2

PNL-8645
UC-700

Ultrawideband Radar Clutter Measurements of Forested Terrain, 1991-1992

D. M. Sheen
R. H. Severtsen
J. M. Prince
K. C. Davis
H. D. Collins

June 1993

Prepared for
Defense Advanced Research Projects Agency
with the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

PNL-8645

Battelle

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401. FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

PNL-8645
UC-700

ULTRAWIDEBAND RADAR CLUTTER MEASUREMENTS OF FORESTED TERRAIN, 1991-1992

D. M. Sheen
R. H. Severtsen
J. M. Prince
K. C. Davis
H. D. Collins

June 1993

Prepared for
Defense Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, Virginia 22709
under U.S. Department of Energy
Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

Contents

Figures

Tables

Acknowledgements

This project was sponsored by the Balanced Technology Initiative/Defense Advanced Research Projects Agency (BTI/DARPA) under the direction of Dr. Dominic Giglio of DARPA. Technical guidance was given by Dr. James Ralson of the Institute for Defense Analyses (IDA), Mike Tuley of Georgia Tech Research Institute (GTRI), and Dr. George Ruck of Battelle Columbus.

1.0 Summary

The ultrawideband (UWB) radar clutter measurements project was conducted to provide radar clutter data for new ultrawideband radar systems which are currently under development. A particular goal of this project is to determine if conventional narrow band clutter data may be extrapolated to the UWB case. This report documents measurements conducted in 1991 and additional measurements conducted in 1992.

An experimental impulse radar system was designed and implemented specifically to perform these clutter measurements. The impulse system makes use of very short high-power pulses. A more conventional method of generating ultrawide bandwidths is to use a step-chirp system. This technique uses relatively long pulse widths and subsequent processing for pulse compression.

For both systems, a 19-meter linear scanner was used to provide a synthetic aperture of sufficient length to provide reasonable angular resolution. Since the aperture is synthesized in processing, an additional benefit is that a frequency-dependent aperture may be formed that has a constant beamwidth over the ultrawide bandwidth of the pulse or step-chirp system. The high range and angular resolution was used to maximize the number of clutter cells available at each measurement site.

The original project, conducted in 1991, consisted of clutter measurements of forested terrain in the Olympic National Forest near Sequim, WA. The impulse radar system used a 30 kW peak impulse source with a 2 Gigasample/second digitizer to form a UHF (300-1000 MHz) ultrawideband impulse radar system. Additional measurements were conducted in parallel using a Systems Planning Corporation (SPC) step-chirp radar system. This system utilized pulse widths of 1330 nanoseconds over a bandwidth of 300-1000 MHz to obtain similar resolution to the impulse system. Due to the slow digitizer data throughput in the impulse radar system and the higher average power available with the conventional step-chirp system, data collection rates were significantly higher using the step-chirp system. The step chirp system gathered data over a 120° swath from 0.5 km to 2.5 km for 6.2 km^2, for approximately 780,000 clutter cells (1.5° by 0.214 m clutter cell size). The impulse system gathered data over a 90° swath from 0.75 km to 1.2 km for 0.7 km^2, for approximately 120,000 clutter cells (1.5° by 0.214 m clutter cell size).

Additional forest clutter measurements were undertaken in 1992 to increase the amount of ultrawideband clutter data available, and especially, to increase the amount of data from the impulse radar system. The following improvements were made to increase the data collection rate of the impulse radar system. Peak power was increased from 30 kW to over 100 kW by the implementation of an improved solid-state pulser. The data-throughput burden on the digitizer was relieved by performing internal averaging in the instrument rather than outputting all waveforms to the computer. These improvements increased the clutter data collection rate by at least 10 times. The additional power and

data collection rate available are expected to increase the available range to approximately 3-4 kilometers.

The additional forested site was selected near to the site of the 1991 measurements. The site of the 1991 measurements is referred to as the "Original Site," and the site of the new measurements is referred to as the "Maynard Site." Total measurable terrain at this location covers an angular swath of up to 180° and a range of 300 m out to 2-4 km for 800,000 up to 2,000,000 clutter cells. Scanned measurements were conducted in September and October 1992 at the Maynard Site. Over 60 scans were taken covering an angular swath of 180° and ranges from 300 m to 3.3 km. The area covered is approximately 17 km^2. Usable clutter data was obtained for approximately 1 million clutter cells.

Statistical results for the 1991 and 1992 clutter measurements are summarized in Tables 1.1 to 1.3, including the approximate slope parameter for these results under the assumption that they fit the Weibull distribution. The 1991 impulse and step-chirp measurements were processed using a rectangular constant beamwidth window and a 300-1000 MHz frequency band. The 1992 impulse measurements were processed using a rectangular constant beamwidth window and a 300-800 MHz frequency band. The frequency band was reduced for the 1992 measurements due to significant RFI in the 800-900 MHz (cellular phone) band. These results are for coniferous forest with much of the illuminated area coming from facing slopes of the surrounding mountains. Thus, the clutter coefficient may be biased upward relative to other clutter measurements.

Table 1.1. Summary of 1991 Impulse Clutter Measurements

Polarization	VV	HH
Frequency Band	300-1000 MHz	300-1000 MHz
Aperture Window	Rectangular	Rectangular
Angle Coverage	171°-261°	171°-261°
Beamwidth (constant)	1.5°	1.5°
Range Coverage	750 m - 1200 m	750 m - 1200 m
Range Resolution	0.214 m	0.214 m
Number of Cells	117,800	120,900
Mean σ^o	-5.4 dB	-9.0 dB
Median σ^o	-12.4 dB	-16.8 dB
Std Dev/Mean σ^o	---	---
Max σ^o	14.1 dB	12.4 dB
Weibull Spread σ^o	2.17	2.44

Table 1.2. Summary of 1991 Step-Chirp Clutter Measurements

Polarization	VV	HH
Frequency Band	300-1000 MHz	300-1000 MHz
Aperture Window	Rectangular	Rectangular
Angle Coverage	171°-291°	171°-291°
Beamwidth (constant)	1.5°	1.5°
Range Coverage	500 m - 2500 m	500 m - 2500 m
Range Resolution	0.214 m	0.214 m
Number of Cells	780,000	780,000
Mean σ^0	-7.4 dB	-11.5 dB
Median σ^0	-14 dB	-18.8 dB
Std Dev/Mean σ^0	4.2 dB	4.7 dB
Max σ^0	16 dB	10 dB
Weibull Spread σ^0	2.02	2.14

Table 1.3. Summary of 1992 Impulse Clutter Measurements

Polarization	VV	HH
Frequency Band	300-800 MHz	300-800 MHz
Aperture Window	Rectangular	Rectangular
Angle Coverage	115° to 0° to 295°	115° to 0° to 295°
Beamwidth (constant)	1.35°	1.35°
Range Coverage	300 m - 3300 m	300 m - 3300 m
Range Resolution	0.3 m	0.3 m
Number of Cells	974,000	974,000
Mean σ^0	-6.4 dB	-9.3 dB
Median σ^0	-18.4 dB	-19.1 dB
Std Dev/Mean σ^0	6.1 dB	6.5 dB
Max σ^0	22.8 dB	23 dB
Weibull Spread σ^0	2.97	2.83

2.0 Introduction

Impulse and step-chirp radar systems were set up using a 19-meter linear scanner with the goal of providing as much forested terrain land clutter as possible. A conceptual drawing of the scanned radar systems is shown in Figure 2.1. The aperture of the scanner is used to form a small synthetic aperture over which data is gathered and stored in the computer for synthesis of a narrow scanned beam.

Ultrawideband radars are expected to be useful due to their simultaneous characteristics of high resolution and relatively low frequency. For additional information see OSD/DARPA Ultra-Wideband Radar Review Panel (1990). High resolution is obtained from the ultra-wide bandwidth, and the low frequency is useful for foliage and ground penetration. An additional application of this technology is for short range radar systems.

Ultrawideband radar systems may be realized using two different techniques. The first technique utilizes conventional radar methods in which a synthesized frequency is time-gated to provide a relatively long pulse. Data recorded over a wide band of frequencies can then be pulse compressed using the Fourier Transform to provide the high resolution available in wideband systems. This technique is denoted "step-chirp." The second technique utilizes an instantaneously wideband signal, typically a very short pulse or impulse. This pulse may be generated using solid-state switches, spark gap generators, or optically activated switches, and other techniques. The transient signal is then received and digitized directly using a high sample rate digitizer. Advantages of this technique include simplicity of the system, high peak power rates available, and instantaneous (not pulse compressed) high range resolution. Disadvantages include: low average power, wide instantaneous noise bandwidth, and lack of control over the source characteristics.

Both of these measurement systems made use of a 19-meter linear scanner, which was used to allow synthesizing a narrow beamwidth. Nominal beamwidth for the antennas used allows data to be gathered over a nominal 30° swath. Subsequent beam synthesis forms a beam on the order of 1° beamwidth (3 dB). This beam is synthetically swept through a ±15° angular swath as shown in Figure 2.1. Several scanner positions were used to allow measurements over a 90-180° total swath. An additional benefit of the scanned system is that a beam can be formed with an angular width that is independent of frequency. This is important for the clutter coefficient (σ^o) to be rigorously defined. If the full scanned aperture were used to form the synthesized beam, then the beamwidth would decrease with increasing frequency. Using Fourier transforms of the transient data, the scanned data can be windowed with an aperture width proportional to the wavelength to realize a constant beamwidth as a function of frequency.

High range resolution is inherent in the impulse system and may be obtained by inverse Fourier Transformation in the step-chirp system. Thus a range-angle sectoral image of the data is obtained for each scan. Resolution of the data images is 1° in angle and approximately 0.2 meters in range. Note that with the small 19-meter aperture, the range resolution will be much higher than the cross-range resolution (equal to range times beamwidth in radians).

The frequency range of interest is 300-1000 MHz, which is the UHF band. This band was chosen for a number of technological reasons. Many potential applications, such as foliage penetration and ground penetrating radar systems, are expected to use this frequency range. The lower frequency was chosen to keep antenna size reasonable and to eliminate the FM broadcast band. Radio frequency interference (RFI) is the dominant factor limiting the range of the ultrawideband radar systems. Note that this is not the case for conventional narrowband microwave radar systems which are typically thermal-noise limited. The upper frequency limit of 1000 MHz was chosen since the impulse system requires a high-speed transient digitizer, and 2 Gigasamples/ second is the highest speed digitizer available (at the time of the measurements). Thus, to satisfy the Nyquist sampling criterion a limit of 1 GHz was established.

Forested terrain was chosen as the most important type of terrain to measure since it is expected to have high clutter levels and is therefore most important for the design of UWB short range radar systems that must operate in this environment. Forested terrain is also representative of the terrain type for foliage penetrating radar systems.

Statistical results from these measurements are important because it is unknown what the effect of high resolution (small clutter cell size) will have on the clutter statistics. Specifically, an increase in the occurrence of very high discrete clutter values due to the high range resolution, may cause an increase in the false alarm rate of UWB radar systems.

Ultrawideband radar forces a new interpretation of some conventional radar parameters. Ultrawideband systems typically have a high frequency to low frequency ratio is excess of 3 to 1. Therefore, it may not be sufficient to simply use the center frequency for the computation of beamwidth, antenna gain, radar cross-section (RCS), clutter coefficient (σ^0), etc. In this report, consistent formulas for high resolution RCS, and clutter coefficient are developed.

In particular, the synthesized beamwidth poses a problem for the definition of the clutter coefficient (σ^0). If the full aperture of the linear scanner is used to synthetically form the narrow beam, then the beamwidth will be frequency dependent. That is, the beamwidth will decrease in proportion to the wavelength. The clutter coefficient is defined to be the RCS divided by the area of a resolution cell. This leads to an inconvenient definition as the resolution cell size is frequency dependent. Therefore, a constant beamwidth is desirable, since the desired output is a set of clutter coefficient values that depend only on the spatial coordinates, and not on the specific frequency within the band. This may be achieved in the synthetic beam steering of the data by dependent window to the linear aperture. The width of the window is set to be the full width of the aperture at the lowest frequency of interest and is then made to reduce in width proportional to the wavelength.

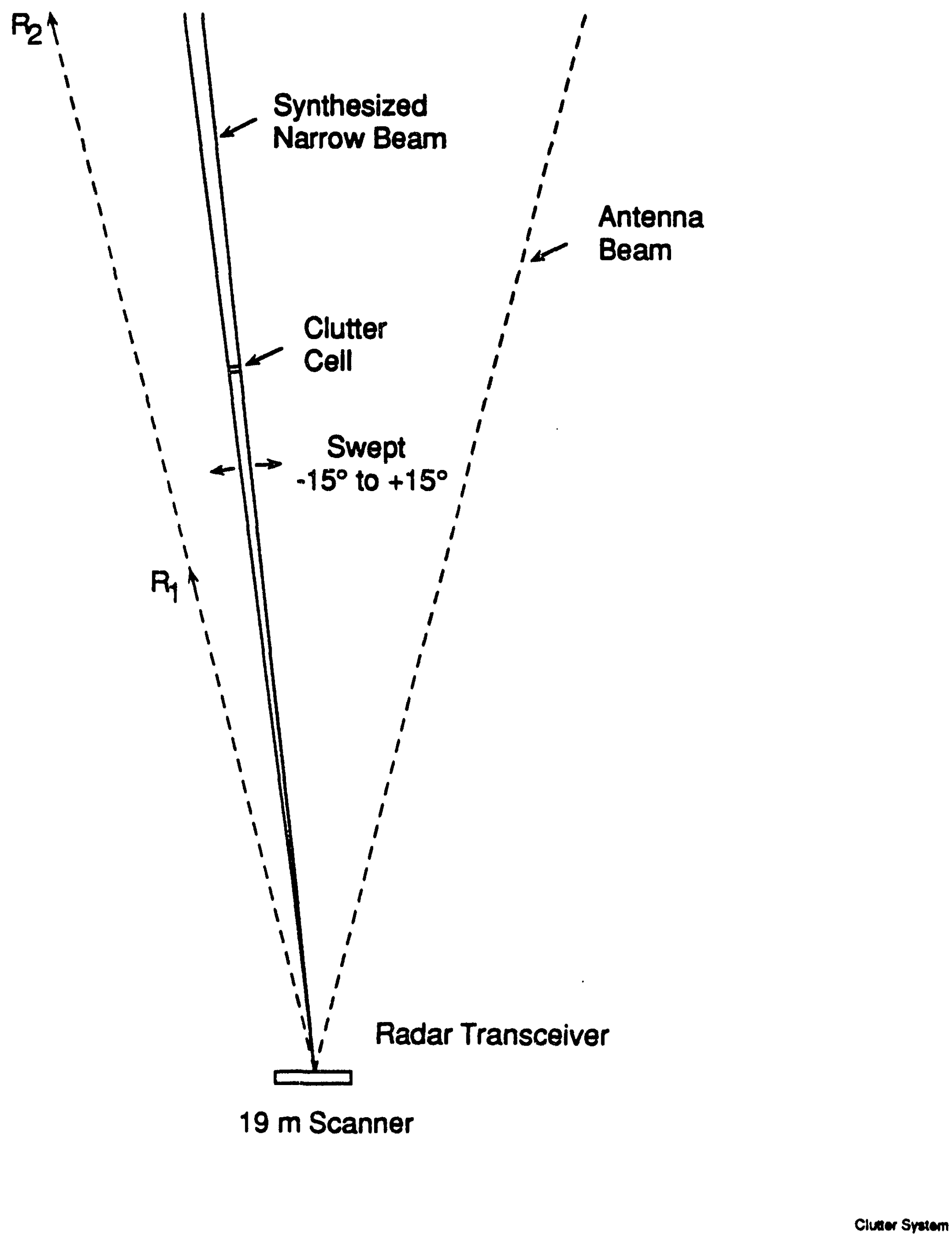


Figure 2.1. Drawing of Scanned Clutter Data Collection System

3.0 Impulse Radar Design

Due to the novelty of impulse radar systems, it was necessary to a develop a suitable experimental radar system for the ultrawideband radar clutter measurements. Commercially available components were used wherever possible in the impulse radar system.

The step-chirp system used was a Systems Planning Corporation Mark IV. This system was set up and operated by SPC during the 1991 measurements. Since this system has been commercially available for some time, it will not be discussed in great detail in this report. A brief description of the Mark IV as configured for these measurements is given in Appendix A.

3.1 System Description

A block diagram of the impulse radar system is shown in Figure 3.1. Components of this system include: the digitizer (Tektronix DSA 602A), high power pulser, receiver, antennas, and scanner. The nominal specifications are listed in Table 3.1.

Table 3.1. Nominal Impulse Radar System Parameters

Transmitted Power	100 kW (peak)
Pulse Width	< 1 nsec
Antenna Bandwidth	30° (nominal)
Linear Aperture	19 meters
Synthesized Beamwidth	1-1.5°
Antenna Element Gain	8-10 dBi
Digitizer Sample Rate	2 GS/s
Receiver Bandwidth	300-1000 MHz (nominal)
Receiver Noise Figure	2 dB (nominal)
Range Resolution	0.214 m (700 MHz BW)

Operation of the high power pulser is controlled by the PRF Generator which generates a short logic pulse approximately 300 times per second to trigger the main pulser (Current Research model HVTP). The output of the main pulser is passed through a diode pulse sharpening network to the transmitting antenna. A delay generator is used to trigger the digitizer after a prescribed delay has occurred. The received signal is boosted by an amplifier module near the antenna and then routed to the digitizer. The data received by the digitizer is then transferred to the computer or averaged internally and then transferred to the computer. The data is stored temporarily on a large disk drive and then permanently archived to 8-mm tape.

Critical transmitter and receiver modules are located on the carriage of the 19-meter linear scanner to limit cabling losses. The scanner carriage is controlled by the computer, with data recorded uniformly across the full aperture.

3.2 Digitizer

The transient digitizer forms the heart of the impulse radar receiver. A Tektronix DSA 602A digitizer with an analog bandwidth of DC to 1000 MHz was used in the impulse radar system. This digitizer has 8 bits of resolution and a 2 Gigasamples per second (2 GS/s) sample rate. This allows sampling up to the Nyquist frequency of 1000 MHz. Data can be transferred to the computer using the IEEE-488 interface. This interface has a fairly slow data transfer rate of approximately 10,000 samples per second as configured in the impulse radar system. This allows approximately 20 512 sample waveforms per second to be transferred to the computer.

An additional feature of this digitizer is that it can record the time delay (or skew) from the trigger to the first data sample. This time shift will in general be random from 0 to 500 picoseconds (at 2 GS/s). Often it will be required that many waveforms be recorded and subsequently summed in order to increase the signal-to-noise ratio. The time-skew value can be used to re-align (de-skew) the waveforms prior to summing in the computer. This feature can thus be used to maintain coherence over many waveforms and improve the signal-to-noise ratio. Key specifications of the DSA 602A digitizer are summarized in Table 3.2.

3.3 Pulser

A Current Research model FTP and Current Research model IDM diode sharpening network were selected for the transmitter power impulse generator for the 1991 measurements. The output of the pulser is passed through the diode sharpening network which reduces the pulse width to approximately 400 psec. A Current Research model HVTP and Current Research model MIDM diode sharpening network were selected for the transmitter power impulse generator for the 1992 measurements. The output pulse width is approximately 400 psec.

Table 3.2. Specifications of the Tektronix DSA 602A Digitizer

Tektronix DSA 602A	
Digitizer Sample Rate	2 GS/s
Bandwidth	DC-1000 MHz
A/D Resolution	8 bits
Sensitivity	10 mV/div to 1 V/div
Record Length	512 to 32,768
Data Transfer	IEEE-488
Synchronization	Records delay to first sample (time skew)

The first version of this pulser was capable of generating a pulse with peak amplitude in excess of 1200 volts (50 ohm load) for a peak power of approximately 30 kW. The second version of this system is capable of generating a peak amplitude of approximately 2500 volts (50 ohm load) for a peak power of approximately 125 kW. Typical output pulses and spectra for these two pulser systems are shown in Figures 3.2 and 3.3.

3.4 Receiver

The receiver module was designed to limit the bandwidth and amplify the received signals. A block diagram of the receiver is shown in Figure 3.4. The limiter was used to protect the amplifiers from the large transmitter leakage signal that occurs during transmitter pulsing. The 300 MHz low pass filter was used to eliminate unwanted RFI, predominantly from FM broadcast stations. The 850 MHz high pass filter was used to prevent significant aliasing in the DSA 602 digitizer. The amplifiers simply increase the signal strength prior to transmission over approximately 30 meters of cable to the digitizer. The receiver has a measured gain of approximately 54 dB over the 300-850 MHz band, as shown in Figure 3.5.

