of power - DSMS requires 50,000 watts.
- Safer to work around low power transmitters.
- Easier to keep operational (fewer parts to check for failure, smaller parts to swap).
- More measurement flexibility (operate from helicopter, van, car, aircraft, boat, ship, roof of building, tower, hanger, crane, with limited power, space and cooling).

The most striking difference between the two radar systems is the size. DSMS operates from a 24-foot-long shelter, with 50 kVA of electrical power for equipment and cooling. The SCI-1000 is basically a table-top box with a laptop computer. It is remarkable that the two systems are capable of providing the same quality data, and nearly the same measurement.

The SCI-1000 clearly has the fundamental capability required for high resolution close-in and long range full scale RCS measurements. However, the system's hardware and software are currently optimized for close-in, static measurements. To support longer range, full scale, dynamic measurements, the following modifications or additions will be needed:

- Integration of auxiliary dynamic measurement parameters:
    - telemetered roll, pitch and heading from the target
    - range to target, attenuation
    - antenna pointing angles (azimuth and look-down angle)
    - boresight video
    - GPS time
- Operate multiple radar bands, simultaneously:
    - modularize Frequency Sweep Source hardware to separate bands
    - provide multiple Signal Processors in the Data Collection Computer
- Operate V and H polarizations simultaneously
- Modify Data Collection software to allow:
    - realtime data monitor during data collection
    - realtime monitor and control of dynamic parameters
    - more sweeps per second to measure higher doppler rate phenomena

2. TEST OBJECTIVES AND APPROACH

In order to evaluate the SCI-1000's suitability for static, high resolution, short range RCS measurements and full-scale boat or ship dynamic RCS measurements, a dual-scenario testing approach was devised. Radar stability, sensitivity, and accuracy were assessed with targets at 'short' (500-800 foot) distances. Dynamic target measurement tests conducted at distances of one mile verified the system's capability to measure moving targets and to perform short range calibrations for long range measurements.

In order to evaluate the system's ability to perform short range, static measurements the following tests were designed:

- Frequency linearity and Phase stability – determines the ability to produce fine resolution measurements for small targets, or spotlighting
- Noise Equivalent RCS (NERCS) – determines the lowest RCS level detectable
- Dynamic range – determines the ability to measure low RCS level objects in the presence of large RCS level objects
- Range resolution and Accuracy – determines the accuracy in reporting range extent at a given range resolution
- RCS level accuracy – determines the ability to accurately measure both low and high RCS level objects
- Realtime data processing – determines the timeliness and usefulness of realtime data products
- System setup – determines the ease of system setup

Many of the short range tests pertained to long range measurement objectives also. However, some additional tests were designed:

- Short range calibration – tests the ability to perform a calibration at a different range from the measurement object
- Tracking of dynamic targets – tests the ability of the system to track a moving target in both azimuth and range
- Long range Noise Equivalent RCS (NERCS) – verifies that the long range NERCS follow short range NERCS as expected

3. SUMMARY OF COMPARISON RESULTS

Table 1 on page 5 provides a summary of the determined characteristics of the SCI-1000 versus DSMS. Notice that the last column provides the estimated characteristics of the SCI-1000 with modifications.

Table Summary of Measurement Capabilities	DSMS As is	SCI-1000 As is	SCI-1000 w/ Minor Mods
Measurement types :			
Close range ISAR imaging	Yes	Yes	
3-D ISAR (Scanner)	No	Yes	
Long Range Ship Measurements	No	No	Yes
Measurements from Helo	Yes	No	Yes
High Speed Doppler	Yes	Close Range	Yes
Basic radar capabilities:			
Bands Covered	S, X & Ku	0.2-18 GHz	
Bands Simultaneously	3	1	3 (Hardware & Software Mods)
Polarizations Simultaneously	VV,HH,VH,HV	1	VV,HH (Hardware & Software Mods)
Transmit Power	1000 W	0.4 W	
Antenna Gain (as tested)	26 dBi	24 dBi	Sized for Need
Sensitivity at 1 nmi (X band)	5 dBsm	5 dBsm	-8 dBsm (Slower Sweep Time)
Range Resolved Sens. at 1 nmi	-19 dBsm	-19 dBsm	
Resolution at 1 nmi	3 inches	24 inches	12 inches
Resolution at 10 nmi	3 inches	N/A	24 inches
Resolution at 800 feet	3 inches	3 inches	1.5 inches
Bursts Per Second	> 100	40	>200
Time of Burst	25 ms	0.8 ms	0.8 - 8 ms
Instantaneous Dynamic Range	> 60 dB	> 60 dB	
Physical characteristics of radar (no antennas):			
Weight	4500 lbs	75 lbs	100 lbs
Size	12'x4'x4'	2'x2'x1'	2'x2'x2'
Power requirements	50 KVA	0.3 KVA	0.5 KVA
Auxiliary data:			
Boresight Video	Yes	No	Yes
Range to Target	Yes	Yes	Better
System Attenuation	Yes	Yes	Yes (may not be needed)
GPS Time	Yes	No	Yes
Target Motion	Yes	No	Yes
Antenna Pointing Angle	Yes	No	Yes
Transponder	Yes	?	?
Measurement control			
Target Pedestal Integration	Yes	Yes	
Target Range Tracking	Yes	Awkward	Yes
Dynamic Range Tracking	Yes	Awkward	May not be needed
Stored Setups	Yes	Yes	
User Interface (Static meas.)	Optimized	Optimized	
User Interface (Dynamic meas.)	Optimized	Awkward	optimized
Measurement monitoring:			
Built-in Post Processing	No	Yes	
Range Feedback to Pilot	Yes	No	Yes
Realtime During Data Collection	Yes	No	Yes
Realtime Displays Simultaneously	> 6	2	2 or 4
Realtime WBRCS vs Time	Yes	No	Yes
Realtime WBRCS DRP	Yes	Yes	
Realtime WBRCS DRP History	Yes	No	Yes
A/D Histograms	Yes	No	Yes
Realtime WBSS vs Time	Yes	No	Yes
Realtime SS vs Frequency	Yes	Yes	
Realtime WBSS DRP	Yes	Yes	
Realtime WBSS DRP History	Yes	No	Yes
Realtime Aux Data	Yes	No	Yes
Calibration:			
Various Calibration Targets	Yes	Yes	
Minimum Calibration Distance	150'	10'	
Phase & Magnitude Calibration	No	Yes	
Calibrated Attenuators	Yes	Yes	
Calibrated Cable Delays	Yes	No	Yes
Peak Detect	Yes	No	Yes
Security			
Removable disks	Yes	Yes	
Internal disks	No	No	

Table 1. Measurement Capability Summary Table

4. TESTS

4.1. Test articles

A wide variety of items were used in these measurements. Many items are calibration targets from the DSMS inventory, or are used to support DSMS measurements.

4.1.1. The Avon boat

A 16' long Avon boat was used for many tests. This boat is fiberglass, semi inflatable, with outboard gas engine, center control console and two bench seats, and may be operated by one person. The boat is equipped with a marine band VHF radio for communications between the test team and boat driver. Buoys deployed from the boat were used as markers to keep the boat generally at a fixed range. A 2' trihedral was added to the boat to have the boat's signature cover a wide dynamic range.

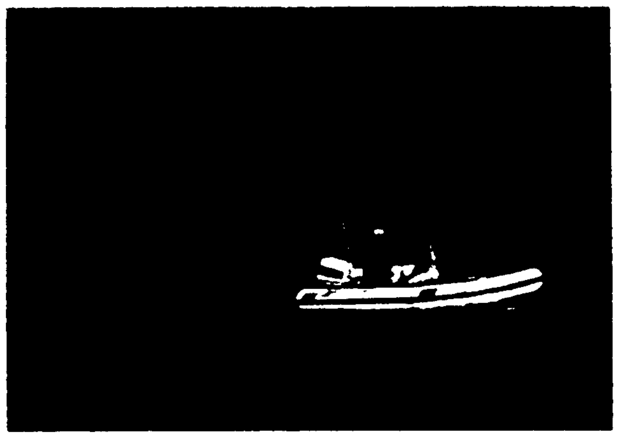

Figure 2. Avon Boat with Trihedral

4.1.2. Trihedrals

Two different triangular trihedrals were used for various tests. These trihedrals have been measured at indoor ranges and are used as precision calibration targets by DSMS. They were used to augment the boat signature, provide point scatterers on a pier, and map out multipath lobing at various ranges.

- 24" triangular trihedral (center to tip dimension). RCS is approximately 28 dBsm in X band, and 32 dBsm in Ku band.
- 11.3" triangular trihedral (center to tip dimension). RCS is approximately 15 dBsm in X band, and 19 dBsm in Ku band.

4.1.3. Flat Plate (1'x3')

A 1' by 3' flat plate was used as a calibration target by both systems. This plate was set up on the pier, looking up 12 degrees towards the radar, at a range of ~530' from the radars. The flat plate is affixed to a tripod that rigidly holds the plate in position. The legs of the tripod were oriented to deflect radar energy away from the radar, and the flat plate shadowed the tripod's geared head from the radar. The tripod head allows accurate, smooth movement of the flat plate in both azimuth and elevation. This provided a multipath-free, high signal-to-noise signal at both X and Ku bands. The flat plate was equipped with a boresight scope for coarse pointing; fine pointing of the flat plate was accomplished by peaking the radar return. This plate has also been measured in indoor ranges and is another of the DSMS precision calibration targets. Background returns from the pier were more than 50 dB (range resolved) below the flat plate return. Flat Plate RCS is approximately 30 dBsm in X band, and 34 dBsm in Ku band.

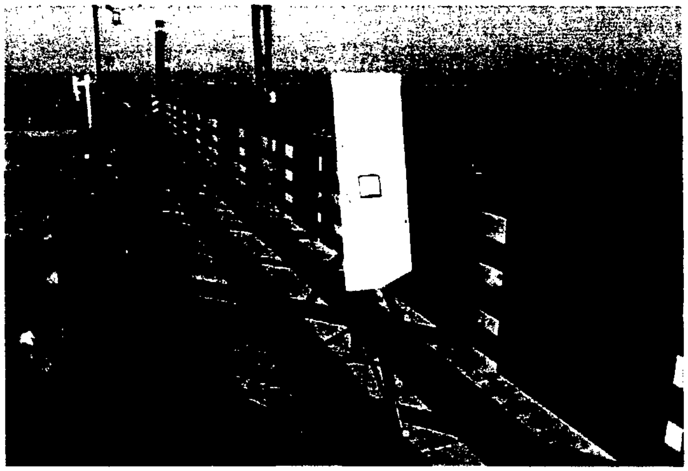

Figure 3. Flat Plate on Pier

4.1.4.Sphere (14" diameter)

NRL routinely suspends a 14" sphere from an aerostat for free space measurements. The sphere was hung approximately 50 feet below the aerostat, and 200 feet above water level. The sphere/aerostat were brought out to the test site by boat and the line anchored at a radar range of approximately 800 feet. It should be noted that the sphere and aerostat range and altitude varied greatly depending on wind conditions. Universal Spinning Corporation manufactures the sphere. Measurements of similar spheres from this manufacturer have been made in indoor ranges and show that the RCS of the sphere can vary by 5 dB over sphere elevation angle. The error is most noticeable near the manufactured equator of the sphere where the two sphere halves are joined. Sphere RCS is approximately -10 dBsm at all frequencies.

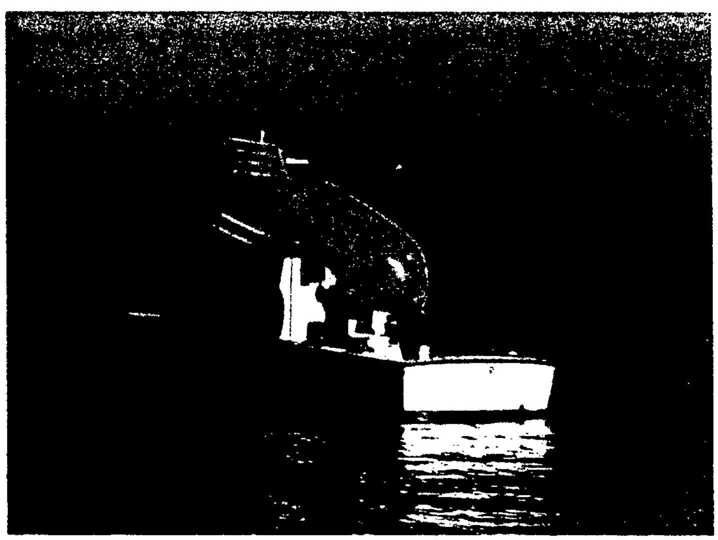

Figure 4. NRL Personnel Filling Aerostat

4.1.5. Sphere (12" diameter)

A 12" diameter sphere (also manufactured by Universal Spinning Corp.) was also used on the pier to assess radar dynamic range. This sphere was suspended from a line run diagonally between hand rails on the pier. An operator out of the radar scene slid the sphere across this line by pulling an additional string attached to the sphere. This moved the sphere in range away from the radar over a distance of approximately 8 feet. Sphere RCS is approximately –11.4 dBsm at all frequencies.

4.1.6. Dihedral (3" x 3")

The SCI-1000 has the ability to measure calibration targets placed at distances as close as 10 feet from the radar antennas. A 3" x 3" dihedral corner reflector was shipped with the SCI-1000 system and used to demonstrate the feasibility of performing close-in calibrations for use in longer range measurements.

4.2. Static High Resolution Tests

Measurement assessment strategies were created for SCI-1000 measurements at short ranges. These tests were designed to assess measurements of individual objects, as opposed to entire boats or small ships. The radar characteristics tested show the suitability of this system to locate and discriminate scatterers, and to determine minimum detectable scatterer size. Resolution was set to 3 inches with a maximum range of 800 feet. Out of the full 800 feet of alias-free range, only 64 feet of range extent was recorded to disk. This reduced the data volume considerably.

4.2.1. Calibration Technique Fidelity

The SCI-1000 radar system was calibrated with a 3" x 3" dihedral corner reflector at a range of 15 feet. The corner reflector was placed on the deck railing at a distance of 15 feet from the radar antennas. Easily moved objects were then removed from the vicinity of the calibration target, leaving the platform as the only potential clutter source. The calibration target was viewed by the radar using the SCI-1000's real-time diagnostic mode and a software gate was positioned around the calibration target response in order to eliminate the effects of the platform on the calibration target response. The value of this corner reflector is approximately -2 dBsm at 10 Ghz. The antennas were then pointed towards the 12" x 36" flat plate located on the pier at a range of approximately 500 feet. The SCI-1000 radar registered a value of +30 dBsm at 10 Ghz which is in good agreement with the theoretical value for the flat plate.

4.2.2. Noise Equivalent RCS (NERCS)

After calibrating the SCI-1000, the radar antennas were pointed into the sky to eliminate radar returns from any scatterers. This left only the radar system's noise floor, which was then calibrated as if it were a return from an actual target. This RCS level represents the minimum detectable signal at the measured range. NERCS at 1000' were about –30 dBsm. It should be noted that this NERCS figure is non range resolved. Range resolved NERCS would be further reduced, depending on the number of range steps.