3.5 Antennas

The antennas for the impulse radar system must have moderate gain, beamwidth of at least 30°, and acceptable transient response. Commercially available wideband antennas in the UHF frequency band are often variations of log-periodic antennas. These antennas are not well suited to our application since the phase center shifts with frequency and therefore widens the transmitted pulse.

Transverse electromagnetic (TEM) horn antennas were chosen for the impulse system due to their wideband operation and excellent pulse response. A commercial antenna could not be found so a pair of antennas were fabricated at PNL. Separate transmit and receive antennas are necessary to prevent the transmitter pulses from damaging the receiver. A metallic screen was also positioned between the transmit and receive antennas to further increase the isolation between the transmitter and receiver.

A drawing of the antenna pair is shown in Figure 3.6, and a photograph is shown in Figure 3.7. The bandwidth of the TEM horn antennas is demonstrated in Figure 3.8 in which the antennas were placed approximately 10 m apart and the transmission coefficient was measured. The isolation between the transmit and receive sides of the TEM antenna pair is shown in Figure 3.9.

Antenna patterns were computed in the following way. The TEM antenna pair was placed on a tripod with another TEM horn used as a receive antenna approximately 10 m away. The antenna pair was then rotated $\pm 15°$ to obtain the pattern. A calibrated scale for the gain measurements was obtained by comparison with a log-periodic antenna of known gain. The vertical polarization antenna pattern measured in this way is not symmetric due to the presence of the metallic screen in between the two antennas. When the antenna pair is used in the radar system the effective antenna gain will be symmetric since the transmit and receive antennas have the screen on opposite sides. The effective symmetrical antenna gain is therefore the geometric mean of the positive and negative angle patterns. In addition, the patterns at 300, 650, and 1000 MHz were averaged as will be the case for the wideband impulse system. The effective vertical and horizontal polarization lateral antenna patterns are presented in Figures 3.10 and 3.11.

3.6 Impulse Radar System Point Measurements

To demonstrate acceptable pulse response and proper operation of the radar system, the impulse radar system was configured outside our facility and the following point measurement was made. The reflected transient response and spectrum from a 6' by 12' flat plate calibration target at a range of approximately 100 meters was recorded and is shown in Figure 3.12.

3.7 Scanned Radar System

The transportable scanner is used to position the antennas along the 19-meter horizontal linear aperture. The scanner is a full two dimensional scanner capable of scanning an aperture in excess of 19 meter by 5 meters. The y-axis capability was used simply to lower and raise the antenna pair. During data collection the antennas are raised to the maximum height allowed by the scanner. A photograph of the scanner and radar system is shown in Figure 3.13. Accuracy of this scanner is significantly better than 1 mm, which is extremely high accuracy for the frequency range of the impulse radar system. This scanner design has been effectively used for two-dimensional close range imaging at 10 GHz and 35 GHz.

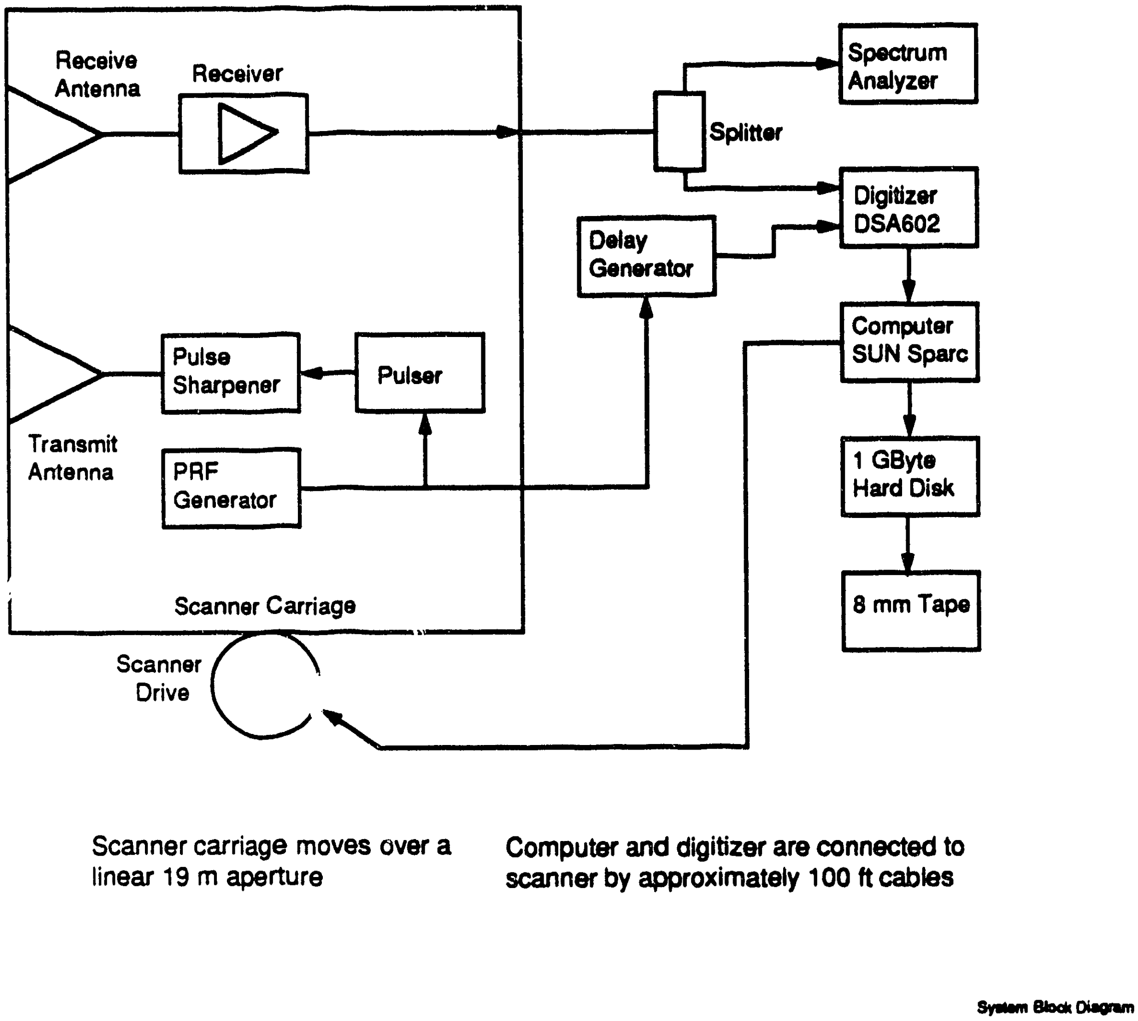


Figure 3.1. Impulse Radar System Block Diagram

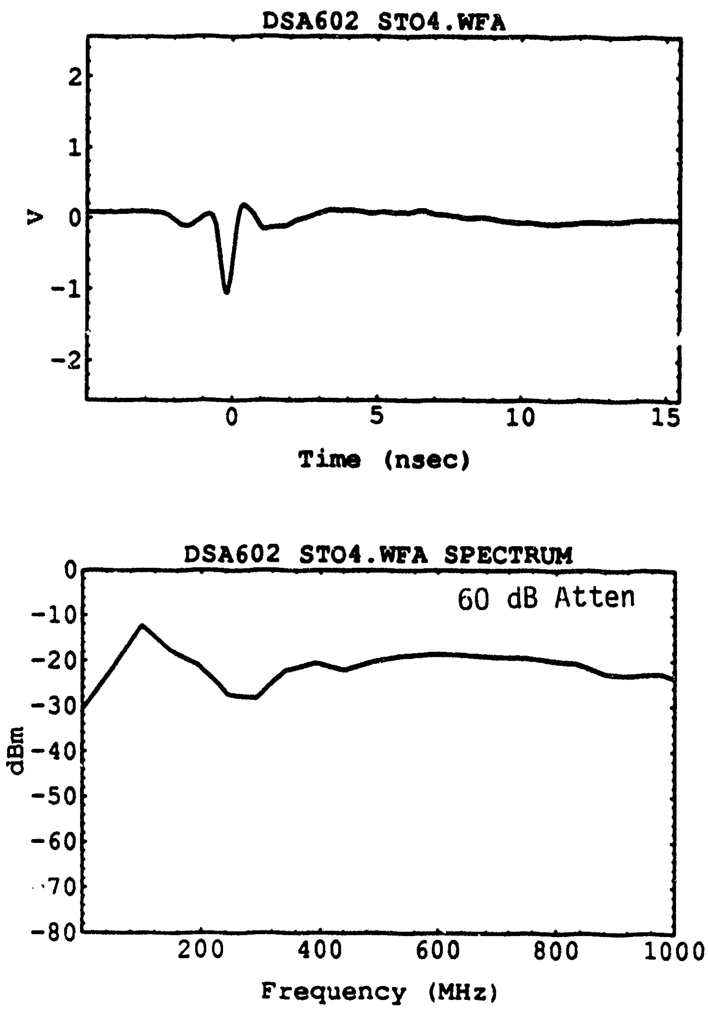


Figure 3.2. 30 kW Pulser/Diode Module Pulse Response and Spectrum

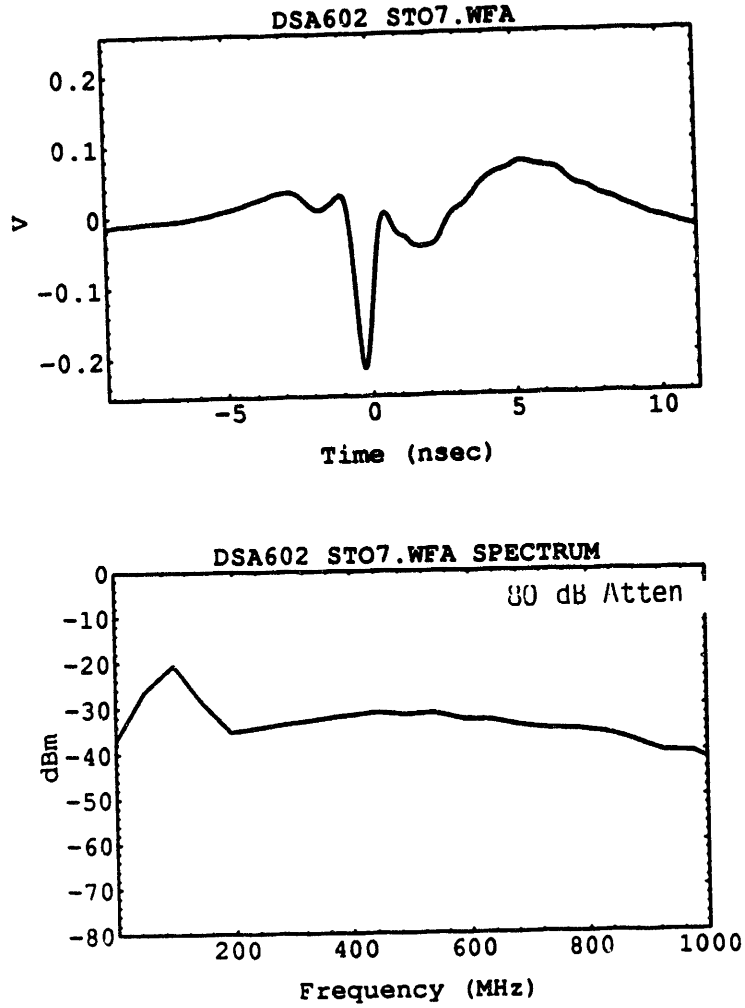


Figure 3.3. 100 kW Pulser/Diode Module Pulse Response and Spectrum

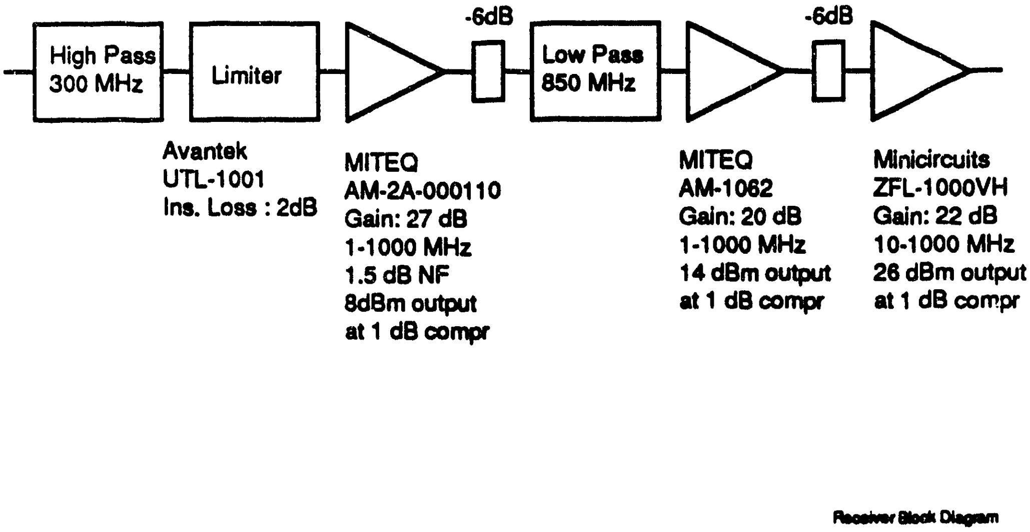


Figure 3.4. Block Diagram of the Receiver

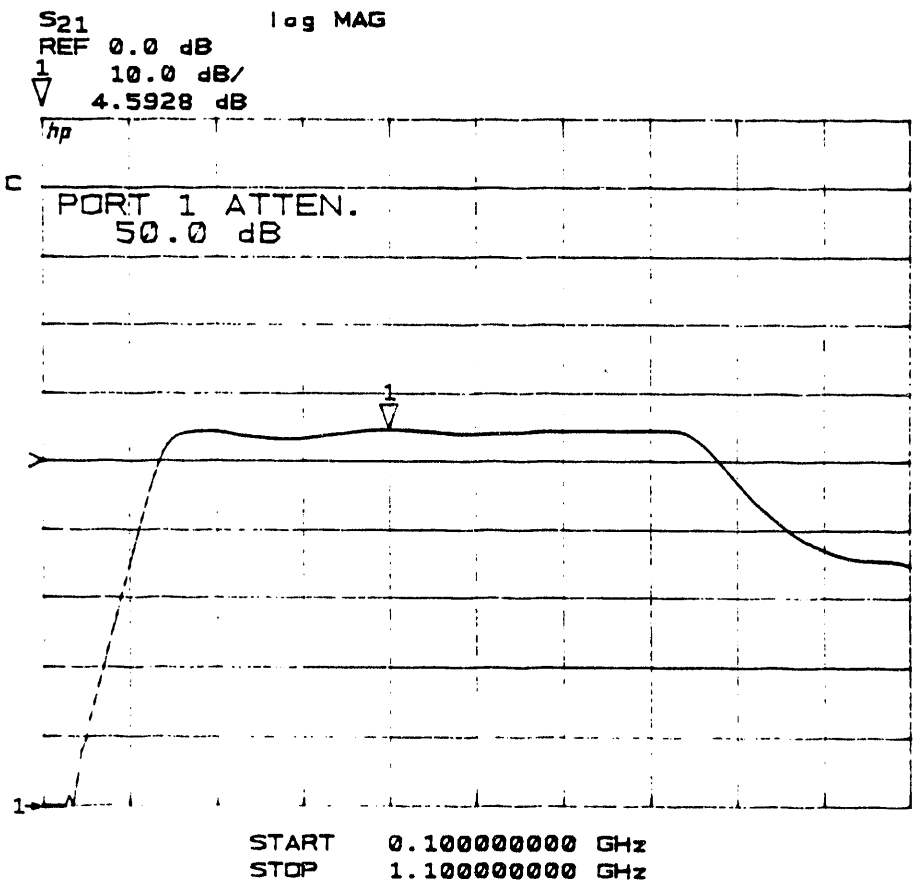


Figure 3.5. Measured Gain of the Receiver (100-1000 MHz)

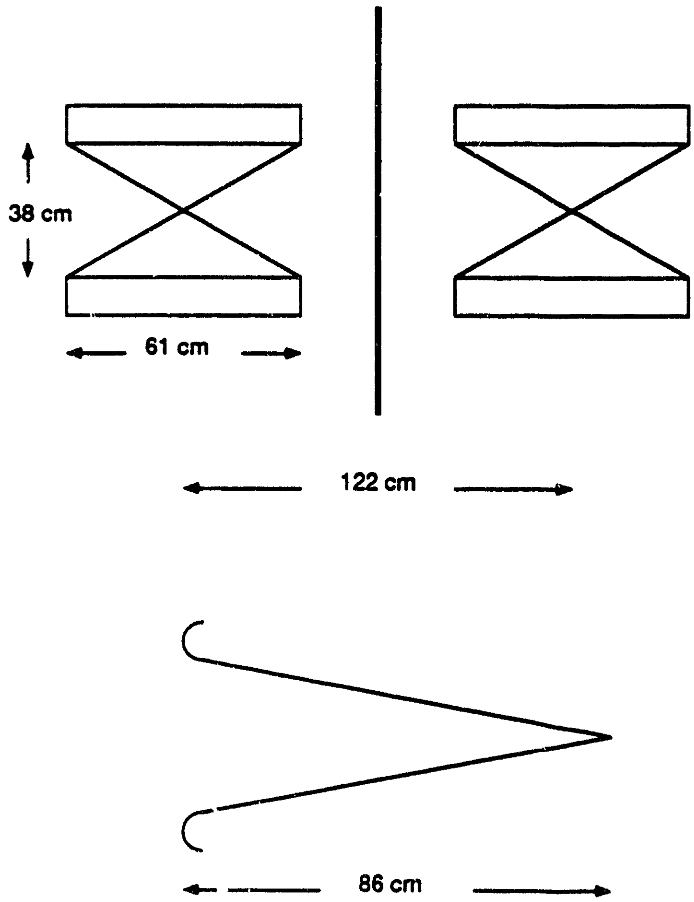


Figure 3.6. Drawing of the Antenna Pair

Antenna Pair

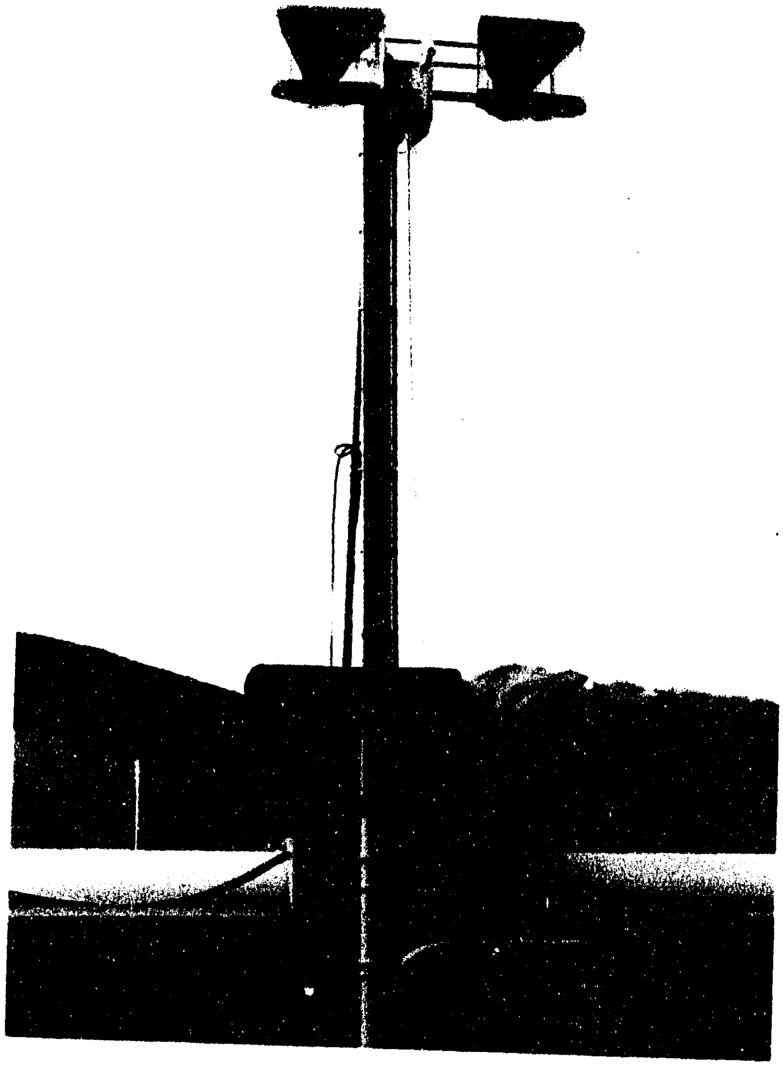


Figure 3.7. Photograph of the Antenna Pair

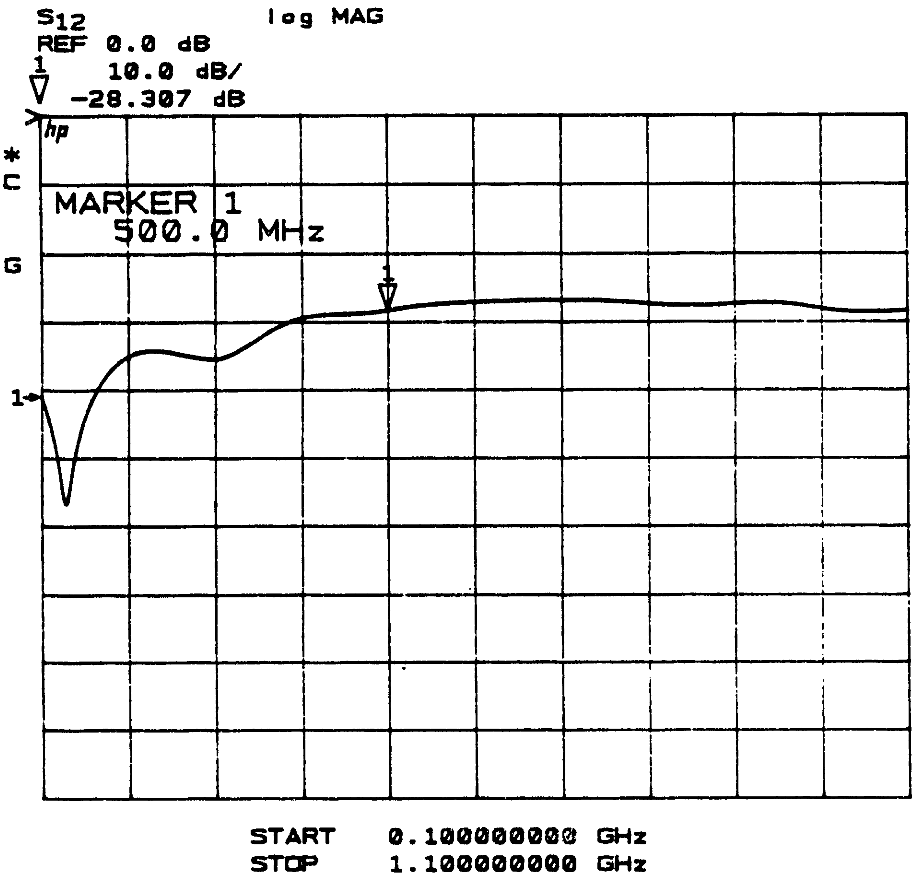


Figure 3.8. Transmission between Two Antennas (100-1100 MHz)

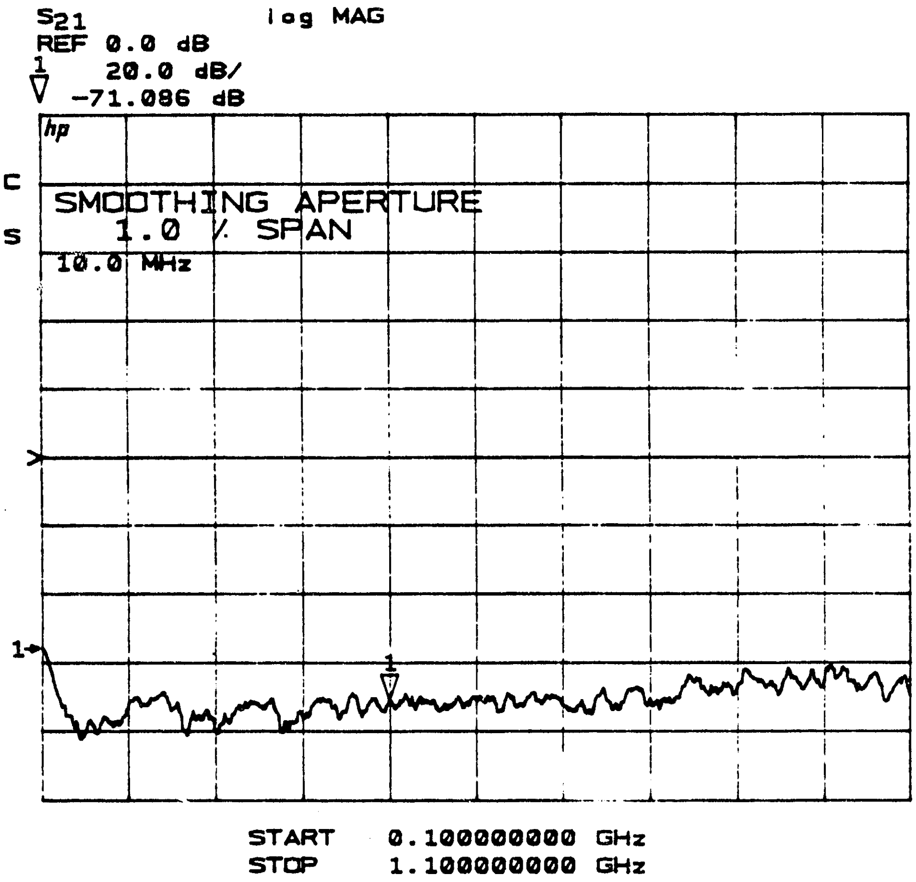


Figure 3.9. Isolation between Transmit and Receive Antennas (100-1100 MHz)

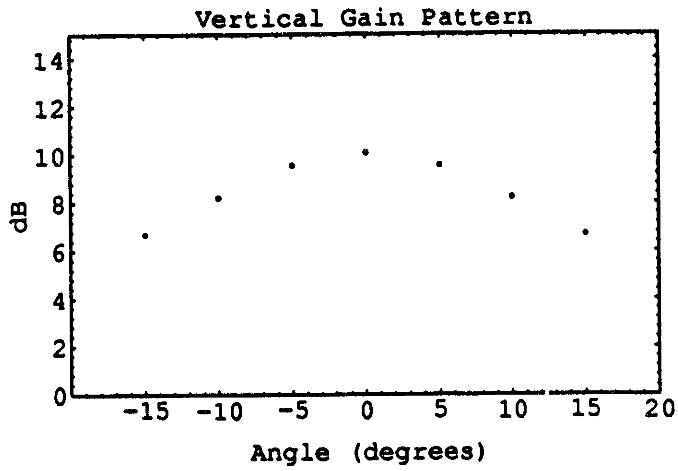


Figure 3.10. Vertical Antenna Pattern (±15°) Averaged over 300-1000 MHz

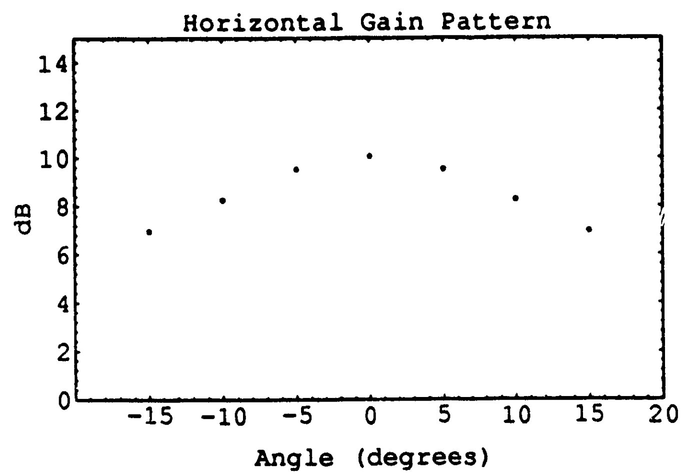
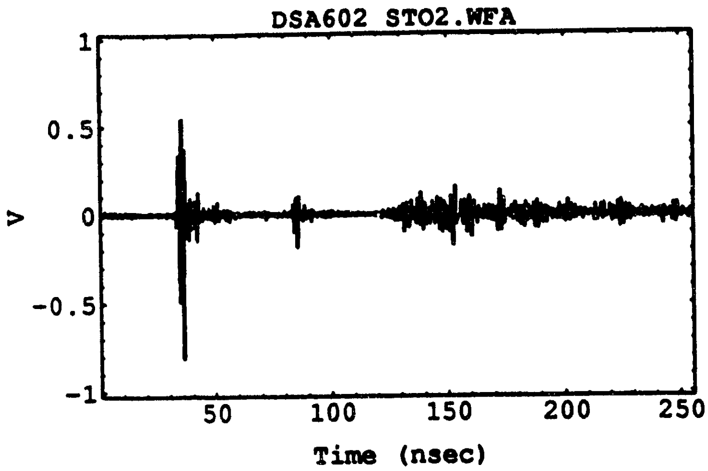


Figure 3.11. Horizontal Polarization Pattern (±15°) Averaged over 300-1000 MHz



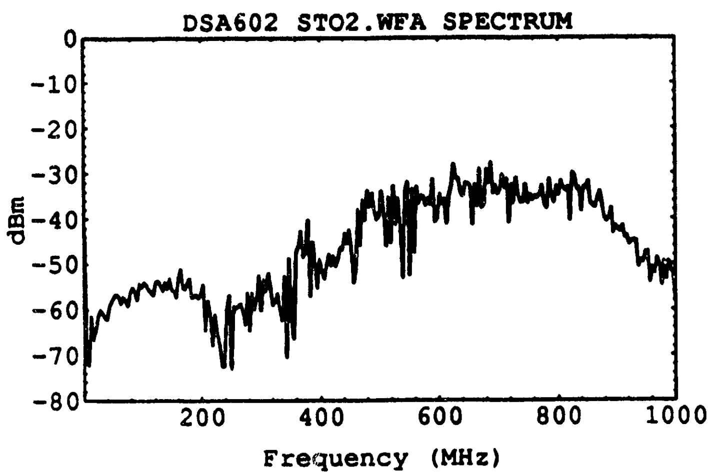


Figure 3.12. Pulse Response/Spectrum from Flat Plate Calibration Target

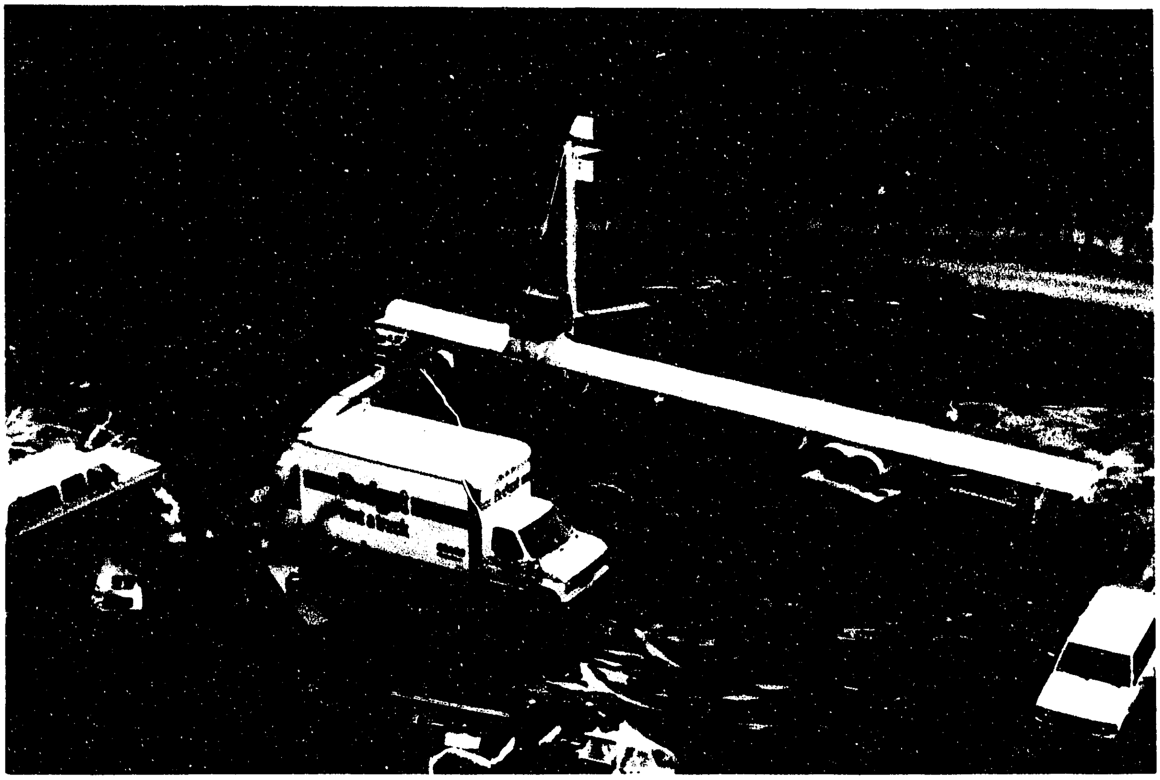


Figure 3.13. Photograph of Scanned System

4.0 Radar Clutter Imaging and Calibration to Radar Cross Section

In this section, a summary of the UWB clutter processing steps is described. The following steps in the processing are summarized: data collection, time skew correction and coherent integration, apodization for constant beamwidth, synthetic beam steering, calibration to ultrawideband RCS and clutter coefficient, and a discussion of the statistics calculated on the clutter data.

4.1 Data Collection

The data for the ultrawideband scanned radar is collected from the transient digitizer in the following manner. The scanner, of length $L = 19$ m, is moved to the extreme left to begin data collection. The radar is pulsed and the received delayed transient waveform is digitized N_I times, where N_I is typically equal to 100. The transient waveform is sampled every $\Delta t = 500$ psec for $N_t = 512$ samples. The time between trigger from the time delay generator and first sample point is called the "time skew" and is denoted by t_s. Each waveform and its time skew value are downloaded over the IEEE-488 bus from the DSA 602 digitizer to a SUN Sparcstation II computer and written to hard disk. The scanner carriage is moved by $\Delta x = L/(N_x\text{-}1)$, where N_x is typically 256, and another N_I waveforms are digitized. This procedure is repeated until the full scanner aperture has been covered.

For the 1992 measurements, internal averaging in the digitizer was used to improve the clutter data collection rate. For these measurements time skew correction was not used. This causes a minimal reduction in the high frequency content of the received waveforms due to the variation in time skew.

4.2 Time Skew Correction and Coherent Integration

Fourier transforms are used exclusively in the processing of the transient radar data and its calibration to RCS and clutter coefficient, σ^0. The continuous Fourier transform pair is given by

$$FT\{h(t)\} \equiv H(\omega) \equiv \int_{-\infty}^{\infty} h(t)e^{-j\omega t} \tag{4.1}$$

$$FT^{-1}\{H(\omega)\} \equiv h(t) \equiv \frac{1}{2\pi}\int_{-\infty}^{\infty} H(\omega)e^{j\omega t} \tag{4.2}$$

Time shifting in the time domain is equivalent to frequency-dependent phase shifting as given by,

$$h(t-t_s) = FT^{-1}\left\{H(\omega)e^{-j\omega t_s}\right\} \tag{4.3}$$

The Discrete Fourier Transform (DFT) pair is given by

$$DFT\{h(k\Delta t)\} \equiv H(\omega_n) \equiv \sum_{k=0}^{N_t-1} h(k\Delta t)e^{-j2\pi kn/N_t} \tag{4.4}$$

$$DFT^{-1}\{H(\omega_n)\} \equiv h(k\Delta t) \equiv \frac{1}{N}\sum_{n=0}^{N_t-1} H(\omega_n)e^{j2\pi kn/N_t} \tag{4.5}$$

where k represents the time sample index, and n represents the frequency sample index, and the frequency domain samples, ω_n, are given by,

$$\omega_n = \begin{cases} \dfrac{2\pi n}{N_t\Delta t} & n=0,1,\ldots,\dfrac{N_t}{2} \\ \dfrac{2\pi(n-N_t)}{N_t\Delta t} & n=\dfrac{N_t}{2}+1,\ldots,N_t-1 \end{cases} \tag{4.6}$$

Time shifting by times less than Δt is accomplished by phase shifting in the discrete frequency domain as in,

$$v(k\Delta t-t_s) = DFT^{-1}\left\{V(\omega_n)e^{-j\omega_n t_s}\right\} \tag{4.7}$$

The raw data (N_x by N_I waveforms) is indicated by $v_{raw}(k\Delta t, l\Delta x, m)$, where k represents the time sample index; l, represents the scanner position or x index; and m represents the waveform number at that position. The time sample index k ranges from 1 to N_t. The spatial sample index, l, ranges from $-N_x/2+1$ to $N_x/2$. The waveform number index, m, ranges from 1 to N_I. The total number of waveforms taken in a scan is thus N_x times N_I.

The N_I waveforms collected at each point are coherently summed by correcting for the time skew value of each waveform, as shown above, and summing the corrected wave-forms,

$$v_{ci}(k\Delta t, l\Delta x) = \frac{1}{N} \sum_{m=1}^{N_I} DFT^{-1}\left\{ DFT\left\{ v_{raw}(k\Delta t, l\Delta x, m) \right\} e^{-j\omega_n t_s(l,m)} \right\} \tag{4.8}$$

where v_{ci} represents the coherently integrated data.

4.3 Frequency Dependent Apodization for Constant Beamwidth

It is desirable for this ultrawideband radar system to have a well defined clutter cell size. Therefore, the data is processed to have a constant beamwidth as a function of frequency. This is accomplished by apodizing the data in the frequency domain with a window function that narrows as frequency is increased. This is easily accomplished with the scanned data as follows,

$$\mathrm{rect}(x) = \begin{cases} 1 & |x| \leq \frac{1}{2} \\ 0 & |x| > \frac{1}{2} \end{cases} \tag{4.9}$$

$$V_{apod}(\omega_n, l\Delta x) = \mathrm{rect}\left(\frac{l\Delta x}{L(\omega_{low}/\omega_n)} \right) DFT\left\{ v_{ci}(k\Delta t, l\Delta x) \right\} \tag{4.10}$$

where V_{apod} represents the apodized data in the temporal frequency domain.