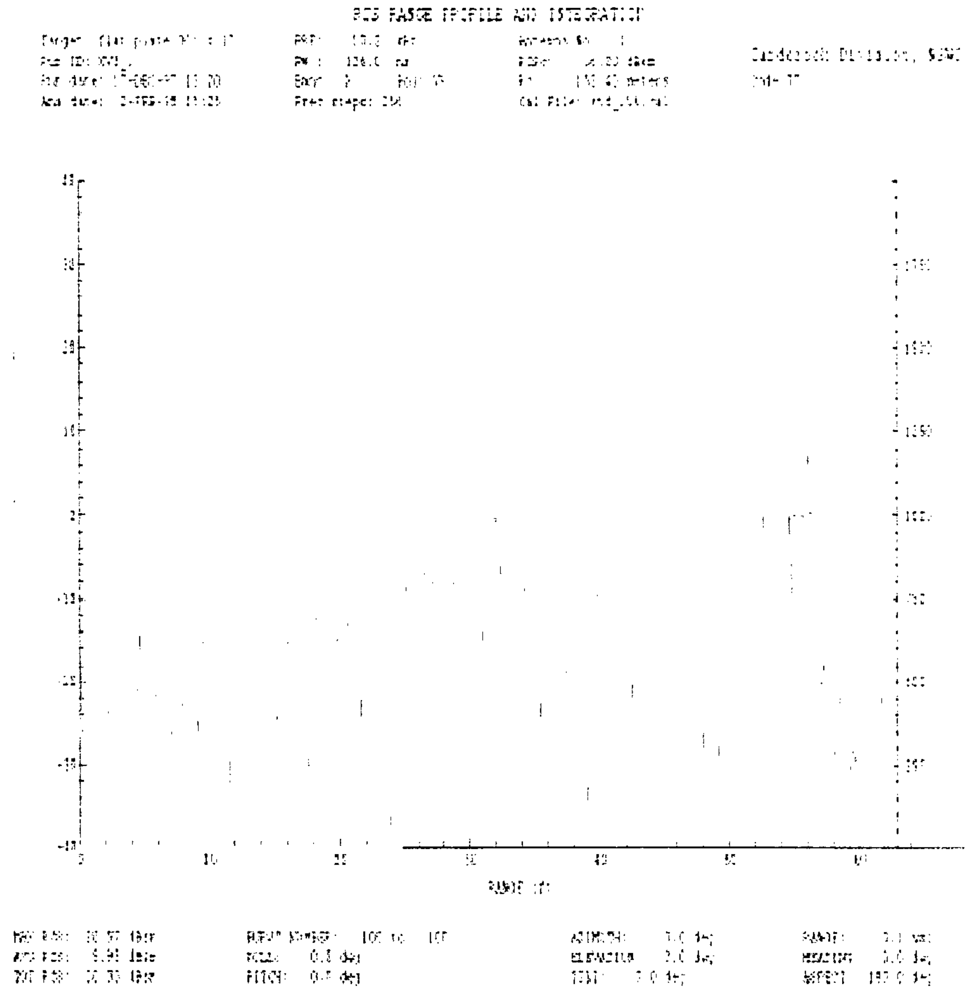

Figure 5. Flat Plate Point Spread Function from SCI-1000

4.2.3.Frequency Linearity

In order to assess frequency linearity, a stationary flat plate was measured and then imaged in 1-D (Down Range Profile). The resulting point spread function (PSF) of the flat plate was examined for width of main lobe, amplitude of first side lobes, and taper of remaining side lobes. Highly linear frequency sweeps yielded point spread functions with energy well focussed in the main lobe. Figure 5 shows the resulting Point Spread Function measured by the SCI-1000. The side lobes of the PSF were seen to be 40 dB down from the peak, indicating extremely linear frequency. Other artifacts seen in Figure 5 are returns from the pier and returns from equipment on the pier. These artifacts have no impact on the radar's frequency linearity.

4.2.4.Dynamic Range (Flat Plate, Pier, Free Space)

To test the SCI-1000's Dynamic range, a large target was measured, and without changing any settings, the radar's measurement floor was measured (radar Noise Equivalent RCS (NERCS)). This procedure was devised to illustrate the wide variation of target RCS that the system was capable of measuring. This is important, since ship's signatures may have large returns at broadsides, and smaller returns in other areas (for example, bow aspects). To provide a large RCS Target, the flat plate was peaked on the radar giving a 30 dBsm X band return. Then, an operator on the pier turned the flat plate away from the radar, and the return disappeared and the pier appeared from the sidelobes of the plate return. After that, the radar antennas were pointed up in the air to record NERCS data which is the radar's measurement floor. Over the course of the run, the measured RCS dropped from 30 to –30 dBsm as illustrated in Figure 6 with NO attenuation changes.

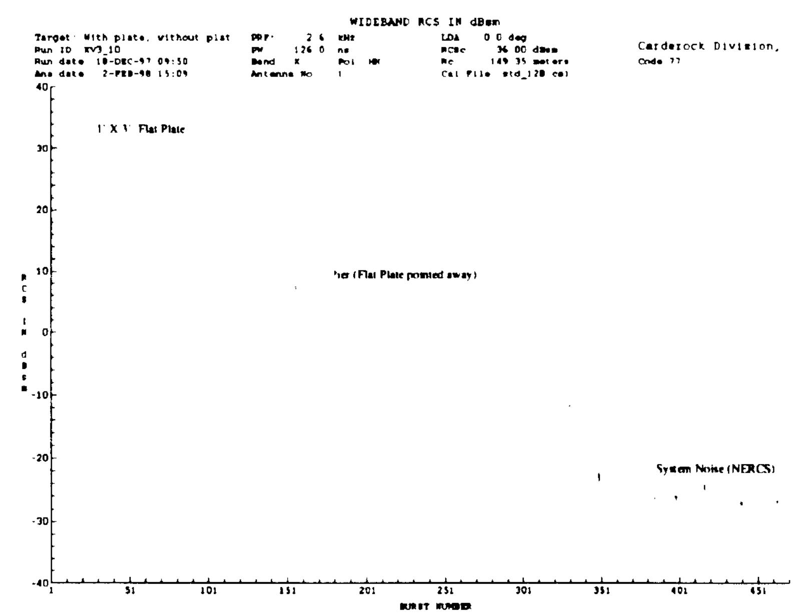

Figure 6. RCS Levels of Flat Plate, Pier, and Free Space

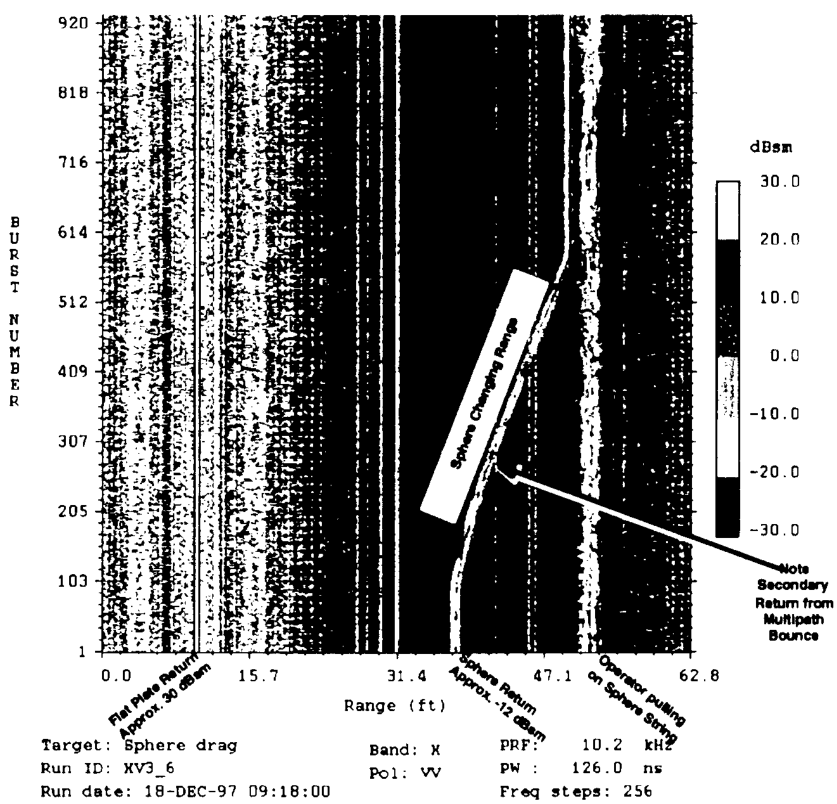

Figure 7. Sphere and Flat Plate Returns in SCI-1000 Dynamic Range Test

4.2.5. Dynamic Range (Sphere in Presence of Flat Plate)

Another test to quantify the SCI-1000's Dynamic Range was to measure a small target in the presence of a large target. The 12 inch diameter sphere was moved while measuring the flat plate and the sphere at the same time. By moving the sphere, it can be discerned in the background clutter of the pier. It is clear from this test that the SCI-1000 has sufficient dynamic range to detect a -12 dBsm sphere (with multipath return) while also accurately measuring a 30 dBsm flat plate. Figure 7 shows data collected in this test.

4.2.6. Range Resolution and Accuracy (Trihedral in Proximity of Flat Plate)

A tape ruler was placed on the deck of the pier beside the flat plate. During the measurement, an operator moved the 11.3 inch trihedral in 6 inch increments along the tape ruler, starting behind the flat plate and ending in front of the flat plate. It is clear from these tests that the range resolution is 3 inches and accurate. Figure 8 shows the Downrange Profile History of the SCI-1000 data from this measurement.