4.4 Synthetic Beam Steering/Focusing

The scanned data is now synthetically beam-steered by time shifting and summing the N_x waveforms in the following way. The range, R, to the center of the covered swath is a function of the time delay, t_d, and is given by

$$R = \frac{c\left(t_d + N_t \Delta t/2\right)}{2} \tag{4.11}$$

The time shift, Δt_{bs}, necessary for each position is a function of the beam-steer angle, θ, which in the far-field of the scanner is given by,

$$\Delta t_{bs} = \frac{2l\Delta x}{c} \sin\theta \tag{4.12}$$

Thus the focused data, v_{foc}, is obtained by the following formula,

$$v_{foc}(k\Delta t,\theta) = \frac{1}{N} DFT^{-1}\left\{\sum_{l=1}^{N_x} V_{apod}\left(\omega_n, l\Delta x\right) e^{-j\frac{2\omega_n}{c} l\Delta x \sin\theta}\right\} \tag{4.13}$$

if the range is sufficiently far away so that the covered swath is in the far field of the scanner. If this condition is not met, a slightly more complex form will account for the curvature of the wavefront,

$$v_{foc}(k\Delta t,\theta) = \frac{1}{N} DFT^{-1}\left\{\sum_{l=1}^{N_x} V_{apod}\left(\omega_n, l\Delta x\right) e^{-j\frac{2\omega_n}{c}\left(R-\left[(l\Delta x - R\sin\theta)^2 + (R\cos\theta)^2\right]^{1/2}\right)}\right\} \tag{4.14}$$

4.5 Calibration to Ultrawideband RCS and Clutter Coefficient

The focused data, v_{foc}, must now be calibrated to radar cross-section (RCS) and clutter coefficient (σ^0) utilizing the response from a calibration target of known RCS. For this set of data the calibration target used was a 6' by 12' rectangular flat plate made of metallic screen. The calibration procedure for a single frequency continuous wave system is first described and then the extension to the ultrawideband case. The power received by the radar is given by the radar equation (Skolnik 1980),

$$P_r = P_t \frac{G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \qquad (4.15)$$

where P_t is the power transmitted, G is the gain, λ is the wavelength, R is the range to the target, and σ is the radar cross section of the target. Radar cross section is defined by,

$$\sigma \equiv \lim_{R \to \infty} 4\pi R^2 \frac{|E_r|^2}{|E_i|^2} \qquad (4.16)$$

where E_r is the reflected field strength at the radar, and E_i is the strength of the incident field at the target. For a flat rectangular plate aligned normally to the radar, the RCS is,

$$\sigma = \frac{4\pi A^2}{\lambda^2} \qquad (4.17)$$

where A is the area of the flat plate, and the physical optics approximation is assumed to be valid. The power from a calibration target, with known RCS $= \sigma_1$ and known range R_1, is measured and is also assumed to follow the radar equation,

$$P_1 = P_t \frac{G^2 \lambda^2 \sigma_1}{(4\pi)^3 R_1^4} \qquad (4.18)$$

The power from a second target or clutter, with unknown RCS $= \sigma_2$ and known range R_2, is measured and is also assumed to follow the radar equation,

$$P_2 = P_t \frac{G^2 \lambda^2 \sigma_2}{(4\pi)^3 R_2^4} \qquad (4.19)$$

Power at the receiver is related to voltage by,

$$P = \frac{1}{2} \frac{V^2}{Z_0} \qquad (4.20)$$

Taking the ratio of the powers from the unknown and known targets, the transmitted power, wavelength, and system gain cancel to yield,

$$\frac{P_2}{P_1} = \frac{\sigma_2 R_1^4}{\sigma_1 R_2^4} \tag{4.21}$$

Solving for the unknown RCS yields,

$$\sigma_2 = \sigma_1 \left(\frac{|V_2| R_2^2}{|V_1| R_1^2} \right)^2 \tag{4.22}$$

The transient waveform may be calibrated in a similar way to the above continuous wave calibration by Discrete Fourier Transform of the transient voltage waveform and calibrating the system at each discrete frequency. A discrete calibration spectrum, $S(\omega_n)$, is defined by,

$$|S(\omega_n)| = \frac{|V_1(\omega_n)|}{\sqrt{\sigma_1(\omega_n)}} \left(\frac{R_1}{R_0} \right)^2 \tag{4.23}$$

where $V_1(\omega_n)$ is the DFT of the transient waveform received from the calibration target (known RCS $= \sigma_1(\omega_n)$) and R_0 is an arbitrary reference range. The RCS of the unknown target as a function of frequency is thus,

$$\sigma_2(\omega_n) = \frac{|V_2(\omega_n)|^2}{|S(\omega_n)|^2} \left(\frac{R_2}{R_0} \right)^4 \tag{4.24}$$

where $V_2(\omega_n)$ is the DFT of the transient waveform received from another target or clutter (unknown RCS $= \sigma_2(\omega_n)$). The system frequency response is band limited so that a low frequency cutoff (ω_{low}) and high frequency cutoff (ω_{high}) are specified so that calibration will be enforced only over this frequency band. The low end and high end cutoff frequencies for this system are typically 300 MHz and 1000 MHz, respectively. The band limited, calibrated response is given by,

$$\sqrt{\sigma_2}(\omega_n) = \begin{cases} \dfrac{V_2(\omega_n)}{|S(\omega_n)|}\left(\dfrac{R_2}{R_1}\right)^2 & \omega_{low} \le \omega_n \le \omega_{high} \\ 0 & \text{elsewhere} \end{cases} \tag{4.25}$$

where the negative frequency side of the spectrum has been set to zero. The spectrum is then translated, so that the center frequency, e.g. ω_c = 650 MHz, is shifted to DC. This process will yield a transient waveform in the time domain with approximately the theoretical range resolution of,

$$\Delta R = \frac{c}{2B} \tag{4.26}$$

where $B = (\omega_{high} - \omega_{low})/2\pi$ is the bandwidth of the system. The high resolution (ultra-wideband) square-root RCS is thus given by,

$$\left|\sqrt{\sigma_2}(k\Delta t)\right| = \frac{2(\pi/\Delta t)}{\omega_{high} - \omega_{low}} \left|DFT^{-1}\left\{\sqrt{\sigma_2}(\omega_n + \omega_c)\right\}\right| \tag{4.27}$$

The ultrawideband RCS is defined

$$\sigma_2(k\Delta t) = \left|\sqrt{\sigma_2}(k\Delta t)\right|^2 \tag{4.28}$$

The UWB clutter coefficient, σ^0, is calculated simply from the UWB RCS by dividing by the area of a clutter cell, A,

$$\sigma_o \equiv \frac{\sigma}{A} \tag{4.29}$$

$$A = R\theta_{bw}\Delta R \tag{4.30}$$

$$R = \frac{c(t_d + N_t\Delta t/2)}{2} \tag{4.31}$$

where R is the range to the clutter cell and θ_{bw} is the synthesized beamwidth (approximately equal to 1.5° for a rectangular window). This high resolution calibration to clutter coefficient is applied to the $v_{foc}(k\Delta t, \theta)$ data to obtain high resolution two dimensional (range, angle) images of clutter coefficient.

4.6 Clutter Statistics

The high resolution calibrated clutter coefficient images are then sampled every clutter cell and statistics of the clutter are calculated. The number of samples, minimum, maximum, mean, median, standard deviation, skewness, kurtosis, histogram, and cumulative distribution are calculated.

To allow comparison of this data to existing clutter data and models, the cumulative distribution is plotted on "Weibull paper" as described below. The Weibull probability density function for clutter coefficient, σ^0, is given by,

$$w\left(\frac{\sigma^o}{\sigma^M}\right) = \ln(2)m\left(\frac{\sigma^o}{\sigma^M}\right)^{m-1} e^{-\ln(2)\left(\frac{\sigma^o}{\sigma^M}\right)^m} \tag{4.32}$$

where σ^M is the median clutter coefficient value, and m is called the slope parameter. The Weibull cumulative probability distribution function is given by,

$$W(\sigma^o) = 1-e^{\ln(2)\left(\frac{\sigma_o}{\sigma^M}\right)^m} \tag{4.33}$$

A measured distribution function, $W(\sigma^0)$, may be mapped so that it will appear as a straight line with slope, m, if it matches the Weibull distribution, by the following formulas,

$$y = 10\log_{10}\left(\left[\frac{1}{1-W(\sigma^o)}\right]\right) \tag{4.34}$$

$$x = 10\log_{10}(\sigma^o) \tag{4.35}$$

where x represents the horizontal axis of the plot and equals the clutter coefficient value in dB, and y represents the vertical axis of the plot and is related to the cumulative distribution function as shown. The Weibull slope parameter is typically expressed by its inverse, the Weibull spread parameter.

The statistical parameters are defined in the same manner as in Reference (Billingsley and Larrabee 1991). The mean is defined by

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i \tag{4.36}$$

which will typically be converted to decibels. The median is defined to be the 50% level in the cumulative distribution. The standard deviation (sd), skewness, and kurtosis are defined by

$$\text{sd}\ (x) = \left[\frac{1}{N-1} \sum_{i=1}^{N} \left(x_i - \bar{x} \right)^2 \right]^{1/2} \tag{4.37}$$

$$\text{skewness}\ (x) = \frac{M_3(x)}{\left[M_2(x) \right]^{3/2}} \tag{4.38}$$

$$\text{kurtosis}\ (x) = \frac{M_4(x)}{\left[M_2(x) \right]^{2}} \tag{4.39}$$

where

$$M_q(x) = \frac{1}{N} \sum_{i=1}^{N} \left(x_i - \bar{x} \right)^q \tag{4.40}$$

The standard deviation will typically be divided by the mean and converted to decibels. The skewness and kurtosis will typically be converted to decibels.

4.7 Long Record Lengths

One of the impulse radar system improvements used in the 1992 clutter measurements was longer digitizer record lengths in the DSA 602. The record length used was 8192 (8K) for clutter data and 512 for calibration and noise measurements. The beam steering/focusing algorithm has a range dependence if the far-field assumption is not met. This range dependence can be ignored for the 512 record length (range swath of 38 m) but cannot be ignored for a 8192 record length (range swath of 600 m). Therefore, the clutter data was processed in overlapping increments of 512 to provide analysis over the full 8K record.

4.8 Clutter Imaging Example

To illustrate the data collection and analysis procedure an example of the clutter imaging measurements and processing is discussed below. The scanner is moved to 256 uniformly spaced positions across the 19-meter aperture. At each position typically 100 waveforms are gathered. These waveforms are either averaged in the DSA 602A or using time skew correction in the computer. This data can be represented as an image in which the scanner position is the horizontal axis and time is the vertical axis. Voltage amplitude is then scaled to gray-scale or pseudo-color for display in the image. In this data, strong targets will appear as lines across the image. Targets lying along a line normal to the scanner axis will appear as horizontal lines in the image. Targets off axis will appear as left or right slanted lines. Figure 4.1 shows an unprocessed image of the calibration target at a range of approximately 1 km. This data was then calibrated to clutter coefficient using the methods described above to generate the image in Figure 4.2. Note that this image is a range-angle image. The horizontal axis is angle (-15° to +15°) and the vertical axis is range (38 m total swath).

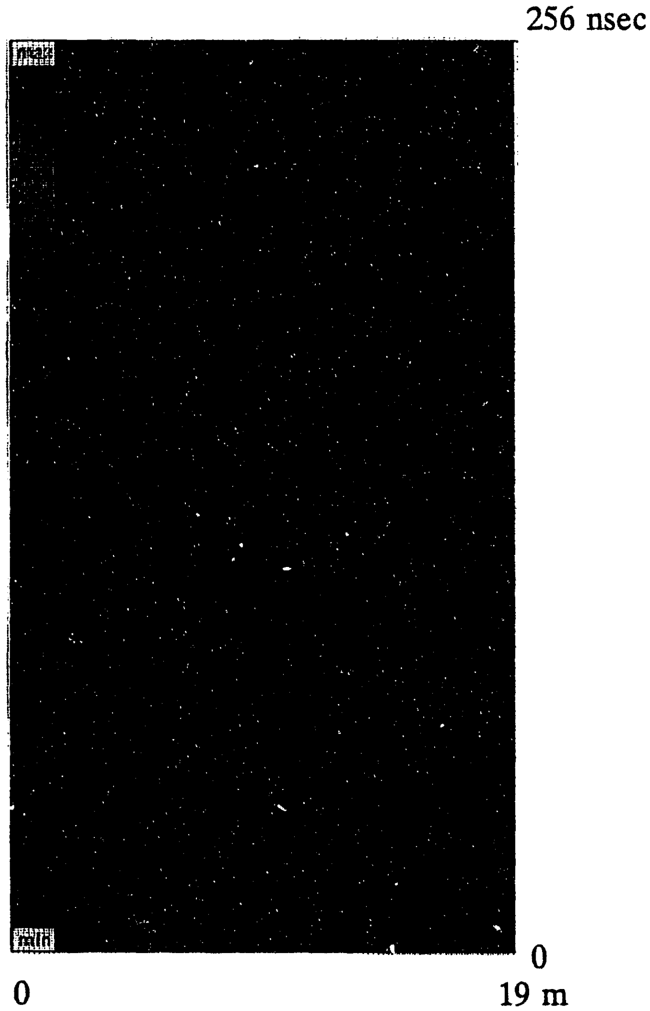


Figure 4.1. Unprocessed Calibration Target Response Image

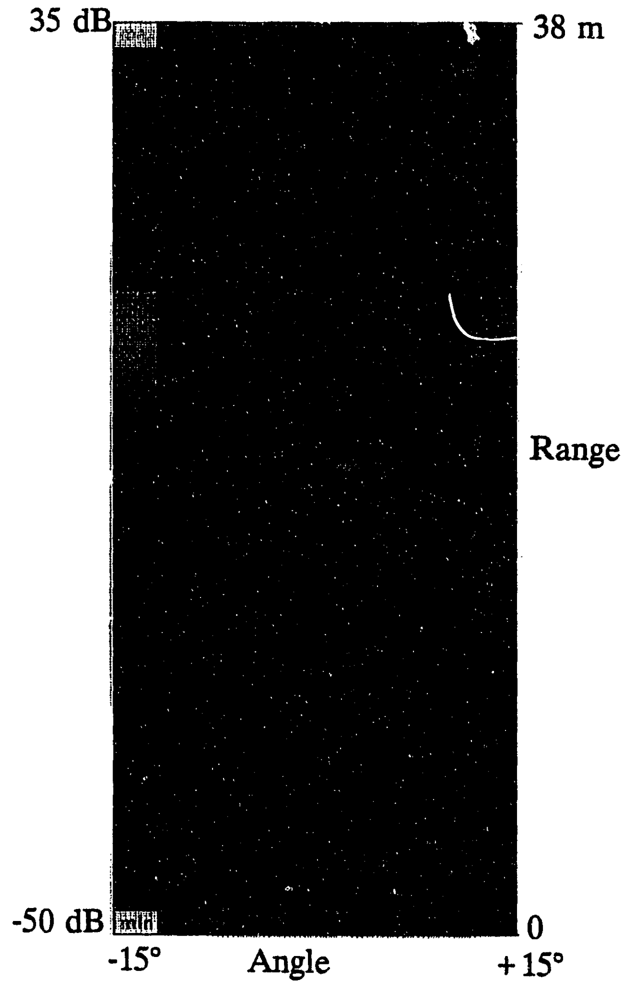


Figure 4.2. Calibration Target Image (Range-Angle) Calibrated to RCS

5.0 Site Selection and RFI Measurements

Choosing a site for the clutter measurements involved a number of often conflicting criteria. These criteria included suitable radar illumination of desirable clutter, low RFI levels, and accessibility to the 19-meter scanner.

5.1 Physical Site Requirements

During 1991, a search for potential sites for the forest and desert clutter measurements was conducted. A convenient forested site was found in the Olympic National Forest near Sequim, WA. A desert site was found in Badger Canyon located near PNL's Richland, WA facility.

During June and July 1992, an extensive search was undertaken for potential new sites for the 1992 impulse radar clutter measurements. A number of criteria were used for determining the suitability of prospective measurement sites. First the radar should illuminate the areas of clutter to be measured. Typically, this means the radar must be located on the side or top of a hill. Second, the site must accommodate a level lot approximately 30 meters in diameter to allow for positioning of the 20 meter scanner. Third, the angular and range swaths available at the site should be as large as possible in order to obtain the largest set of clutter data.

Physical examination of the accessible terrain near Sequim has established three sites that meet the criteria listed above. The three sites are identified as the "Original Site," which is the site of the 1991 impulse clutter measurements; the "Maynard Site," which is near Maynard Peak; and the "Road 150 Site," which is near Road 150. These sites are shown on the topographic map in Figure 5.1.

5.2 RFI Survey

On July 16, 1992, the three prospective forested sites were examined for suitability for the impulse radar clutter measurements. In addition to the physical requirements discussed above, the prospective sites should have low levels of radio frequency interference (RFI), the dominant source of noise for these measurements.

To determine the suitability of these sites for the impulse radar clutter measurements, RFI measurements were made at each of the three sites. One of these sites is the site of the 1991 impulse clutter measurements. This site is known to have relatively low levels of RFI and is used as the reference for the other two potential sites.

The system used to make the RFI measurements consists of a log-periodic antenna (Electro-Mechanics Co. Model 3146A), 15 feet of RG142B cable, an Avantek UT6-0491M amplifier, a Mini-Circuits ZFL-1000LN amplifier, and a Tektronix 2784 Spectrum Analyzer all connected in series. The gain of the Avantek amplifier is approximately 20 dB from 0.1 to 1.1 GHz. The gain of the Mini-Circuits amplifier is approximately 24 dB over the same band. The gain of the two amplifiers and the cable is shown in Figure 5.2. Note that a 40-dB attenuator has been placed before the input to the amplifiers in this measurement. Thus, the gain at the center frequency is about 42 dB. The gain of the log-periodic antenna is shown in Figure 5.3. The average gain over the 300-1000 GHz band is approximately 6 dBi.

The spectrum analyzer was configured to have a resolution bandwidth of 1 MHz and a video bandwidth of 100 Hz. The power levels shown on the spectrum analyzer and plots are the power levels observed at the spectrum analyzer input. The gain of the antenna and amplifiers has not been removed. For all measurements the antenna was polarized half way between vertical and horizontal polarizations. Results for two antenna orientations at the Original Site are shown in Figures 5.4 and 5.5. Results for two antenna orientations at the Maynard Site are shown in Figures 5.6 and 5.7. Results for both antenna orientations at the Road 150 Site are shown in Figures 5.8 and 5.9.

Analysis of these results indicates that the qualitatively lowest levels of RFI are present at the Original Site. The Maynard Site shows peak RFI levels comparable to the Original Site with more carriers evident for a somewhat higher average level. The 334° orientation at the Maynard Site shows higher levels of RFI, due most likely to cellular phone transmitters and television stations in the Port Angeles area. Both RFI measurements at the Road 150 Site show RFI levels significantly higher than the other two sites. This site is line of sight to a number of transmitting antennas located on nearby Blyn Mountain. The 58° orientation is looking directly at the transmitting antennas and therefore shows the highest levels. The other orientation is subdued, but still much higher than the other two sites.

These RFI measurements indicate that for clutter measurements with noise levels similar to the 1991 clutter measurements only the Original Site and the Maynard Site are acceptable.

5.3 Characteristics of the Chosen Sites

Given the stringent site requirements outlined above only two good prospective sites were found. One of which is the site of the original clutter measurements in 1991. The other site is located near Maynard Peak. Measurements from both of these sites look in the general direction of Bear Mountain although from different sides.

The original site is located near Bear mountain in the Olympic National Forest near Sequim, WA. This site has an available has an available range swath of 500 m to over 2500 m, and an angular swath of 150°. The radar site is located on a clearing on a hillside looking out over a valley onto opposing hillsides. A calibration site is located on a bare knoll approximately 1 km from the radar position. This site is well protected from RFI transmitters by surrounding mountains.

The Maynard Site is located approximately 2.2 km southwest from the peak of Bear Mountain. This site has a sharp drop-off for the first 0.5 km and reasonable illumination of the terrain beyond this range. The available angular swath is approximately 150° with a possible extension to 180°. The last 30° sector is shadowed somewhat by the terrain close to the scanner position. The available range swath is limited by nearby peaks located 2-3.5 km from the site Over most of the angular swath the available range should be in excess of 2.5 km. Given the sharp drop-off near the scanner site the total available range swath is approximately from 0.5 km to 2.5 km. There are two excellent sites to place the 6' by 12' calibration target. Both are in clear cut areas approximately 1 kilometer from the radar site.

A significant (perhaps 20%) percentage of this site is composed of clear cuts or smaller trees. Given the extensive logging that has been done in recent years in the Olympic National Forest, this is an unavoidable feature of the terrain in this area. Therefore it is reasonable to include it in the clutter measurements.