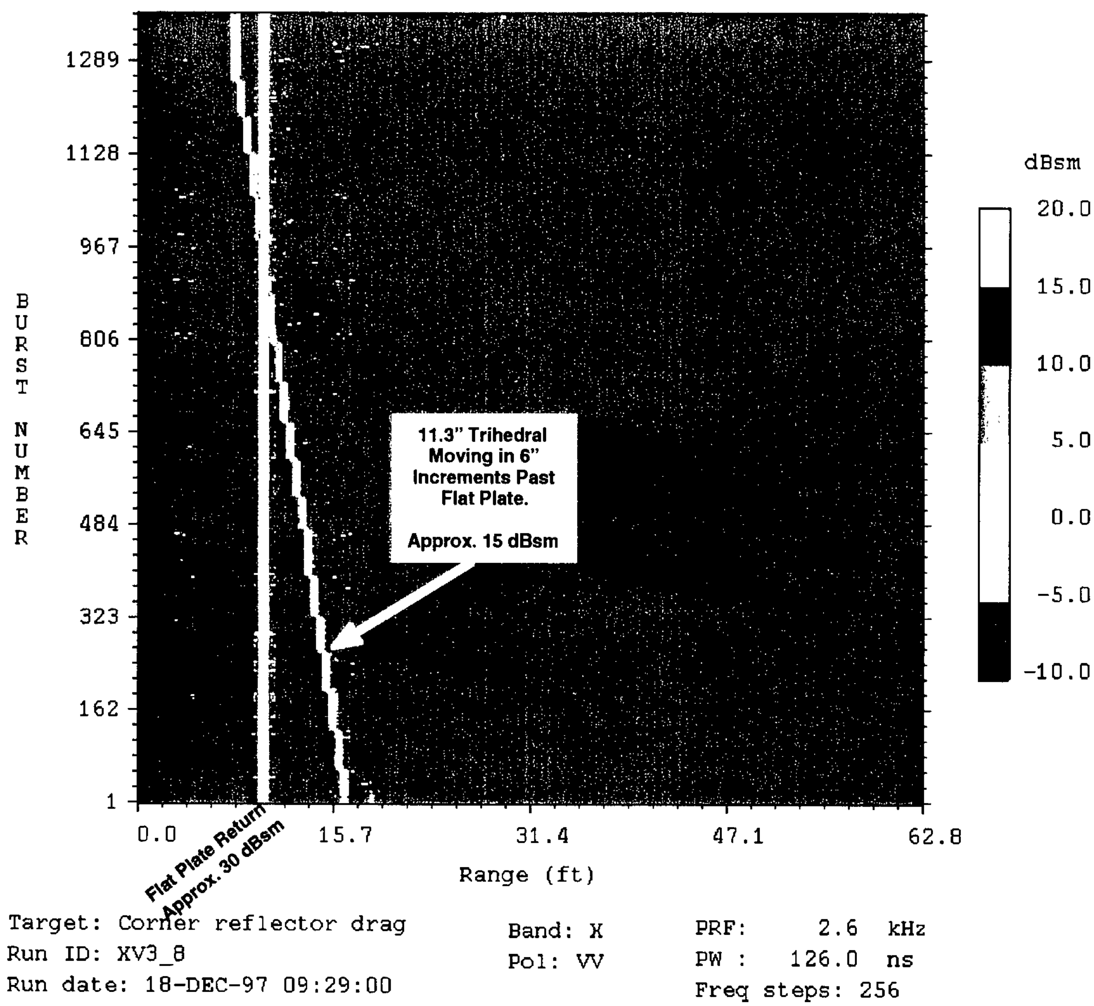

Figure 8. Trihedral and Flat Plate in SCI-1000 Resolution & Accuracy Test

4.2.7. Radar Phase Stability (Imaging Flat Plate)

The stationary flat plate was measured and then ISAR imaged. The point spread function (PSF) of the resulting image was examined in both down-range and cross-range. In order for this PSF to follow the classic shape (according to the FFT weighting window) the frequency must be stable over time. The first side lobes of the PSF were seen to be 30 dB down from the peak, indicating extremely stable frequency. Figure 9 shows the ISAR image of the plate and pier. If the radar had lower stability, the flat pate return would have been smeared vertically instead of resolving to a sharp point. The image of the splashing water shows this smearing effect, but this is due to the dynamic environment, not the radar.

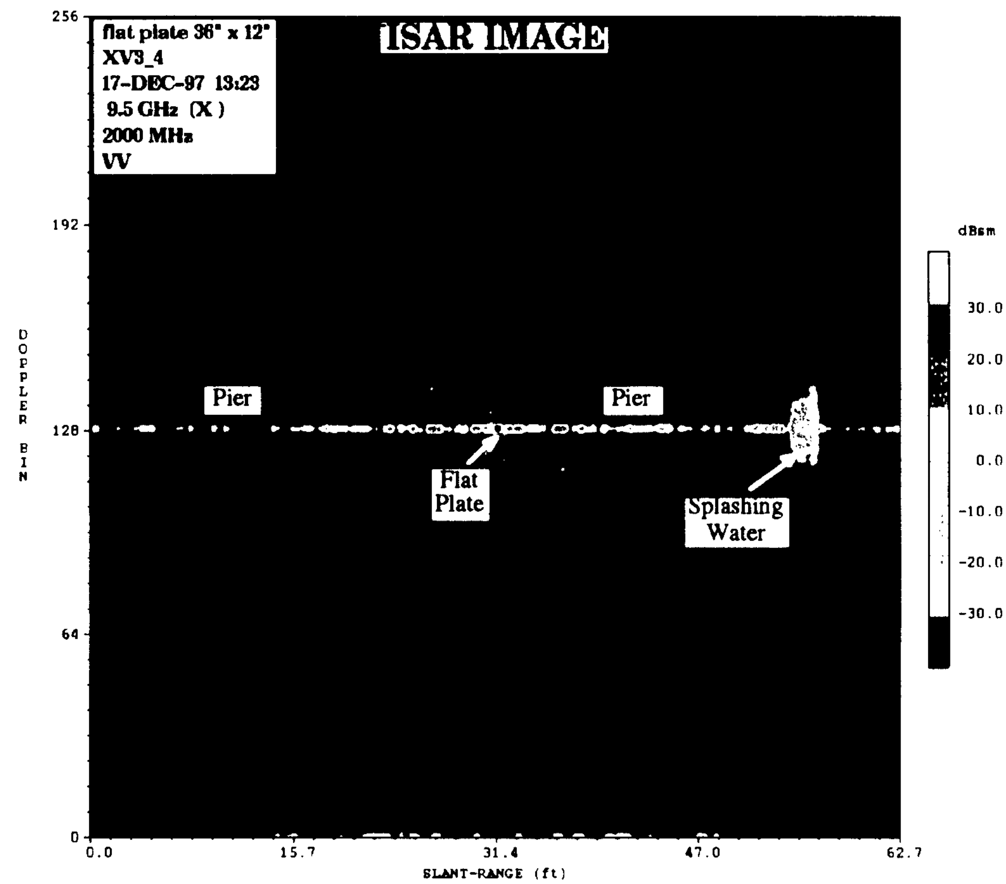

Figure 9. Flat Plate Imaged to Show SCI-1000 Phase Stability

4.2.8. Small Boat Circles

The 16 foot Avon boat was placed at a nominal range of 700 feet. A buoy was placed in the water as a marker for the boat to drive around. RCS measurements were performed over multiple full circles of boat rotation. The boat attempted to drive 2 minute circles. The SCI-1000 radar collected data. Then this radar was secured and data was collected by DSMS. There was no attempt to measure and record the boat's heading, pitch and roll since the SCI-1000 is not configured to integrate this data. SCI-1000 Down Range Profile History for one boat rotation is shown in Figure 10. Data from the two radars were compared and the results show very little difference.