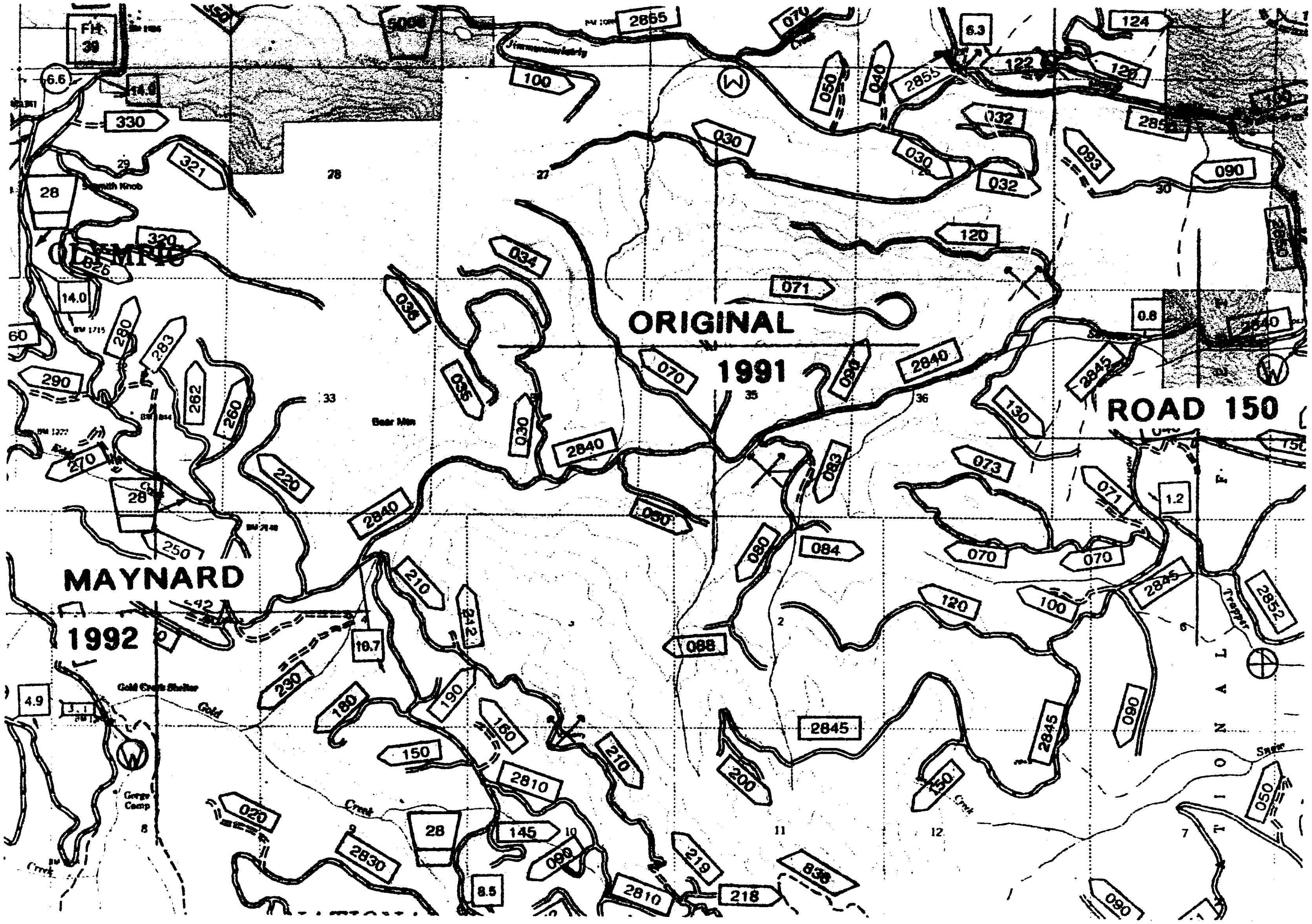


Figure 5.1. Topographic Map Showing the Three Prospective Sites

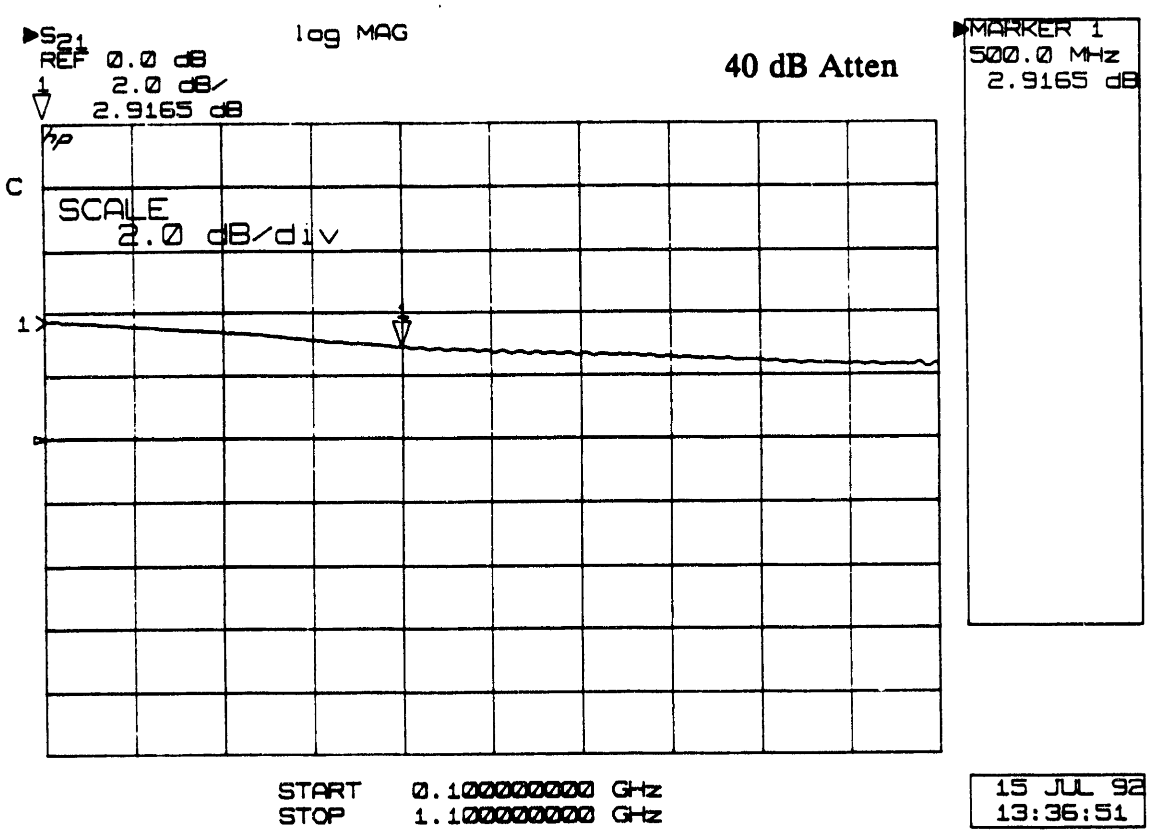


Figure 5.2. Gain of the RFI Measurement System

A series connection of the Avantek UT6-0491M amplifier, a Mini-Circuits ZFL-1000LN amplifier, 15 feet of RG142B cable, and a 40 dB attenuator connected to the input of the Avantek amplifier.

FREQUENCY (MHz)	ANTENNA FACTOR (dB)	GAIN NUMERIC	GAIN dBi
300	14.8	3.16	5.0
325	13.7	4.72	6.7
350	15.0	4.03	6.1
375	15.7	3.99	6.0
400	16.7	3.59	5.5
425	17.5	3.36	5.3
450	17.3	3.94	6.0
475	17.4	4.34	6.4
500	17.7	4.50	6.5
525	18.1	4.50	6.5
550	18.6	4.40	6.4
575	18.9	4.43	6.5
600	19.3	4.46	6.5
625	19.6	4.49	6.5
650	20.2	4.20	6.2
675	20.9	3.88	5.9
700	21.3	3.80	5.8
725	21.2	4.21	6.2
750	21.4	4.26	6.3
775	21.8	4.15	6.2
800	22.1	4.18	6.2
825	22.7	3.84	5.8
850	23.1	3.69	5.7
875	23.7	3.42	5.3
900	24.2	3.21	5.1
925	24.8	3.01	4.8
950	25.0	2.99	4.8
975	25.2	3.03	4.8
1000	25.4	3.03	4.8

Figure 5.3. Gain of the Log-Periodic Antenna

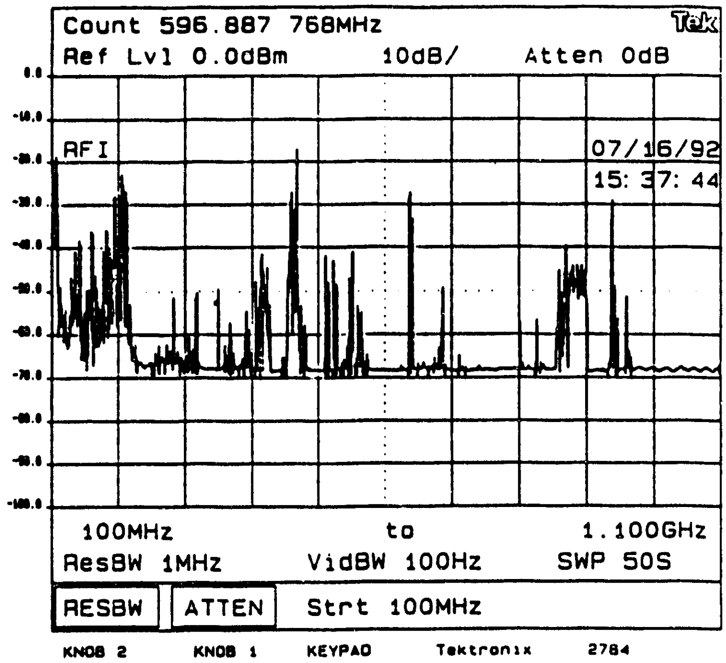


Figure 5.4. RFI Measurement at the Original Site, 212° Orientation

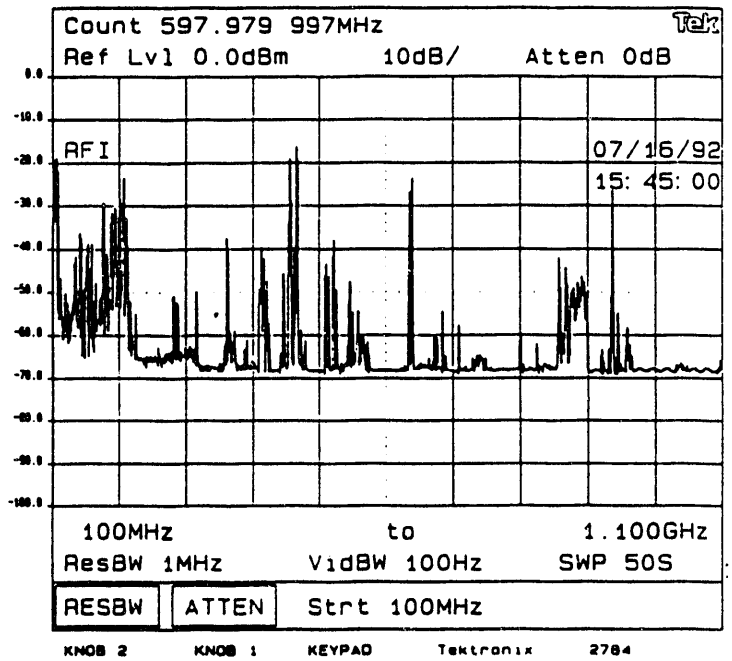


Figure 5.5. RFI Measurement at the Original Site, 304° Orientation

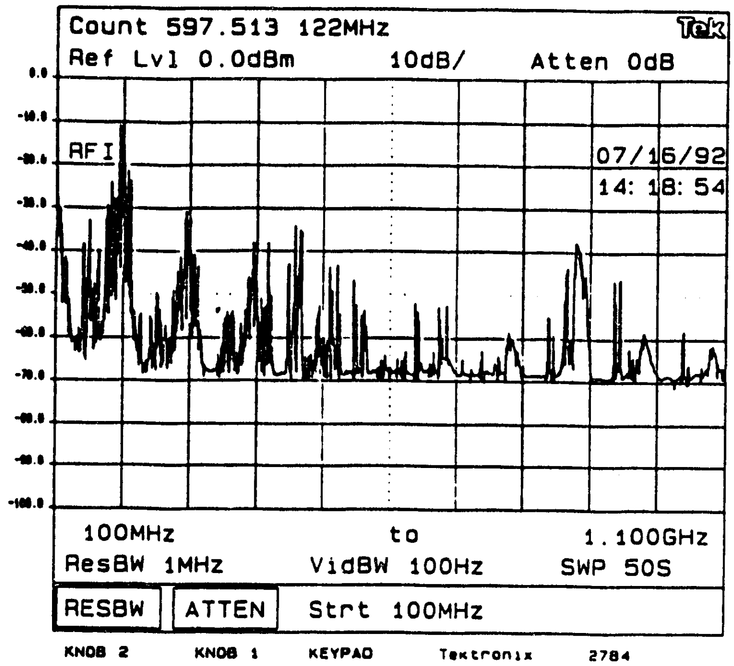


Figure 5.6. RFI Measurement at the Maynard Site, 72° Orientation

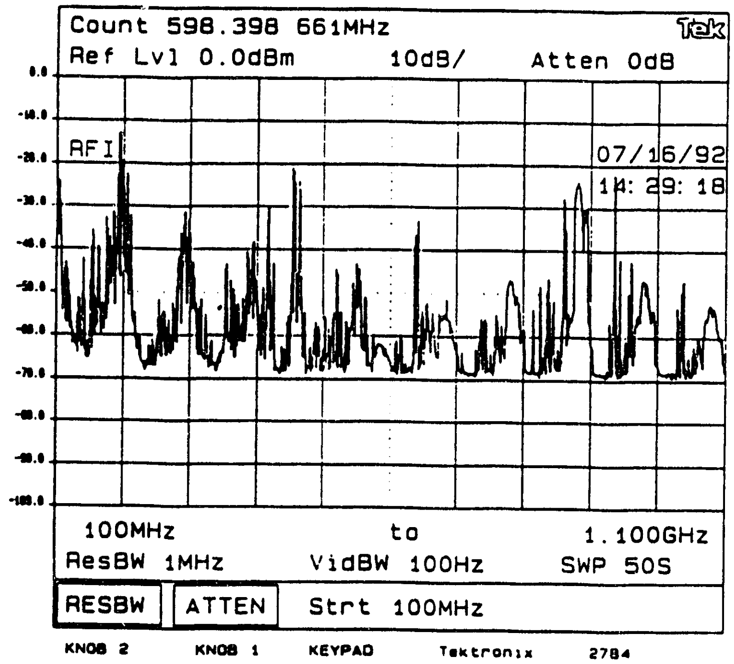


Figure 5.7. RFI Measurement at the Maynard Site, 334° Orientation

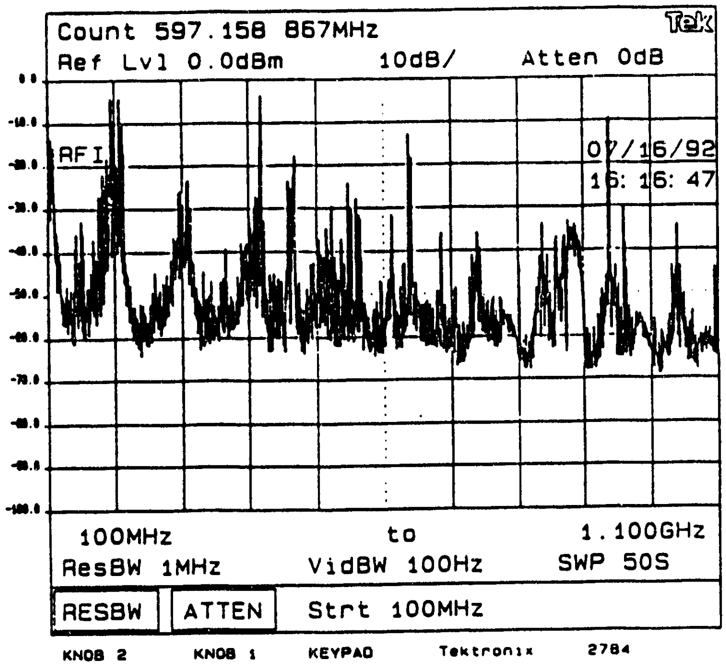


Figure 5.8. RFI Measurement at the Road 150 Site, 58° Orientation

Pointed directly at transmitters on Blyn Mountain.

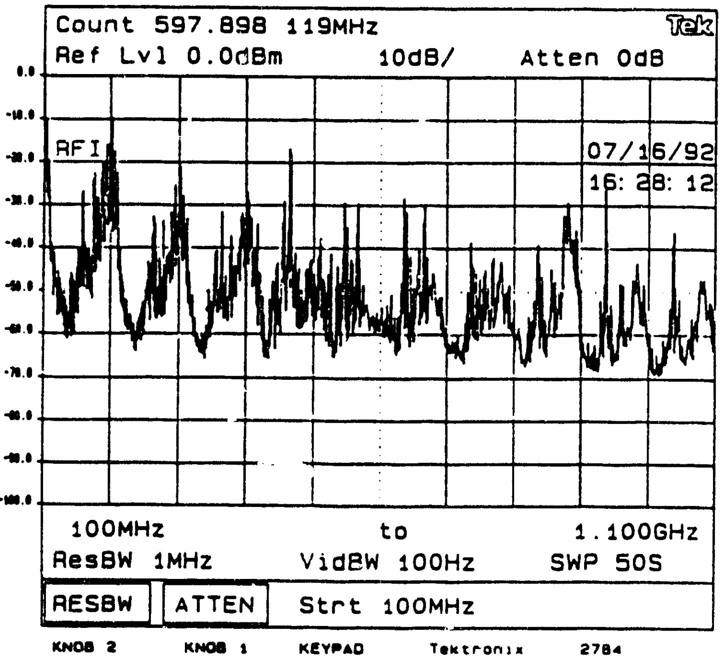


Figure 5.9. RFI Measurement at the Road 150 Site, 224° Orientation

6.0 1991 Forest and Desert Measurements

At the beginning of November 1991, the PNL impulse radar, the 19-meter scanner, and System Planning Corporation's mobile Mark IV instrumentation radar were set up at the Sequim clutter measurement site. Operations were conducted there for two weeks.

6.1 Impulse Forest Measurements (Sequim)

The PNL impulse radar measured clutter coefficients for approximately 120,000 cells covering a total of approximately 0.7 km^2 for both VV and HH polarizations. The SPC Mark IV measured an area covering approximately 6 km^2, in both polarizations. The step-chirp area included all that covered by the impulse measurements.

Measurements were made at three scanner orientations spaced 30° apart. In each orientation scans were performed for 13 slightly overlapping range increments covering 0.75 to 1.2 km in both VV and HH polarizations, for a total of 78 scans.

Each scan collected 100 received waveforms at each of 256 positions in the 19 meter aperture, for a total of 25,600 waveforms. Each scan provided clutter measurements in 155 cells (covering approximately 35 meters total range) in each of 20 synthesized beams for a total of 3100 cells per scan. Time required to complete a scan was 40 to 45 minutes.

A flat plate calibration target was included in the clutter scene on a substantially bare knoll at approximately 1 km range. The target area was rescanned several times during the two week period to check the impulse radar system stability. Figure 6.1 is a panoramic view of the general scene at the Sequim site from the radar scanner location. Figure 6.2 shows the radar setup at the Sequim site. Figure 6.3 is an aerial photograph of the site, and Figure 6.4 is a topographic map of the area.

6.1.1 Calibration

The calibration procedure used follows the analysis in Section 4.5. A flat plate calibration target was placed on a bare knoll approximately 1 km from the radar. The target consisted of two 6 by 6 foot mesh plates assembled as a 6 foot wide by 12 foot high rectangle. The plate was manually oriented for maximum return amplitude while observing the impulse radar voltage waveform output.

Calibration waveforms appeared significantly cleaner in the synthetic aperture data. This is to be expected for two reasons. The narrower synthesized beam would give roughly a 10 dB improvement in target to clutter ratio. Also 25,600 waveforms, rather than 2,000 were averaged suggesting approximately 10 dB further improvement in target to RFI ratio from coherent processing.

A slightly processed B-scan version of a data set collected from the calibration target area is shown in Figure 6.5. This pseudo-color image is representative of the voltage waveforms returned from the target area. Each column in the image represents a coherent summation of 100 waveforms from the target area at that scanner position. Thus, a target located directly ahead of the scanner (perpendicular to the scanner axis) would generate a response at approximately equal time delay from each scanner position, and shows up as a horizontal line in the image. Off axis discrete targets show up in the image as angled lines. The processing described in Section 4.4 converts this data into high resolution focused range-angle images which are calibrated to clutter coefficient, as shown in Figure 6.6. The angular extent of the range-angle images is -15° to +15° with 0.2° increments. The range extent of the images is approximately 38 meters.

The voltage waveform used for calibration was obtained from the focused data by choosing the angle at which the peak response was observed in the focused, uncalibrated data. Therefore, the target did not need to be placed exactly perpendicular to the scanner axis. The voltage waveform used for calibration is shown in Figure 6.7 along with its spectrum. For calibration, this waveform was windowed using a raised cosine window with a total width of 16 nsec. This windowing was done to remove the effects of clutter away from the calibration position. The windowed waveform and its spectrum are shown in Figure 6.8. The windowed waveform was used in the calibration procedure described in Section 4.5 to calibrate the unwindowed response to high resolution UWB radar cross section. The results of the this calibration are shown in Figure 6.9. Note that the peak response is approximately forced to equal the expected RCS from the 6' by 12' calibration target (34.2 dBsm). The expected UWB RCS of the calibration target is exactly equal to the single-frequency RCS at the center frequency. This is because the flat plate square root RCS varies linearly with frequency, and the UWB processing essentially takes an average of the square root of RCS in the transformation back to the time/range domain. If the unwindowed response were processed as though unknown, then the result would be exactly 34.2 dBsm. The clutter present in the waveform causes the result to be slightly different.

The range resolution of the system may be degraded by limiting the bandwidth. This is readily done using the calibration procedure, discussed in Section 4.5, by changing the low and high frequency cutoff points. For example, the resolution of the calibration waveform (Figure 6.7) was reduced by limiting the bandwidth to 100 MHz (600 to 700 MHz), with the resulting RCS vs. range shown in Figure 6.10.

The calibration target was revisited a number of times during the two weeks of measurements to determine if the system was stable. Also, a 3' by 4' flat plate target was also deployed a number of times to verify that the calibration procedure would measure a known target's RCS correctly. The 3' by 4' target was a good choice for a secondary target as its RCS was large enough that it could be seen directly by the system (without scanning) at more than a kilometer. Also, unlike the large target, the 3' by 4' target is not extremely sensitive to alignment errors. This is important because, if the 6' by 12' target were misaligned, then the calibrated RCS measurements of other targets would be too high. Thus, deploying the small target and verifying near-correct results was a valuable tool in verifying the measurement system, calibration algorithms, and target alignment.

Results of the ultrawideband impulse RCS measurements of known targets are summarized in Table 6.1. For these measurements the targets were located at a range of approximately 1.07 km. The targets were approximately normal to the scanner axis and at nearly the same elevation. The table entry under Day 0 was the scan used to calibrate all of the other target and clutter measurements, and is therefore not an indication that the system is yielding the correct results. Two of the other results are within approximately 2 dB of the expected RCS of the 6' by 12' flat plate. The third measurement is somewhat lower than the other two, indicating that the target was probably not as well aligned. The 3' by 4' target was also scanned, with a measured RCS of 17.2 dBsm and an expected value of 18.6 dBsm. These results indicate that the measurement and calibration techniques were yielding reasonably accurate results.

Table 6.1. On-Axis RCS Measurements (UWB) of Known Targets Including the 6' by 12' Flat Plate and a 3' by 4' Flat Plate

Target UWB RCS Measurements (on-axis)				
	Pol	Range (km)	RCS (dBsm)	Notes
6' by 12' Flat Plate Calibration Target				
Expected			34.2	
Day 0	VV	1.07	33.3	calibration
Day 1	VV	1.07	29.8	not aligned
Day 2	HH	1.07	32.2	
Day 2	VV	1.07	32.1	
3' by 4' Flat Plate Target				
Expected			18.6	
Day 2	VV	1.07	17.2	

6.1.2 Clutter Measurements

As indicated above, clutter was measured over a sector with a range from 750 m to 1200 m and an angular extent of 90°. Covering this sector took 39 scans for each polarization for a total of 78 scans. Several typical high resolution calibrated images of clutter are shown in Figures 6.11 to 6.13.

Weather during the measurement period was generally cool and overcast with occasional light drizzle. In the week preceding the measurements rain gauges in the clutter scene collected 0.6 to 1.1 inches of total precipitation (see Appendix B). The impulse radar operating schedule was typically 3 pm to midnight. Temperatures were generally falling during this time, frequently reaching dew point as indicated by typical formation of evening fog.

6.1.3 Forest Clutter Analysis

In this section, extensive statistical results of the impulse measurements from the forested site at Sequim are presented. Table 6.2 summarizes the vertical (VV) and horizontal (HH) polarization data taken for the three lines of sight, 186°, 216°, and 246°. Figures 6.10 and 6.11 show the probability density functions, or histograms, of this data along with a Weibull plots of the cumulative distribution functions. The Weibull plotting technique is discussed in Section 4.6. Above the noise floor, the distributions approximately match Weibull distributions with spread parameters of 2.17 for VV and 2.44 for HH. Below the noise floor, the spread parameter is close to unity which is expected for noise. The distributions may be biased upward somewhat relative to other clutter measurements, since the measured area contained primarily slopes facing the radar with few shadowed regions.

Table 6.2. Summary of VV and HH Polarization Clutter Data Taken in Three Lines of Sight: 186°, 216°, and 246°

Polarization	VV	HH
Frequency Band	300-1000 MHz	300-1000 MHz
Aperture Window	Rectangular	Rectangular
Angle Coverage	171°-261°	171°-261°
Beamwidth (constant)	1.5°	1.5°
Range Coverage	750 m - 1200 m	750 m - 1200 m
Range Resolution	0.214 m	0.214 m

Polarization	VV	HH
Number of Cells	117,800	120,900
Mean σ^0	-5.4 dB	-9.0 dB
Median σ^0	-12.4 dB	-16.8 dB
Max σ^0	14.1 dB	12.4 dB
Weibull Spread	2.17	2.44

A single scan was taken with the transmitter turned off in order to assess the noise equivalent clutter at this sight, with the results summarized in Table 6.3. The distributions of this noise data are shown in Figure 6.16. The mean noise equivalent clutter coefficient observed was -40 dB and is predominantly due to RFI. This represents the approximate noise floor of the impulse clutter measurements.

Table 6.3. Summary of Noise Equivalent Clutter Data

Polarization	VV
Frequency Band	300-1000 MHz
Aperture Window	Rectangular
Range	1000 m
Number of Waveforms	25,600
Number of Cells	3,100
Mean σ^0	-40.1 dB
Median σ^0	-42.1 dB
Max σ^0	-30.2 dB

Figures 6.17 and 6.18 are composite clutter maps, presented to show the correlation of measured clutter coefficient to scene topography. A topographic map of the region covered is given as Figure 6.4. The cells shown are mean values for the 35 meter range blocks measured in each scan. (Each element plotted contains the mean of the 155 range resolved cells.) Cross range resolution is the 1.5° synthesized beamwidth.

6.2 Step-chirp Forest Measurements (Sequim)

The 1991 step-chirp measurements were conducted in parallel with the impulse measurement by Systems Planning Corporation under subcontract to PNL. Their measurement techniques and results are detailed in SPC Final Technical Report 1432 [Sager and Schultheis 1992). The summary portion of this report is reproduced in Appendix A.

6.3 Impulse Desert Measurements (Badger Canyon)

Synthetic aperture clutter measurements were also attempted at a desert location in Badger Canyon, near Richland, Washington. This site was much closer to an urban area with several local UHF TV stations and cellular telephone service. Although the site was selected for low local RFI, interference was substantially more severe than at the rural Sequim location. A photograph of operations and terrain at the Badger Canyon site is shown in Figure 6.19 along with a topographic map in Figure 6.20.

Measurements were terminated when it became clear that clutter coefficients in most of the scene were not significantly above the RFI imposed noise floor. The RFI spectrum at the receiver output is shown in Figure 6.21.

Further complicating the results at the Badger site was the fact that the impulse antennas suffered some damage after the Sequim measurements. Humidity caused the foam-core supporting structure of the antennas to shrink, which caused one of the antenna feeds to short circuit. This short was fixed, however, the observed voltage waveforms had substantially more ringing, as shown in Figure 6.22. This is the waveform/spectrum returned from the 6' by 12' calibration target placed at approximately 1.3 km. Possible explanations for the ringing include multipath effects and the damage that the antennas incurred. A windowed version of this waveform and its spectrum are shown in Figure 6.23.

Due to the unusual target return, the calibration from the Sequim data was used to calibrate the Badger Canyon data. This calibration may not be valid if the behavior of the antennas was significantly changed by the damage. Figure 6.24 shows the focused image of the calibration target area calibrated to clutter coefficient. Figure 6.25 shows a typical calibrated clutter image. The signal levels in this image are mostly due to RFI. Therefore, this data is not representative of the true clutter levels at this site. Figure 6.26 shows a clutter scene in which some bright clutter regions are visible above the RFI background. Table 6.4 summarizes a noise equivalent clutter coefficient measurement, in which the transmitter was turned off. A mean noise level of approximately -27 dB was observed. The distributions of this data are shown in Figure 6.27.

Table 6.4. Summary of Noise Equivalent Clutter Coefficient Measured at Badger

Polarization	VV
Frequency Band	300-1000 MHz
Aperture Window	Rectangular
Range	1000 m
Number of Waveforms	25,600
Number of Cells	3,100
Mean σ^0	-27.2 dB
Median σ^0	-29.0 dB
Max σ^0	-13.8 dB

Table 6.5 summarizes the clutter data taken at the desert site. The distributions of this data are shown in Figure 6.28. Again, it should be emphasized that these measurements are contaminated by significant RFI levels, and are therefore not accurate measurements of the true clutter levels. These results are presented only to document the measurements that were made. The Weibull plot of the cumulative distribution function clearly shows that most of the data is noise, which should have a slope parameter of unity. A small fraction of the data is, however, above the noise floor.

Table 6.5. Summary of the RFI Dominated Clutter Data Taken at Badger Canyon

Polarization	VV
Frequency Band	300-1000 MHz
Aperture Window	Rectangular
Angle Coverage	180° - 240°
Beamwidth (constant)	1.5°
Range Coverage	990 m - 1330 m
Range Resolution	0.214 m
Number of Cells	55,800
Mean σ^0	-20.5 dB