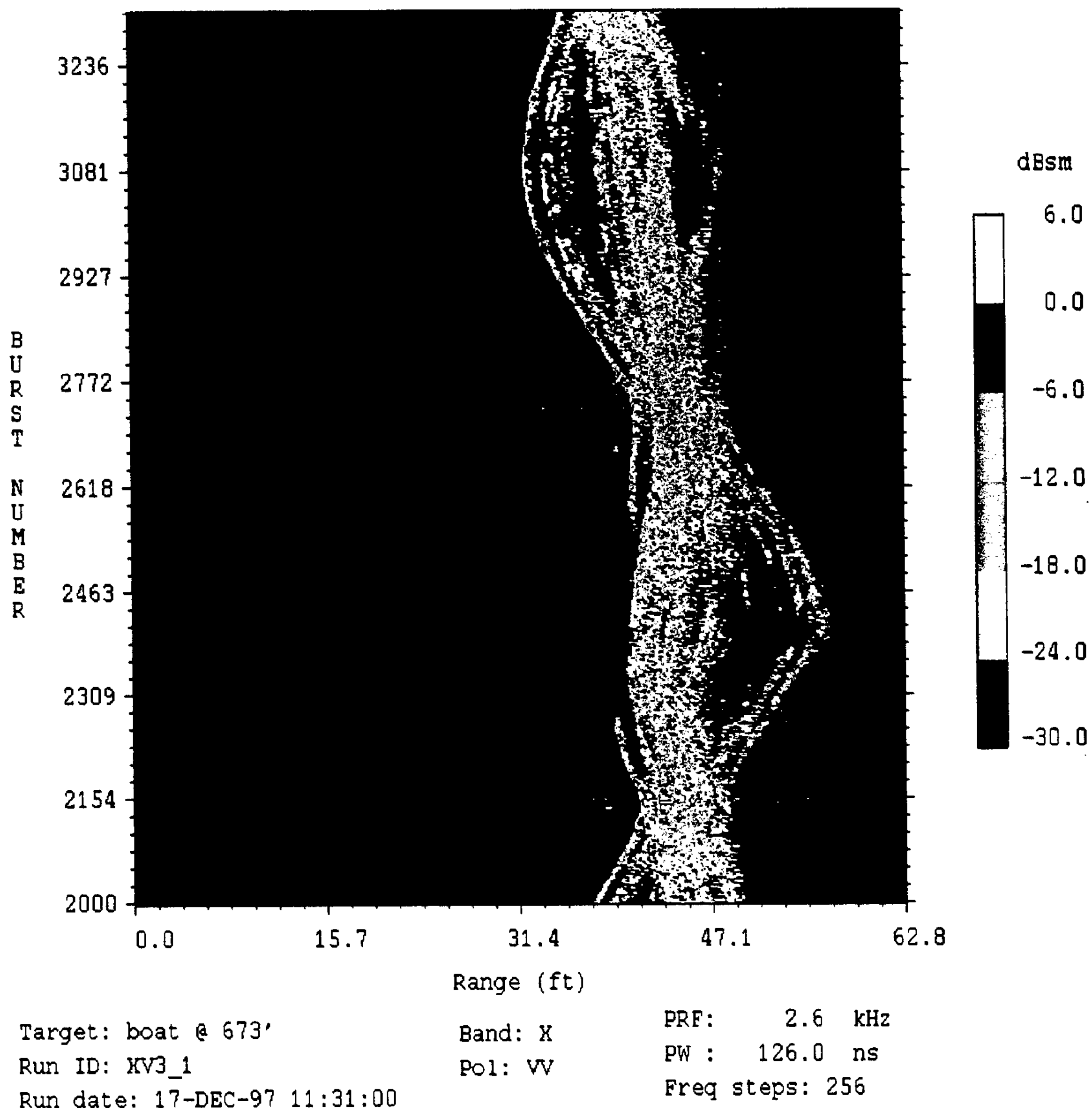

Figure 10. Avon Boat DRPH (SCI-1000)

4.3. Dynamic Long Range Tests

Measurement assessment strategies were created for SCI-1000 measurements at long ranges. These tests were designed to simulate measurements of full scale boats or targets at typical operating ranges. Therefore the resolution was set to 6 inches (for 1600 foot range) or 2 feet (for 6400 foot range). Out of the full alias-free range, only 256 feet of range extent was recorded to disk. This reduced the data volume considerably, and is typical of measuring targets up to 200 feet long.

4.3.1.Noise Equivalent RCS (NERCS)

After calibrating the SCI-1000, the radar antennas were pointed into the sky to eliminate radar returns from any scatterers. This left only the radar system's noise floor, which was then calibrated as if it were a return from an actual target. This RCS level then represents the minimum detectable signal at the measured range. Measured NERCS were found to be –6 dBsm at 3000 feet and 5 dBsm at one nautical mile.

4.3.2.Small Boat Circles

The 16 foot Avon boat was placed at various ranges from 1900 to 6400 feet. The 24 inch trihedral was placed in the boat facing out the starboard side, at a nominal look up of 0 degrees. A buoy was placed in the water as a marker for the boat to drive around. RCS measurements were performed over multiple full circles of boat rotation. The boat attempted to drive 2 minute circles. The SCI-1000 radar collected data. Then this radar was secured and data was collected by DSMS. There was no attempt to measure and record the boat's heading, pitch and roll since the SCI-1000 is not configured to integrate this data. Since boat's heading was not recorded, the data are compared in XY format with Aspect angles approximated. Since data were not measured simultaneously, boat motions (pitch and roll) were different in the DSMS and SCI-1000 measurements, and small variations are seen in the near- and far-range measurements conducted.

The Wideband RCS (WBRCS) vs. time data in Figure 11 and Figure 12 clearly shows the expected return for a trihedral (wide lobe with two sharp spikes at either side from the individual flat plate responses). One of the flat plate spike responses is smaller than the other, most likely due to the nominal orientation of the trihedral and pitch of the boat. Differences between data measured by DSMS and SCI-1000 are very small, and are attributed to the boat's uneven motion.

Data from the 1900 foot (Figure 11) measurement has a considerably lower values than data from the 6000 foot measurement (Figure 12) for several reasons. Multipath lobing structure is different (notice trihedral peak values), radar system noise increases at 6000 feet, and much less sea surface was illuminated at close range and therefore sea clutter returns were lower. Both sensors are affected by all of these factors. The data have been analyzed in depth, and these plots are a small sample of the data recorded. Data from the two radars are very similar in value and character.

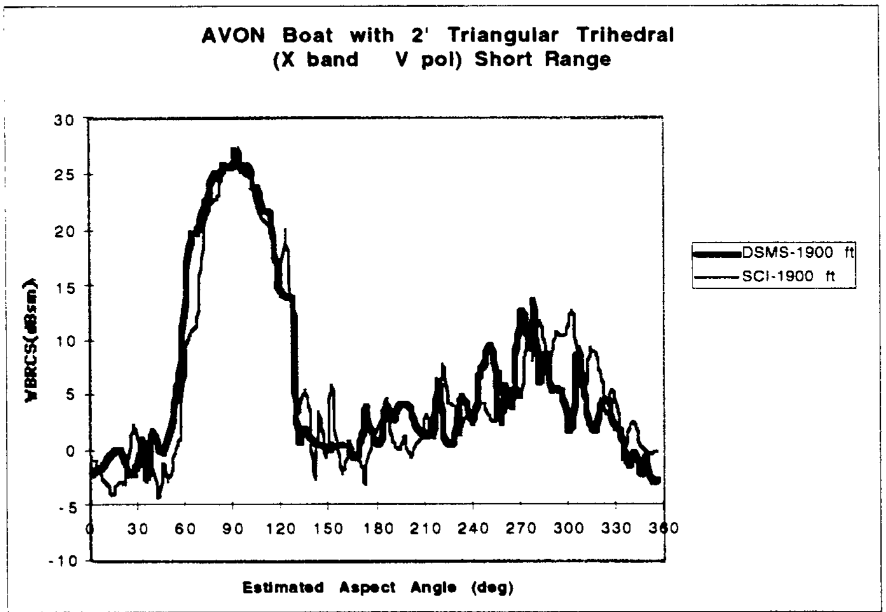

Figure 11. Short Range Avon Data from DSMS and SCI-1000

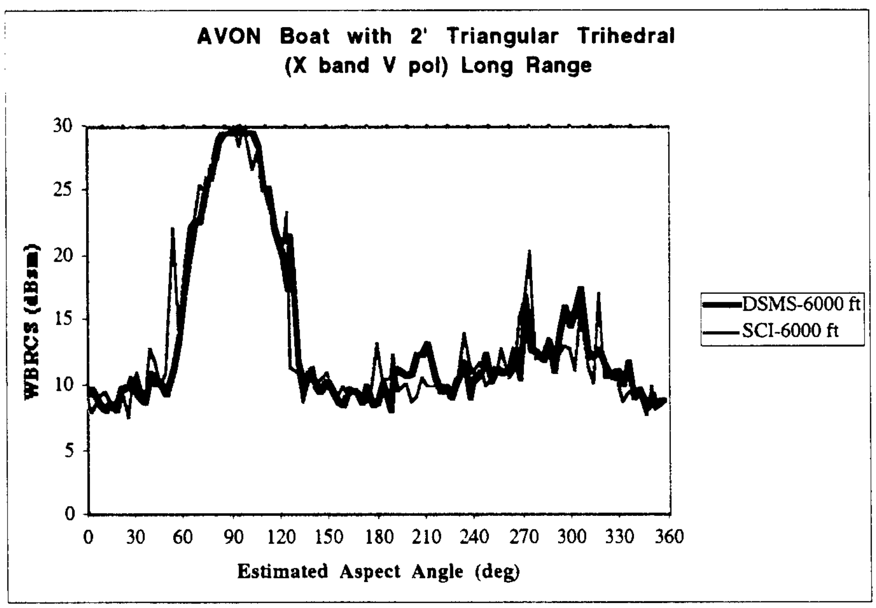

Figure 12. Long Range Avon Data from DSMS and SCI-1000

5. SCI-1000 SYSTEM DESCRIPTION

This is a linear FM homodyne radar system. It consists of a system box, laptop PC and antenna system. The total weight of the system without antennas is about 75 pounds. Various antennas can be connected depending on the target size and range. The standard power is 120 VAC, 60 Hz, 2.5 amps. An optional DC power module allows operation from a standard 12 VDC car battery.