Polarization	VV
Median σ^0	-25.7 dB
Max σ^0	1.9 dB
Weibull Spread	---

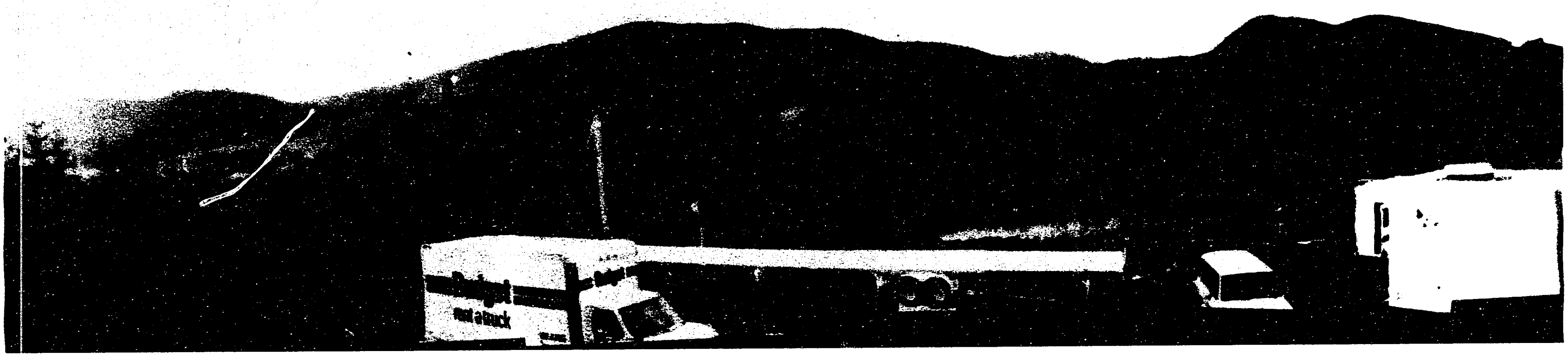


Figure 6.1. Panoramic Photograph Looking Outward from the 1991 Sequim Site

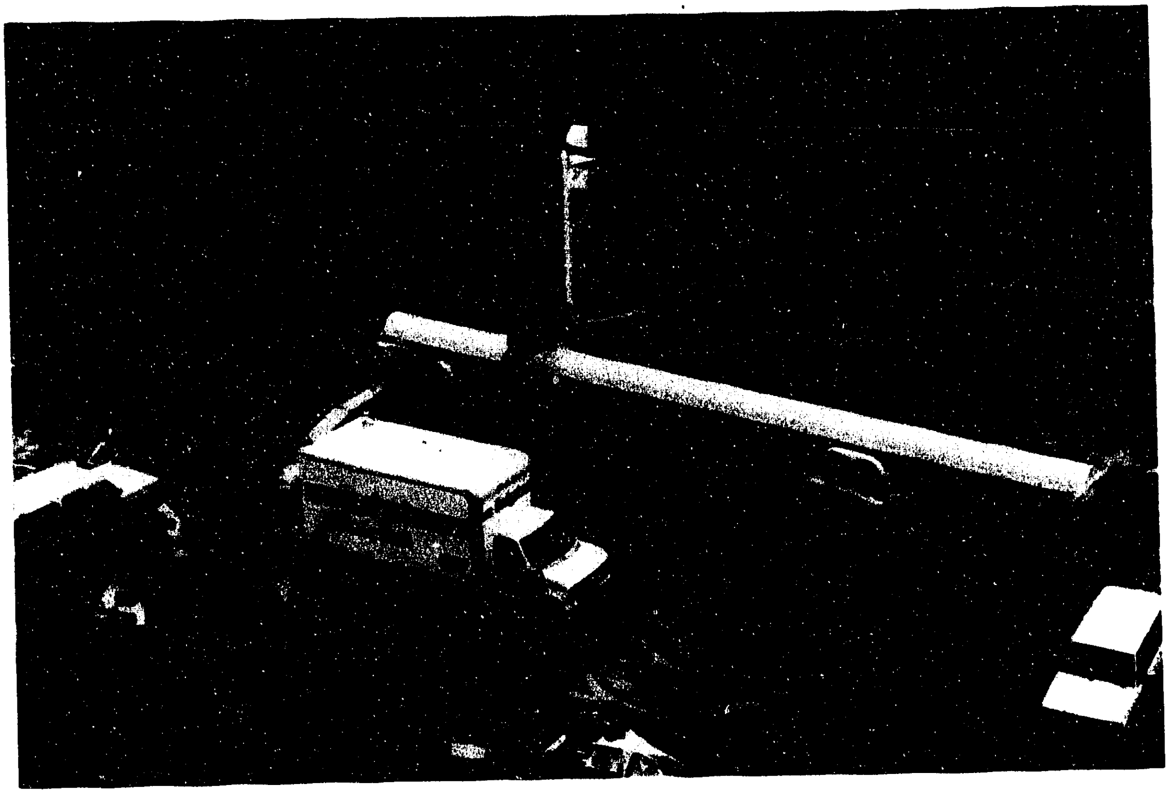


Figure 6.2. Operations at the 1991 Sequim Site

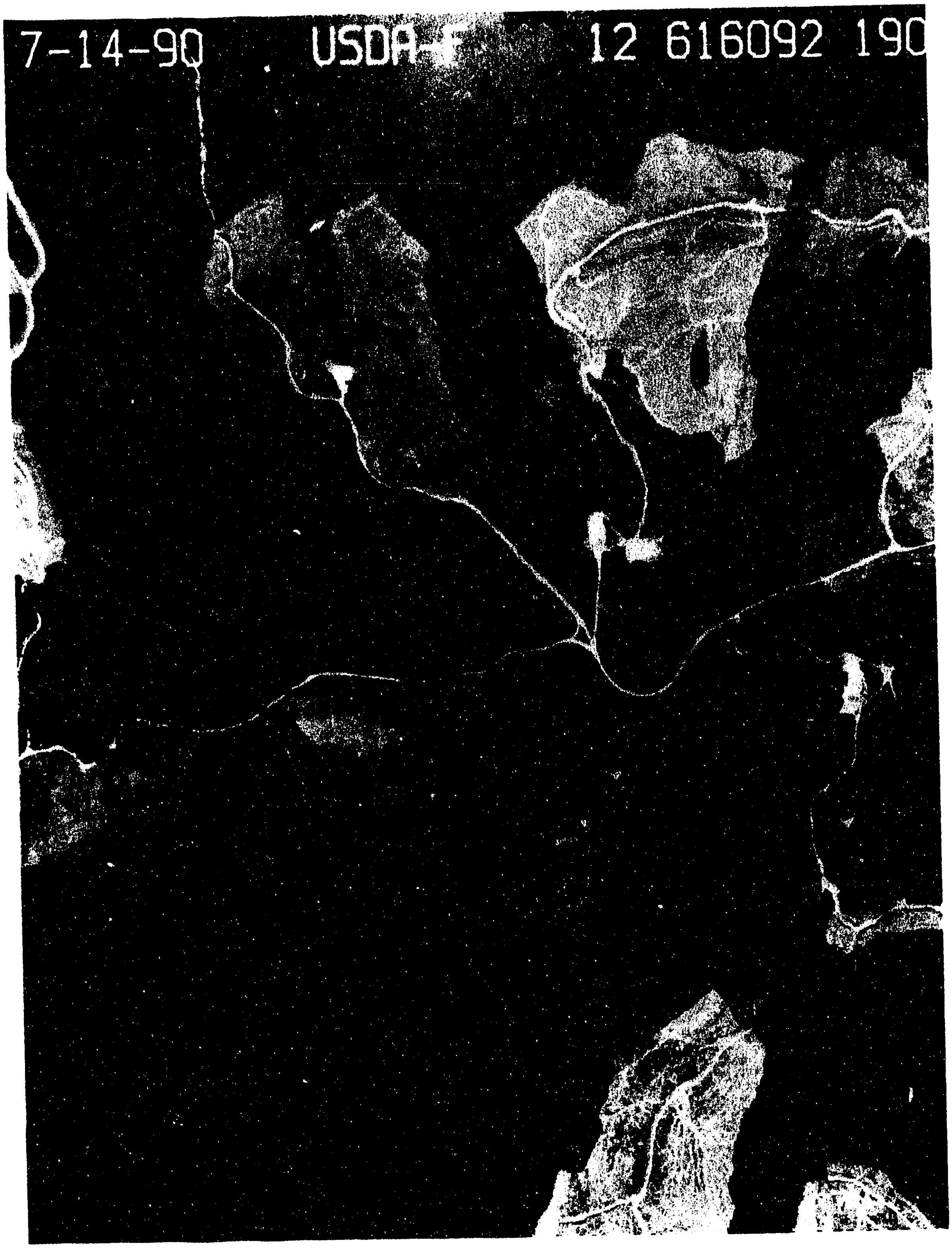


Figure 6.3. Aerial Photograph of the 1991 Sequim Site

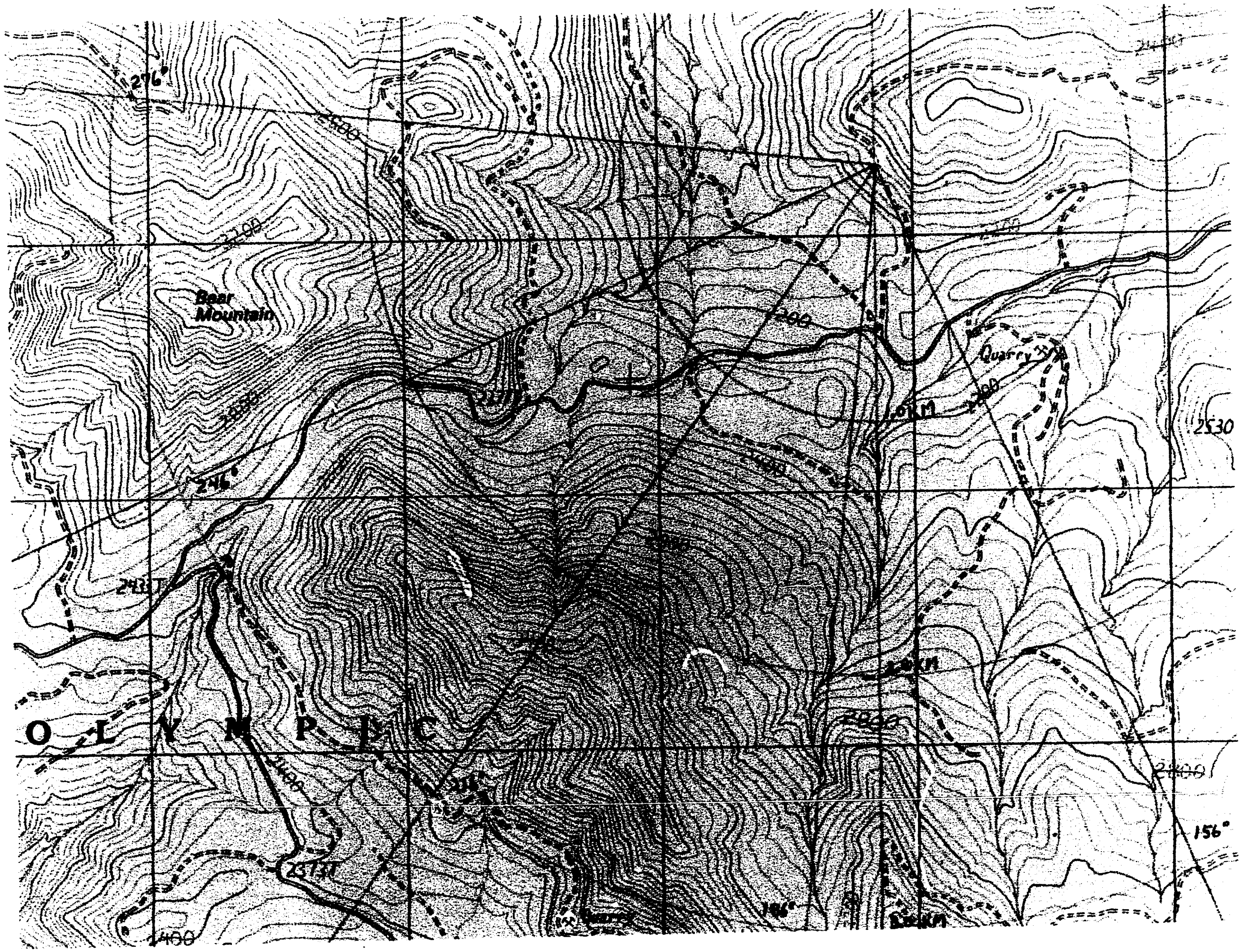


Figure 6.4. Topographic Map of the 1991 Sequim Site

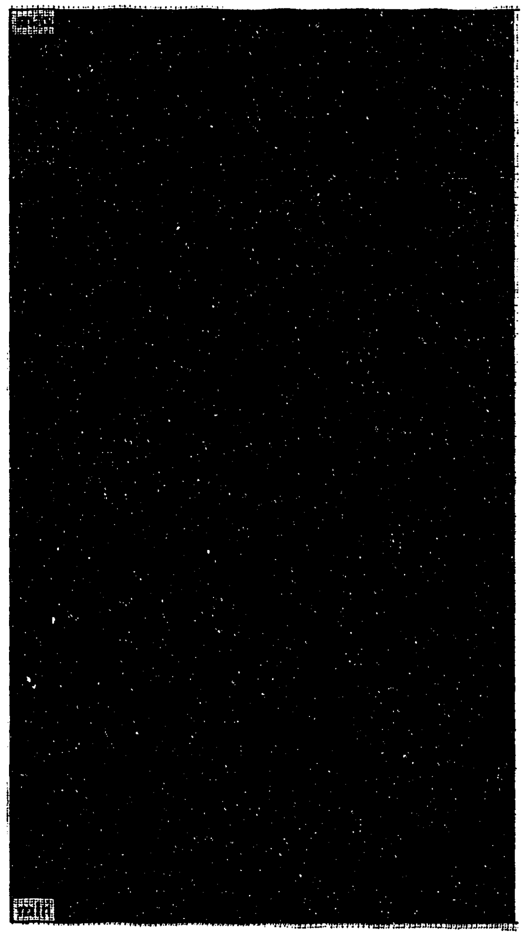


Figure 6.5. Pseudo-Color Image of the A-scans Collected at the 256 Scanner Positions of the Calibration Target

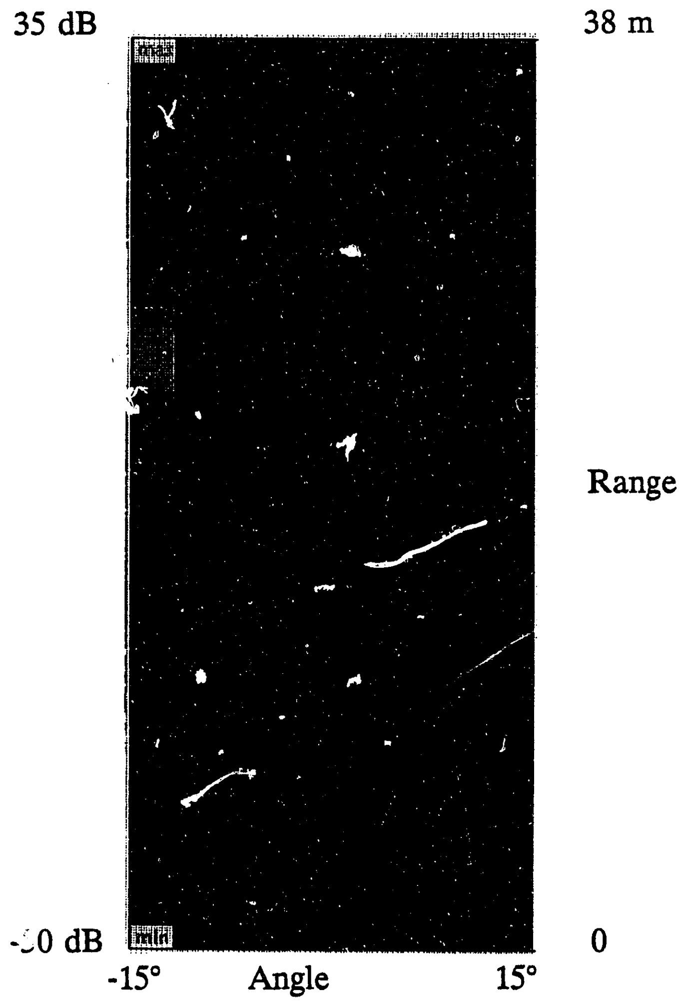


Figure 6.6. **Pseudo-Color SAR Image of Calibration Target Area Calibrated to Clutter Coefficient**

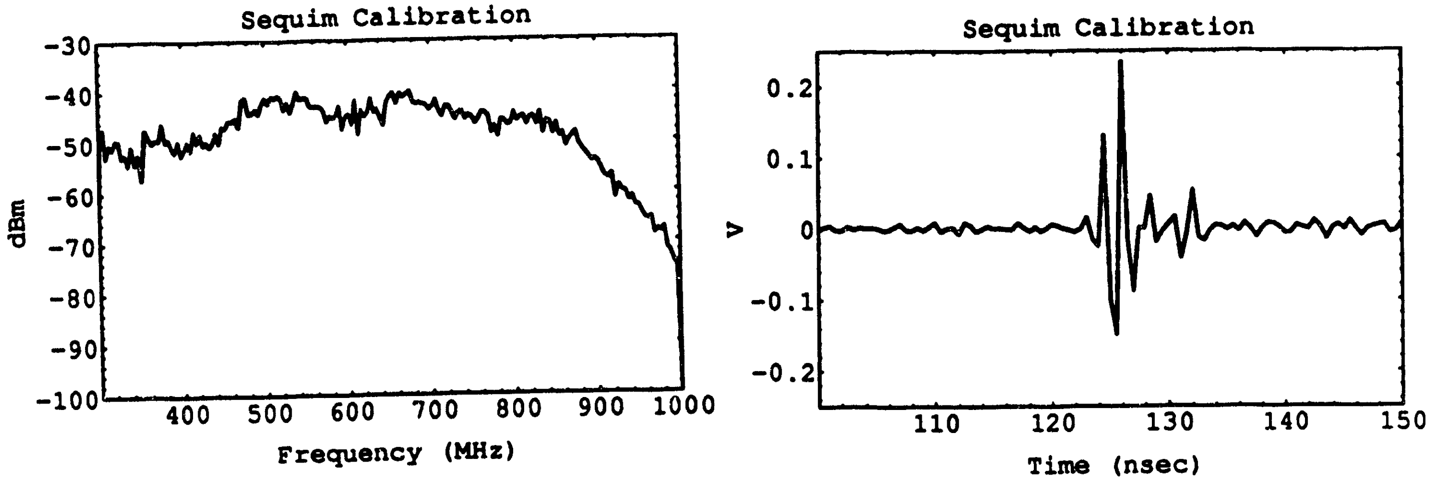


Figure 6.7. Voltage Waveform/Spectrum for Calibration Target

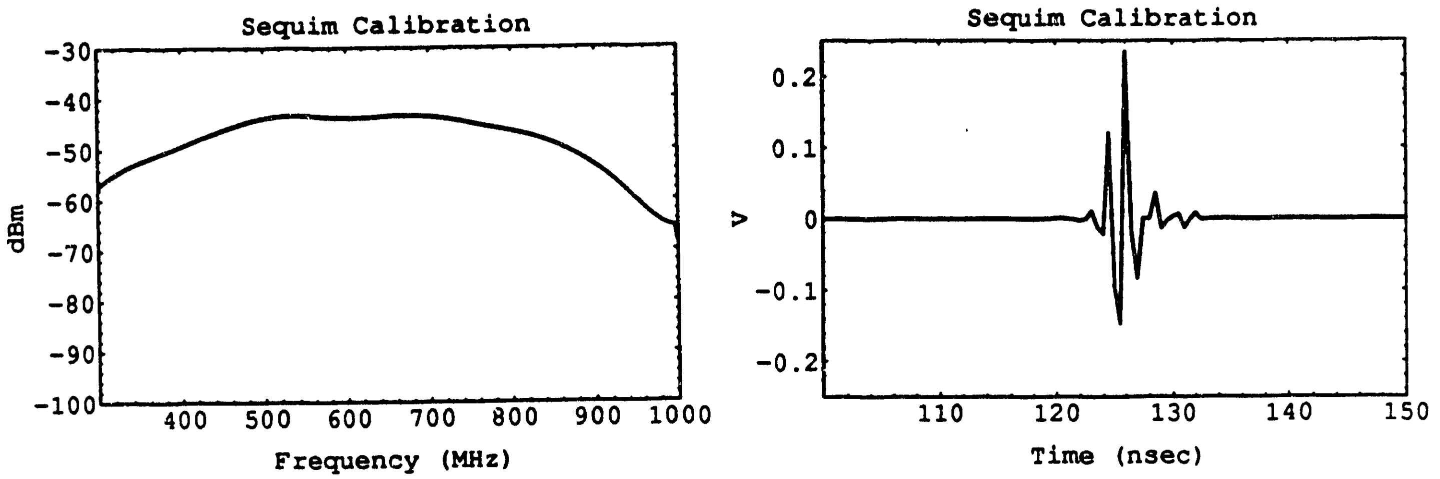


Figure 6.8. Windowed Voltage Waveform/Spectrum for Calibration Target

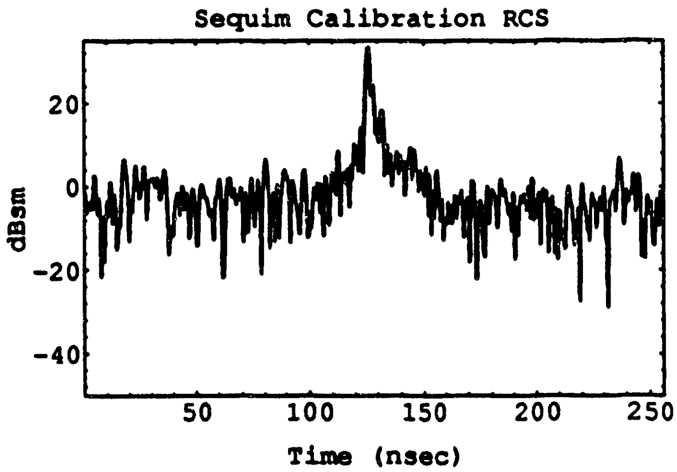


Figure 6.9. RCS Versus Range for the Calibration Target

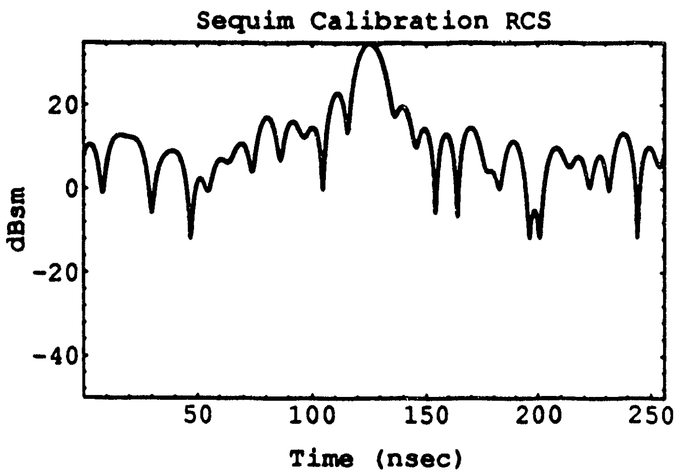


Figure 6.10. Reduced Resolution (100 MHz bandwidth) RCS Versus Range for the Calibration Target

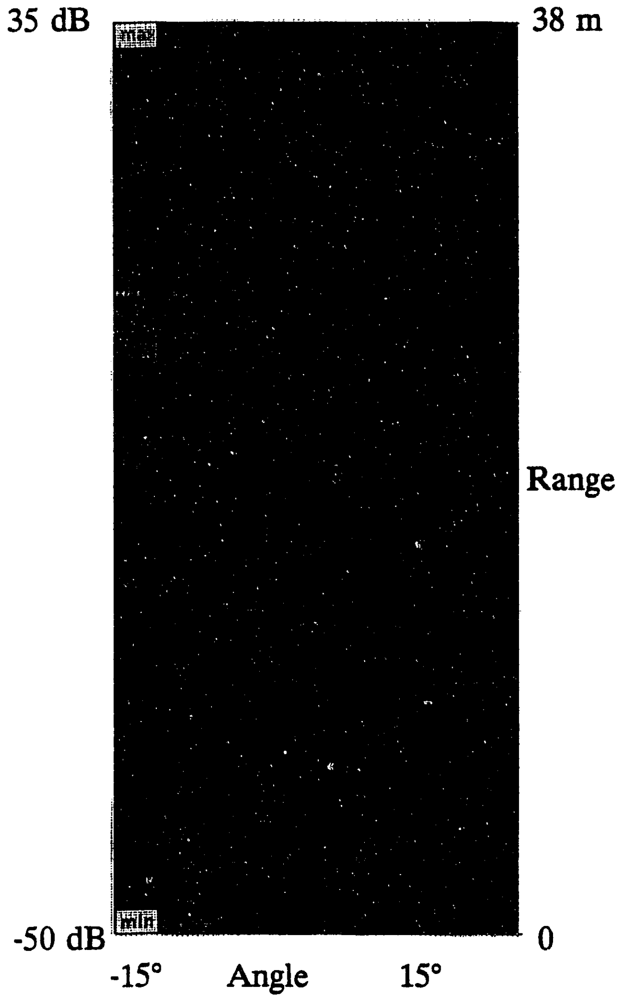


Figure 6.11. Pseudo-Color Calibrated SAR Image of a Relatively Low Clutter Region

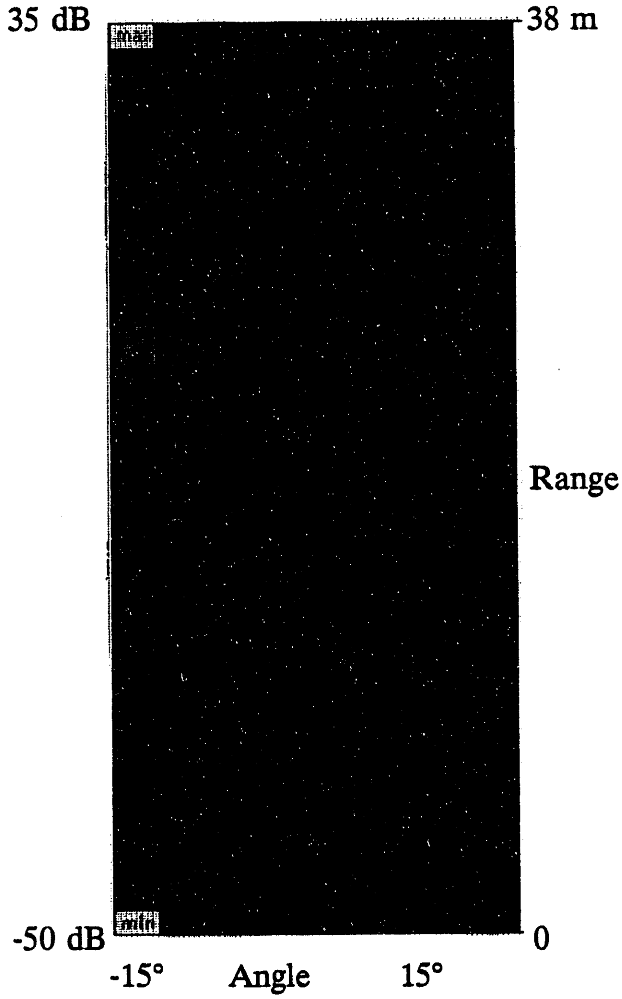


Figure 6.12. Pseudo-Color Calibrated SAR Image of a Relatively Typical Clutter Region

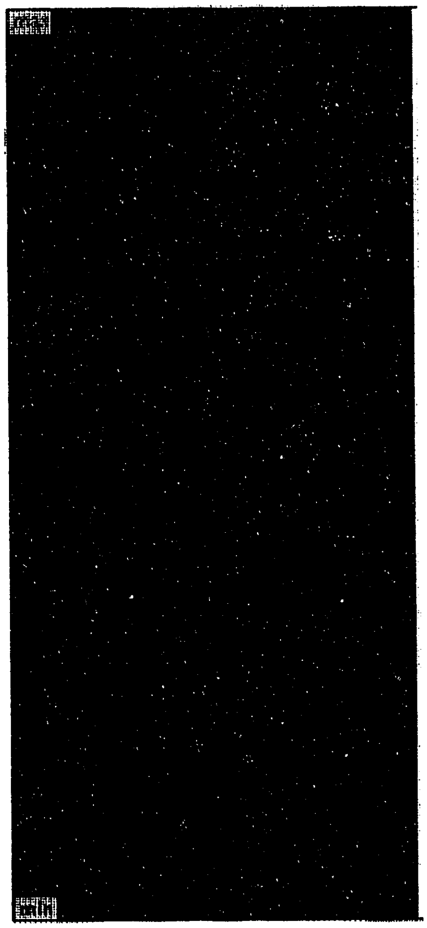


Figure 6.13. Pseudo-Color Calibrated SAR Image of a Relatively High Clutter Region

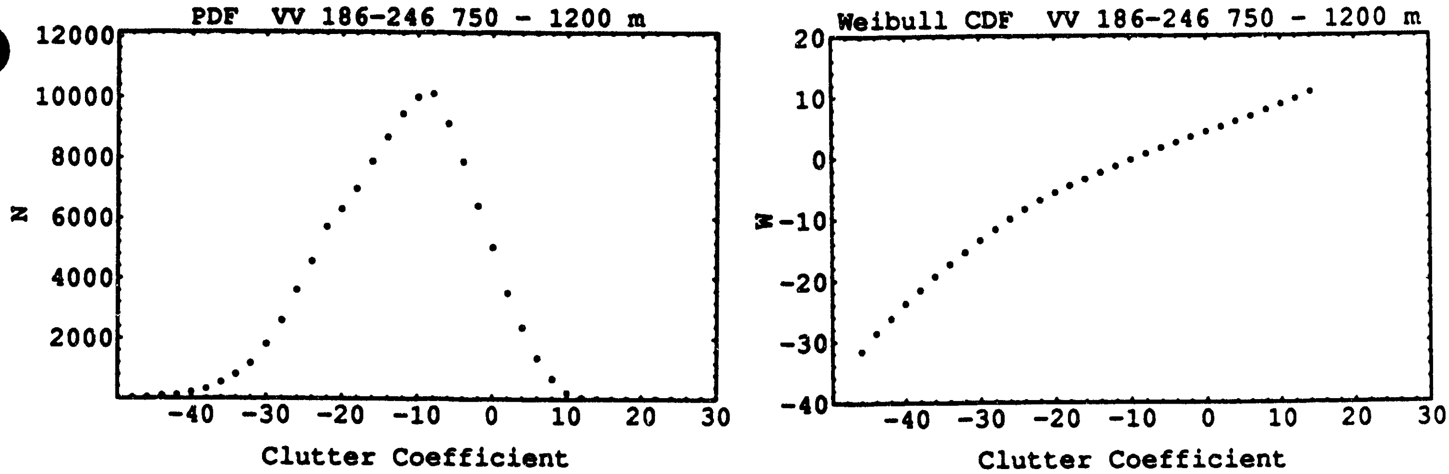


Figure 6.14. Distributions of VV Polarization Clutter Data Taken in Three Lines of Sight: 186°, 216°, and 246°