5.1. The Radar

The basic function of the radar is as follows:

- A linear FM sweep is generated that covers the desired bandwidth (or multiple bands if desired). The sweep speed is adjusted to provide the desired sweeps per second.
- The linear sweep is transmitted out one antenna and compared against the received return (from a second antenna) from the target scatterers. This produces a set of sinusoids whose frequencies are proportional to the range to the set of scatterers. Typically, the range is "alias-free" from the radar to the target.
- Both RF and IF attenuators adjust the signal level to match the dynamic range of amplifiers and the A/D.
- The resulting comparison frequency is sampled with a high speed A/D, after appropriate Video Bandpass filtering.
- Built in digital signal processors can eliminate unwanted data and store the data to disk.

The system box is roughly 1'x2'x2' and weighs 50 pounds. This box contains the transmit and receive hardware. Two RF cables connect the two antennas to this system box. To maximize signal to noise performance, transmit and receive amplifiers are housed in small boxes (3"x2"x5") and mounted directly to the antennas. A single multi-function cable connects the system box to the laptop computer.

The laptop computer is a ruggedized 166 MHz Pentium PC running Windows 95. This PC has user slots that house the A/D and digital signal processor. Data is stored to "Jaz" removable drives. The PC monitor allows both realtime monitor of data and system control.

Although the system tested was designed to operate in a single band (at a time) and polarization, it is conceptually simple to modularize and expand the system to multiple bands and polarizations, simultaneously.

The system configuration that was tested is as follows:

- 400 milliwatt transmit power
- 24 dB gain antennas (rectangular aperture - 8"x10"), 8-18 Ghz response
- VV polarization only
- 8-12 Ghz and 12-18 Ghz (only single band at a time)
- maximum of 40 sweeps per second, 512 steps
- 2' resolution at 1 nmi, 256' range extent
- 6" resolution at 1600', 256' range extent
- 3" resolution at 800', 64' range extent

5.2. The Antenna System

The SCI-1000 uses separate transmit and receive antennas, and for this measurement two 8 x 10 inch horns were used.

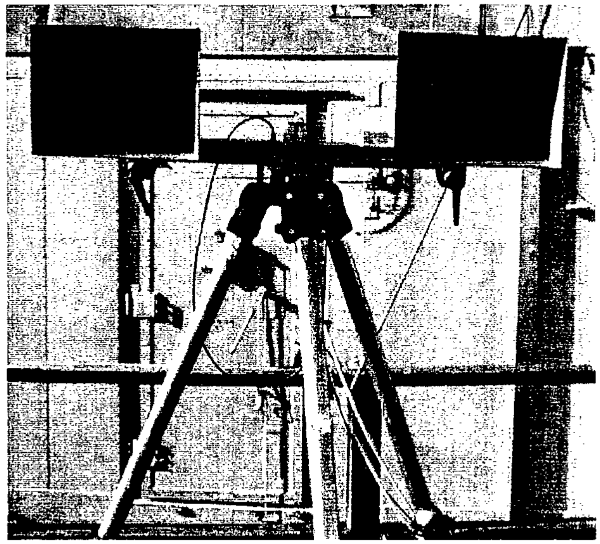

Figure 13. SCI-1000 Antennas

5.3. Radar Control, Realtime Processing, Data Processing

The software is custom developed by SCI. However the data monitor and system control functions use "LabView" software as a platform. This provides a very powerful, simple and robust user interface. Unfortunately, LabView is not a Motif compliant software system. Therefore the display and user-interface functions can not be ported to other remotely located computer systems.

6. DSMS SYSTEM DESCRIPTION

The Deployable Signature Measurement System is a helicopter- or shelter-based calibrated RCS measurement system. It is designed to be a fully functional diagnostic radar to support tasks of RCS signature verification and characterization under static and dynamic conditions. The radar covers S, X and Ku bands in VV, HH, VH and HV polarizations. Universal Time Code, obtained from satellite, target's roll, pitch, heading and boresight video is also automatically recorded during the measurement. The system is portable enough that it can be brought to the test article or to a location that is suitable for test article operations and testing. Two trained RCS measurement engineers or technicians operate the system. It is self-contained in terms of calibration equipment, spares and support equipment. At the test site, the only additional support required is 60 Hz power and a forklift to install the antenna to the shelter. The shelter is transported via a dedicated low-boy, air-ride trailer. The system can be operated from this trailer; or the shelter can be removed by crane and situated in an alternate configuration.

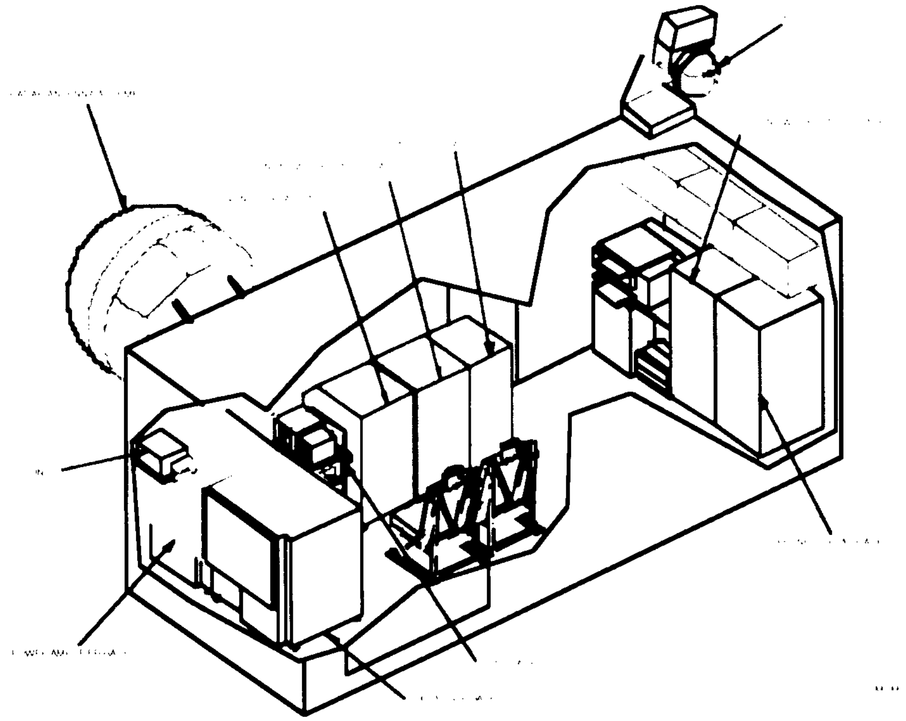

Figure 14. DSMS Shelter Configuration

6.1. The Radar

The radar system is based on a Hughes model MMS 1200. Its components are shock mounted in two racks and weigh about 1500 pounds. A closed-loop, freon-based coolant system keeps the radar at constant temperature to limit system drift. There are three separate Comstron frequency generators and three separate 1.5 kW TWTA's for the three radar bands. This allows the system to collect data on all three bands simultaneously. In addition, a high speed, high power switch allows the system to alternately transmit and receive Vertically and then Horizontally polarized signals. This allows simultaneous collection of both polarizations. Other pertinent specifications include:

Stepped frequency, coherent pulses
PRF's exceeding 50,000
Up to 4 range gates
Up to 4% duty cycle
Automatic Gain Control capability
12-bit A/D's
Variable pulse width, video bandwidth, start frequency, frequency bandwidth, number of frequency steps
Separate IF and RF attenuations for each band

6.2. The Antenna System

The antenna assembly (see Figure 15) has a 3-foot S band dish, with integrally mounted X and Ku horns. Each is designed to provide 6 degree beamwidth (3-dB, 2-way). This very conveniently works out to a footprint of "Target_Range_in Feet/10". This antenna assembly is attached to an upside-down elevation over azimuth gimbal. This allows azimuths from -42 to + 42 degrees and elevations from up 10 to down 90 degrees. A boresighted variable zoom camera is attached to the antenna array and allows the operator to determine very precisely where the antenna system is pointed. The X and Ku band antennas have been factory-aligned in azimuth and elevation to the antenna array. This system is manually controlled from a handgrip near a dedicated display monitor. Antenna azimuth and elevation are recorded with the radar data.

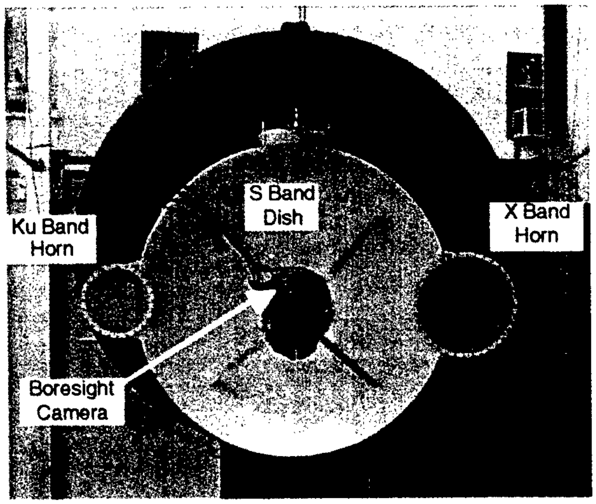

Figure 15. DSMS Antenna Array

6.3. Radar Control and Display System

A SUN computer provides a system control user interface, stores data to 8mm tapes and provides realtime data processing. An oscilloscope displays radar returns and radar range feedback for the operator. A color printer provides hardcopy of realtime processing displays.

The entire RCS measurement system can be controlled from this computer. Typically, the measurement is designed ahead of time and the various radar parameters are stored in "setup" files. There can be many different setup files for different measurement conditions (i.e. calibration setup, target configuration 1, X band only, all bands simultaneously, etc.). Then at the appropriate time, a setup file is loaded which automatically sets all radar parameters (including initial antenna pointing angles and realtime display products). During the measurement, the radar operator manually controls radar range, attenuation and recording start/stop times. A log is automatically updated (in tab delimited format, for spread sheets) with all of the radar parameters for each data collection "run". See Sections 8.1 and 8.2 for run logs.

6.4. Target Motion System

In order to obtain polar plots and statistics over aspect angle, it is important to measure the vessel's heading. In addition, the vessel's roll and pitch motion is useful in many types of data processing. A custom box has been designed and constructed by CDNSWC that contains sensors for roll, pitch, and heading; and telemeters this data to the radar system. The motion sensors obtain 10 samples per second and telemeter at a rate of 9600 baud. The radar system accepts this data stream and merges it with the radar data stream during the measurement. Realtime plots can then make use of this data because it is available at test time.

6.5. Auxiliary Data Collection System

There are various additional data parameters collected along with the radar data. Most of these data streams are collected in real time by the radar computer. This assures that they are time-synchronous with the radar I/Q data. A dedicated, ruggedized PC collects and controls these systems, and then feeds the data to the radar computer over an ethernet link. Data items include helicopter roll, pitch and heading, antenna azimuth and elevation, GPS time and telemetered target's heading, pitch and roll. Time-tagged boresight video is also recorded on SVHS tape decks.

6.6. Calibration systems

Various calibration targets are available for various measurement environments. Most of the calibration targets have been verified by measurement at PMTC's or NRL's indoor range. Included are the following targets:

1 foot by 3 foot flat plate
2 foot by 2 foot flat plate
11.4 inch triangular trihedral
15 inch triangular trihedral
2 foot triangular trihedral
12 inch diameter sphere
16.5 inch diameter sphere
2 foot diameter sphere

Calibration techniques differ for the helicopter and shelter based measurements. For the helicopter, a 2-foot triangular trihedral is placed on the ground. The helicopter then must be flown into the proper position relative to the calibration target's orientation. This provides a multipath-free calibration. A visual alignment background is used to allow the AW to determine the proper helicopter position. The AW provides the pilots with audio commands to position the helicopter. Once in proper position, the measurement system collects short bursts of data. In addition, data is continually stored to tape for post processing quality control. The onboard calibration process allows the realtime processing products to be calibrated.

In the shelter, this calibration technique can not be used because of multipath from in-beamwidth ground clutter. Instead, a variety of shelter based calibration techniques have been devised:

- Trihedral on Pole: A 30-foot pole is used to hold a trihedral so the radar is looking up at it. Angling, and rotating the calibration pole do fine pointing adjustments. The trihedral is high enough that any multipath contribution will be significantly low in amplitude.
- Sphere Calibration: A 40-foot extendible pole is used to retain one end of a low RCS string. The other end of this line is brought to the ground, approximately 60 feet from the base of the pole (either towards the radar, or away from the radar, depending on surrounding clutter). The sphere is then attached to this line and brought 10 to 20 feet away from the pole. At this distance, the radar can separate the sphere radar return from the pole's radar return in order to calibrate on only the sphere return.
- Trihedral/Flat Plate on Ground: If the shelter is located such that there is a significant LDA, then a trihedral or flat plate can be placed on the ground and pointed to maximize the return to the radar. Figure 3 illustrates calibration target used at CBD.

6.7. Data Processing Systems

There are two different data processing systems required. One is a realtime processing system, which is used to insure data quality during the measurement. The second is an offline data processing system used to produce the report ready data products and provide high quality data products for analysis.

6.7.1. Realtime Data Processing

There are many different displays available as part of this system, including: polar plots, Down Range Profile Histories, Down Range Profile line plots, I/Q circularity and I/Q histograms. This system is written with the X-system software which allows many of these displays to be running simultaneously. Once a realtime display window is invoked, the processing type can be selected along with the band, polarization, range gate and scales. The size of the displays can be adjusted and can even be "iconified" to make other display windows more easily seen. The realtime products can be calibrated for RCS dBsm, or can be uncalibrated for radar system trouble shooting.

Radar setup files can automatically specify realtime processing setup files. This allows pre-setup of various display types with customized display parameters.

A color printer is connected to the realtime display monitor allowing hard copy of the realtime products with the push of a button.

6.7.2. Offline Data Processing

Separate sets of computers in the shelter provide high-quality, report-ready data products. These products are in NAVY standard format and are used by other RCS measurement systems (NOSC, RIMS and SCRIF). In order to achieve this standardization, the raw recorded data is first translated into a NAVY standard format (SDF - Standard Data Format). Then each of these measurement systems use the exact same data processing software. This provides high confidence in the data products because they have been heavily tested. There are various data products available, and detailed descriptions are in Section 9. Some examples include:

Plots that sum all target's scatterers together to produce Overall RCS Levels:
- Polar Plots graph RCS levels Vs. target aspect
- Rectilinear plots graph RCS levels Vs. time
- Histograms analyze RCS Data and show RCS Level Distributions
- Statistical tables summarize RCS level

Plots that discriminate the target's scatterers in range:
- Down Range Profile Histories
- ISAR Images

Plots of supporting data:
- Target Heading, Pitch and Roll as telemetered from boat vs. time
- Antenna Pointing Angle (azimuth and elevation) vs. time

7. THE TEST SITE - CHESAPEAKE BEACH DETACHMENT/NRL

This site is located on a 105-foot high cliff, overlooking the Chesapeake Bay, about 40 miles north of NAWC, Patuxent River, MD. Although the area is somewhat popular with local crabbers, there was never interference with testing. The town of Chesapeake Beach, MD has commercial docks and ramps for launching support craft. A long pier off of a sea wall on the grounds of CBD/NRL provided an ideal location for a radar calibration flat plate. In addition, this pier allowed access to the support craft to transfer equipment and personnel to and from the MK Vs. DSMS was positioned on a paved road that ran parallel to the cliff, behind Bldg. 2. Connecting into the electrical boxes in this building provided 60 Hz power.

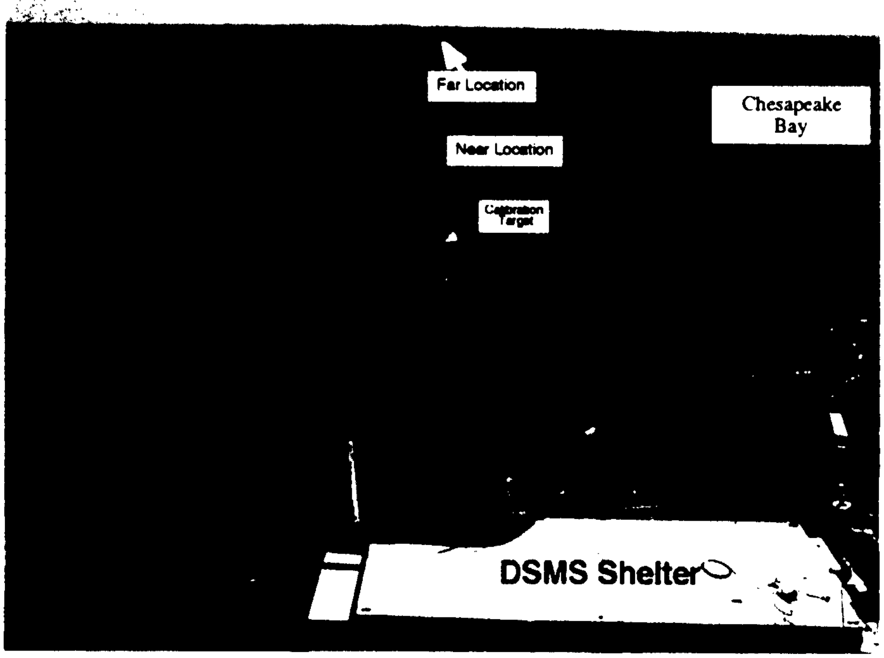

Figure 16. CBD Measurement Site

8. SCI-1000 SYSTEM DRAWBACKS AND RECOMMENDED MODIFICATIONS

There are several modifications to the SCI-1000 that would make the system more suitable for outdoor dynamic measurements. It should be noted that none of the recommended modifications would adversely affect indoor/outdoor static measurements.

The modifications are listed in descending priority order. In most cases the cost or complexity of the modification was not considered in determining priority; instead the added value of the modification to the function of RCS measurements was the only determining factor.

8.1. Generalized, Ratiometric Calculation of RCS

Because the SCI-1000 was designed primarily for static measurements, the basic calculation of RCS from the measured data assumes that the calibration target is at the same location as the test article. For outdoor, dynamic measurements this is almost never the case. Therefore, a more generalized calculation of RCS can be used for both indoor static and outdoor dynamic measurements that takes this range difference into account:

RCS_T = 40log(range_T/range_C) + attn_T - attn_C + SS_T - SS_C + RCS_C
where:

RCS_T = RCS of the test article measured
range_T = range to the test article
range_C = range to the calibration target
attn_T = system attenuation (dB) used to measure the test article
attn_C = system attenuation (dB) used to measure the calibration target
SS_T = received signal strength (dB) while measuring the test article
SS_C = received signal strength (dB) while measuring the calibration target
RCS_C = the known RCS (dBsm) of the calibration target

Note that this equation also allows different attenuation settings for the calibration versus the test article measurement.

8.2. Generalized Calibration

As stated above, many times it is desirable (necessary) to perform a calibration at a closer range than the test article. This may also require using different attenuation settings for calibration versus the test article measurement.

The SCI-1000 has the desirable feature of short range measurements. This is ideal for calibration, because it is much easier to setup a calibration at 10-20 feet from the radar, than at 100 feet away. At short ranges of 10 feet from the radar it would be feasible to have an operator hold a calibration target. In order for this concept to work, it would be necessary to have a "peak detecting" measurement to allow for the variability in target alignment due to an inherently unstable human "tripod".

8.3. Enhanced Realtime Displays

The SCI-1000 has some realtime display capability. However, it is not possible to display data in realtime and record that data at the same time. In outdoor dynamic measurements the target is moving relative to the radar so it is necessary to view some of the data in realtime to verify that the target is being measured properly.

8.4. Range Tracking

Once a realtime capability is established, range tracking of the target can be implemented. Without range tracking, the system is forced to collect and store much more (unnecessary) data than is needed, which ultimately reduces data sampling rate. Although it may be possible to develop automatic range tracking algorithms it will also be necessary to have manual range tracking capability because outdoor dynamic conditions are very difficult to predict.

8.5. Multiple Bands Simultaneously

There are two reasons that measuring with multiple bands simultaneously is important. First, from a scientific standpoint it is often advantageous to compare data from two different frequency ranges. In outdoor dynamic measurements the target-to-radar motion can not be controlled, so trying to duplicate conditions for each radar band separately is not feasible. Secondly, from a financial viewpoint, multiplying the test time by the number of bands required increases costs significantly. Increasing test time also increases the chance of running into bad weather which delays test time, thus further increasing costs.

8.6. Multiple Polarizations Simultaneously

For the same reasons stated above, simultaneous multiple polarizations are needed. It is difficult to make a case giving higher priority to multiple bands vs. multiple polarizations. Therefore, whichever modification is easier to implement in hardware/software should be given higher priority.

8.7. Integration of Target Motion and Aspect Angle Data

In order to produce valid polar plots of the target's RCS signature it is necessary to know the target's heading relative to the radar (target aspect angle). Both antenna heading and target heading are required to compute aspect angle. This requires sensors on the antenna and on the target. In addition, the target heading must be telemetered to the radar system and incorporated into the data stream for realtime displays. This also allows the radar operator to verify this data path from the radar.

Because ships and boats on the water also roll and pitch, it is desirable (often required) to also include these parameters into the data stream. This data should be telemetered along with the target heading.

An alternative that is sometimes used is to record the target motion data at the target, and not telemeter it to the radar. This is a less attractive solution because an additional operator is required onboard the target to monitor the integrity of that system; realtime displays do not have valid aspect information, and more time is needed during data processing to merge this data with the radar data.

8.8. Integration of GPS Time and Boresight Video

In most outdoor dynamic measurements, the target is moving in range and azimuth relative to the radar. This requires tracking the target with the antenna. In order to understand the collected data it is necessary to know where the antenna was pointed during the measurement. This is accomplished by boresighting a video camera with the antenna and recording that video. In order to time correlate the video data with the recorded RCS data, GPS time needs to be included into the radar data stream and into the video data. Recorded GPS time also allows correlation of the radar (and video) data with external events not captured by video.

8.9. More Generalized User Interface

The current user interface does not support outdoor dynamic measurements. Figure 17 on page 24 is an example of a user interface that would allow these and indoor static measurements. Note also that this user interface incorporates all of the previously recommended modifications.

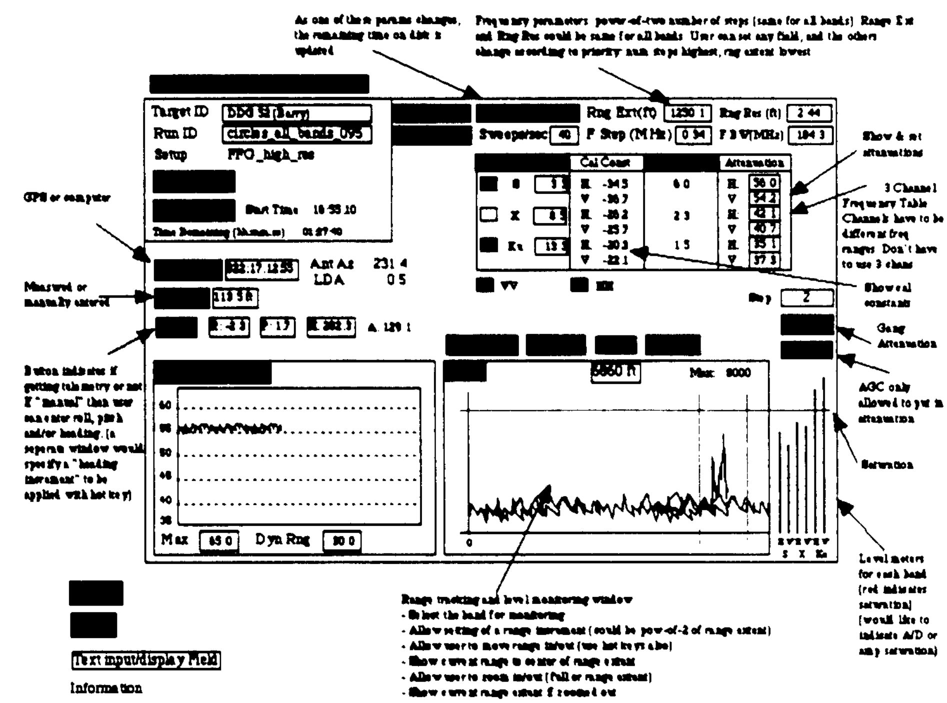

Figure 17. Proposed SCI-1000 User Interface

8.10. Higher Data Rates

The current system provides relatively slow data rates. These data rates are suitable for static measurements. However, for some outdoor dynamic measurements (primarily helicopter-based) sweep rates of 300/second are needed.

8.11. Graceful Degradation

Graceful degradation allows the user to have maximum flexibility over which functions of the system are lost when a particular subsystem fails. The SCI-1000 could be modified to better achieve this goal:

- Modularize the RF sections - make a module that can be used in S, X or Ku bands with little or no modification. The user incorporates as many modules as needed for the number of bands required. If one of the modules fails, the user selects which band will be lost. This also allows easy troubleshooting as the modules are interchangeable.
- Modularize the data collection functions - realtime vs. data storage. If interchangeable modules are used, then the user has the option of giving up realtime display in order to be able to store data (or vice versa). This may not be a desirable mode of operation, but in many situations may be better than losing both data collection and realtime display. In addition, as with modularized RF sections, troubleshooting will be quicker and easier.

9. CONCLUSION

The SCI-1000 is capable of recording calibrated RCS data at data rates sufficient to measure dynamic targets in frequency bands of interest. The system has sufficient sensitivity as tested to measure moderate RCS targets at distances to a nautical mile. With some modification, this lightweight system may be used to measure total RCS of targets closer than a mile away as accurately as some of the Navy's best instrumentation systems. This system can also be used in the spotlight/diagnostic imaging mode (for which it was initially designed) better than the DSMS and RIMS systems.

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