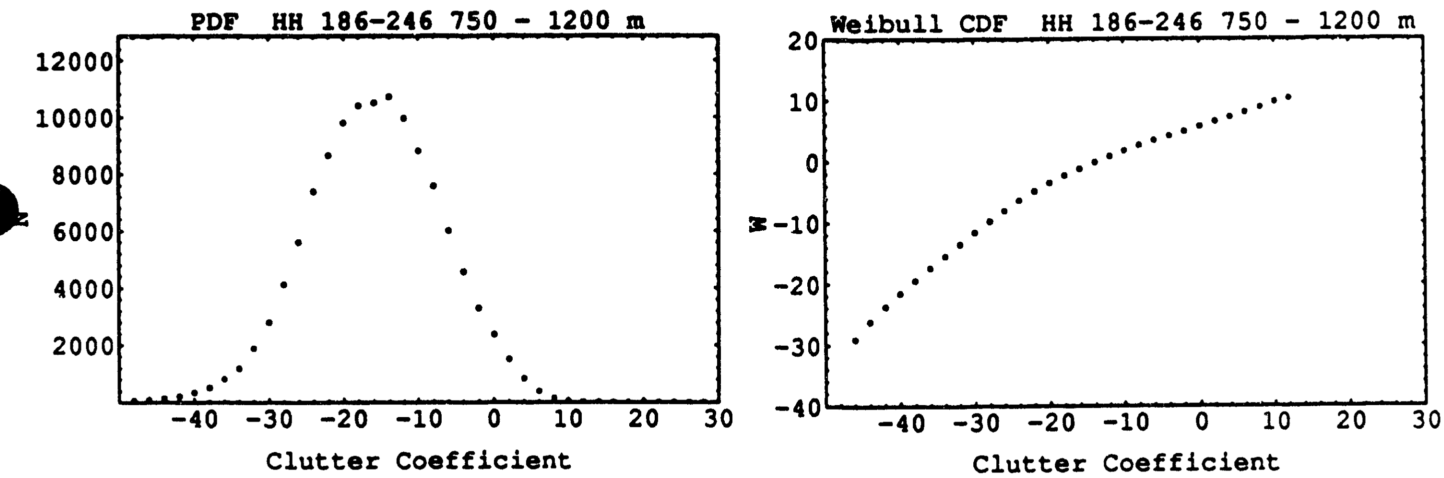


Figure 6.15. Distributions of HH Polarization Clutter Data Taken in Three Lines of Sight: 186°, 216°, and 246°

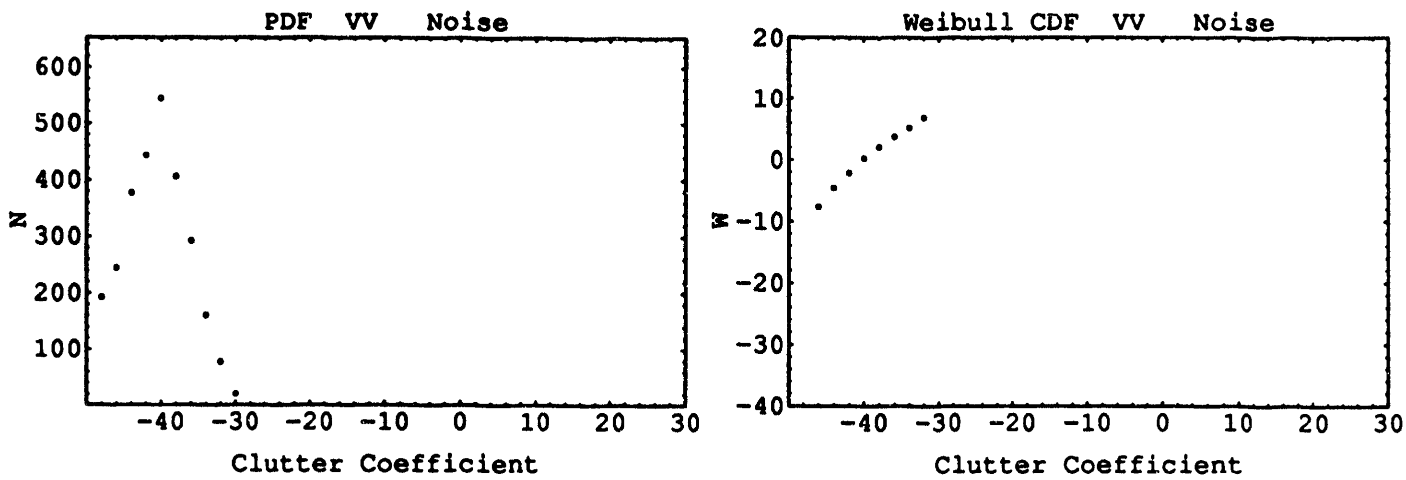


Figure 6.16. Distributions of Noise Equivalent Clutter Data

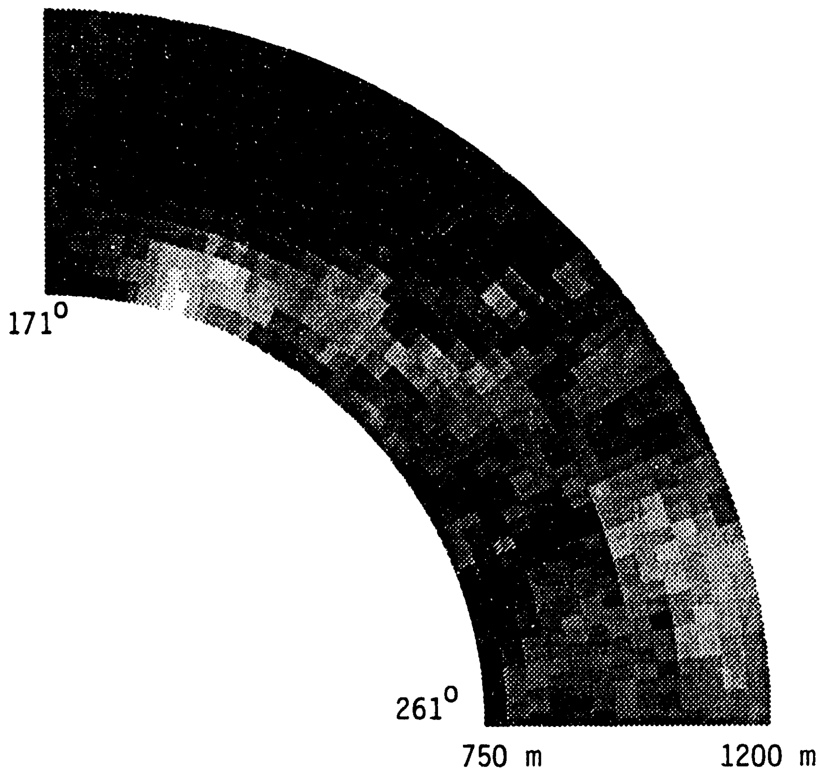


Figure 6.17. Composite Clutter Map of the VV Data

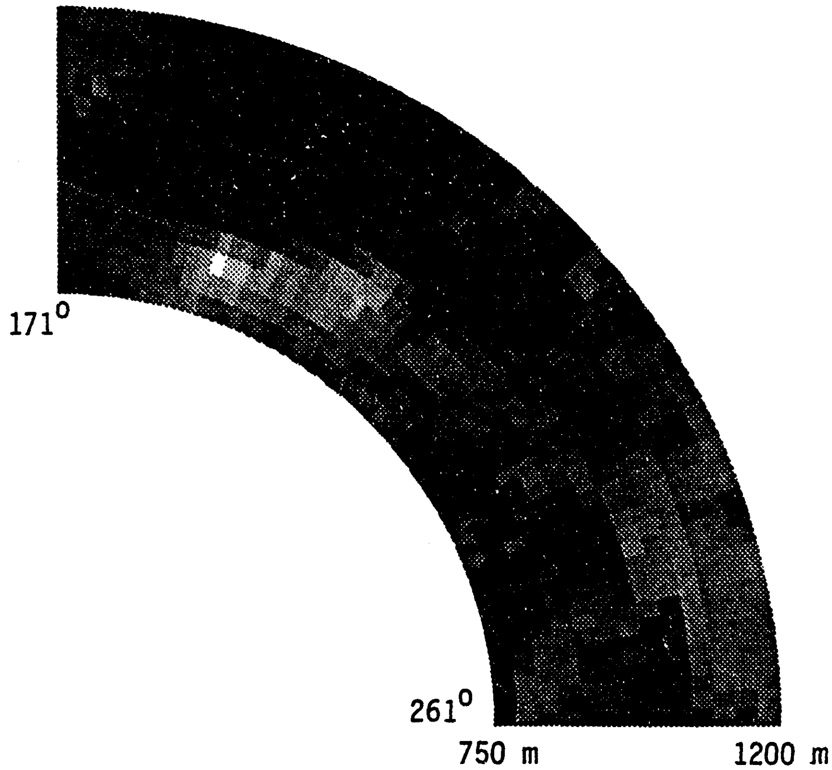


Figure 6.18. Composite Clutter Map of the HH Data

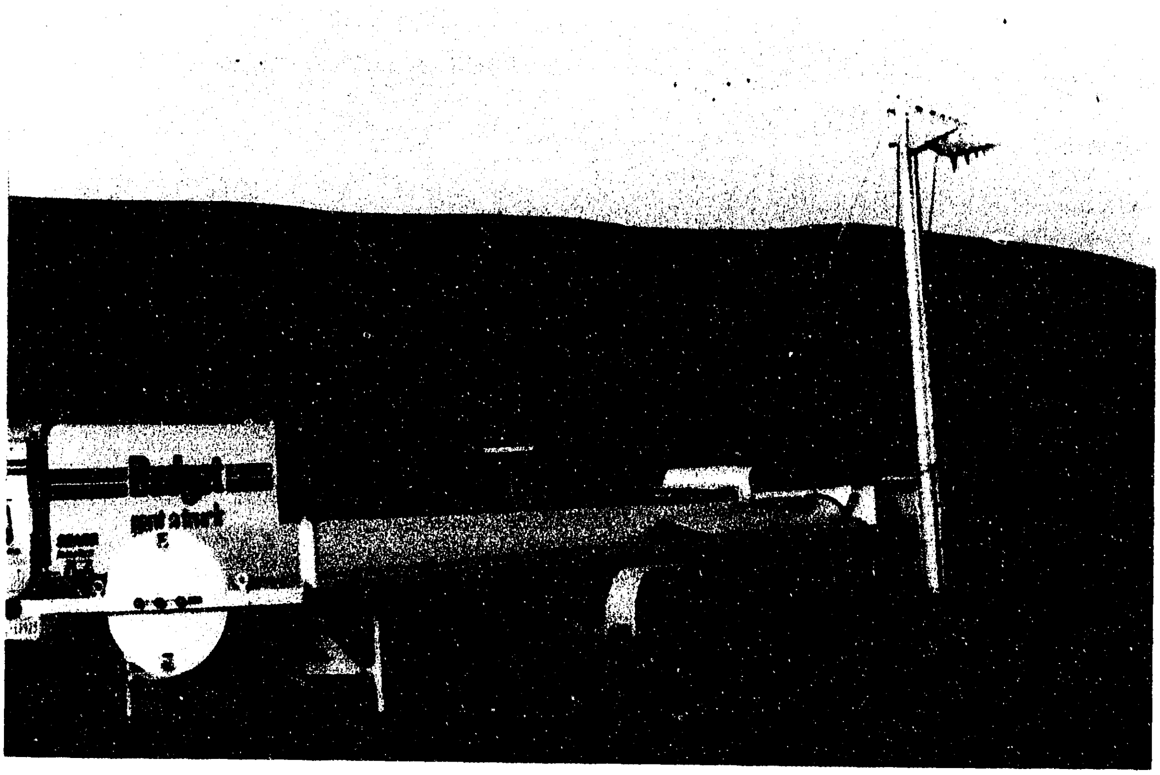


Figure 6.19. Operations and Terrain at Badger Canyon Site

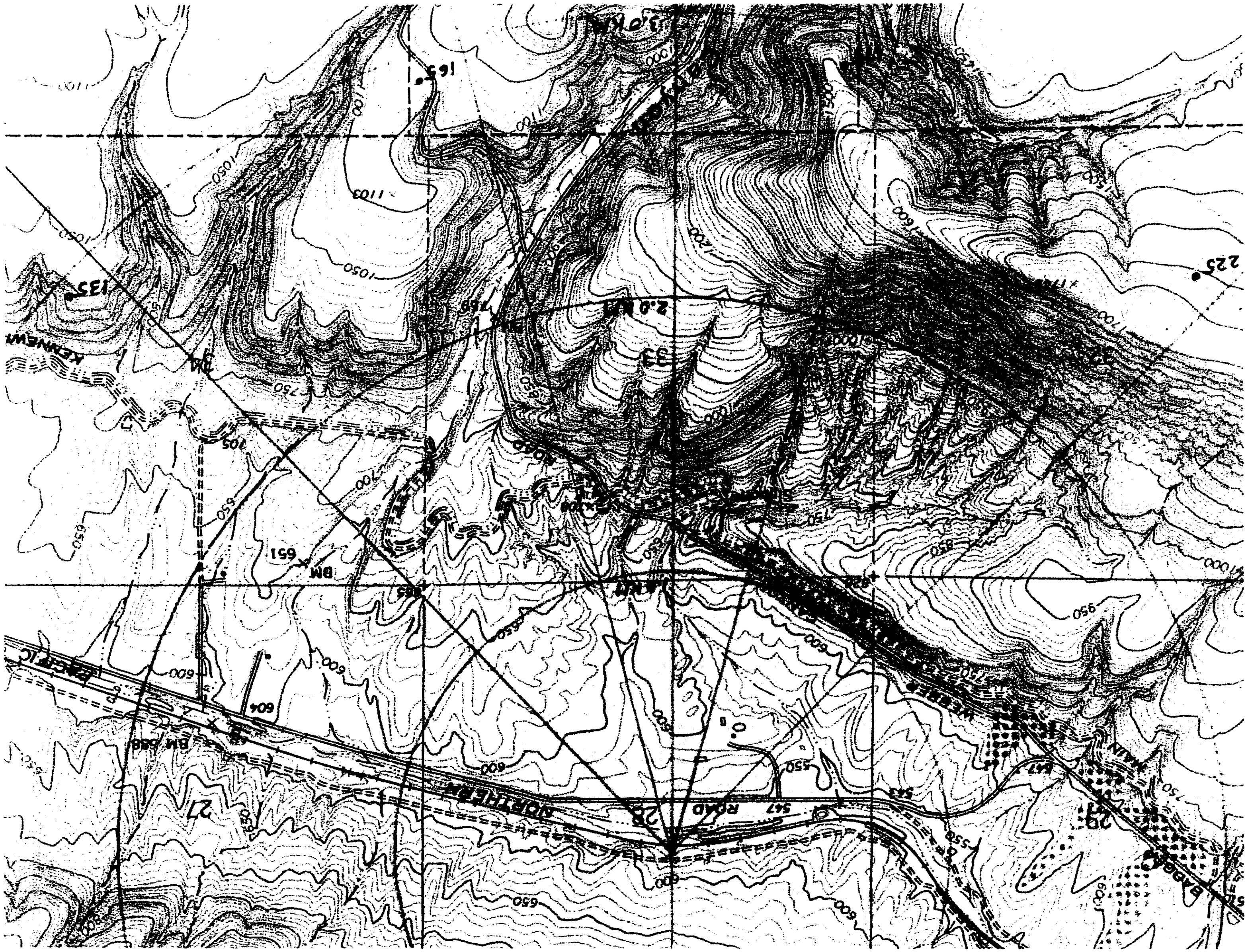


Figure 6.20. Topographic Map of Badger Canyon Site

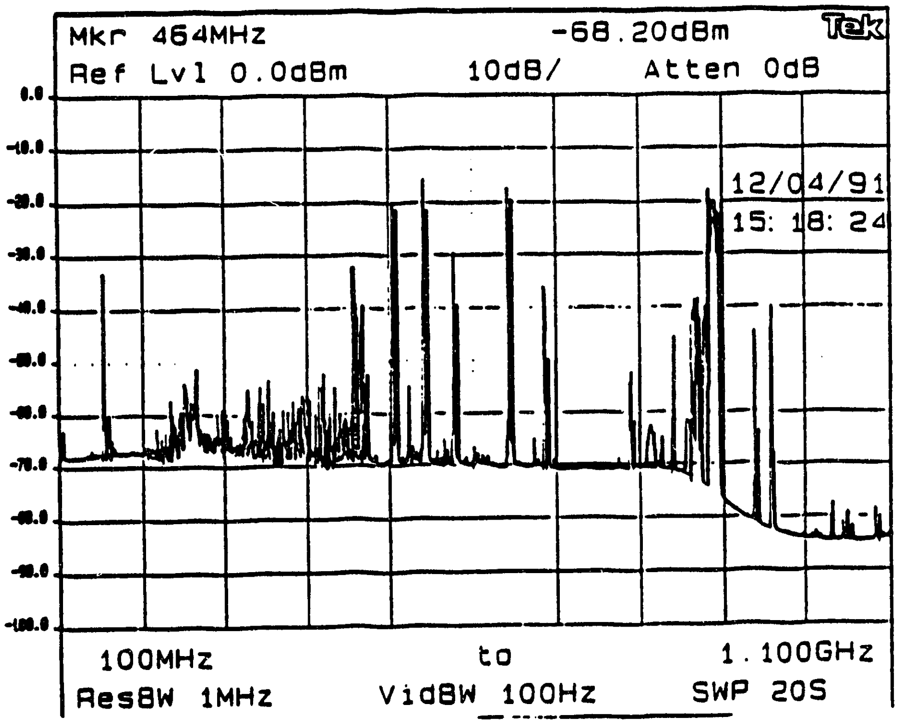


Figure 6.21. Received RFI Spectrum at Badger Canyon

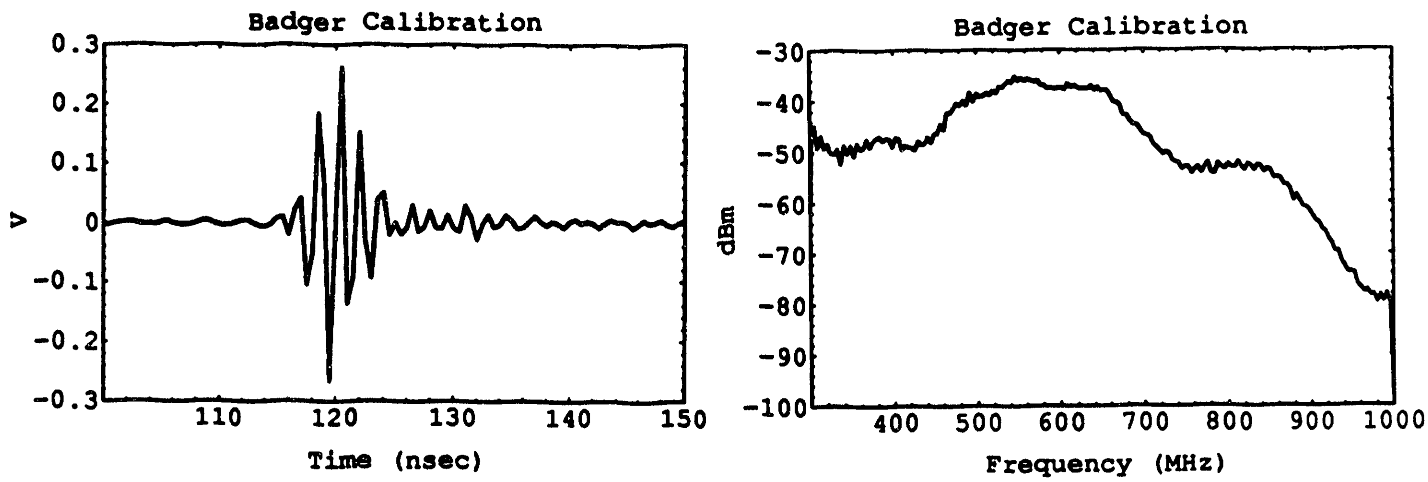


Figure 6.22. Voltage Waveform/Spectrum for Badger Calibration Target

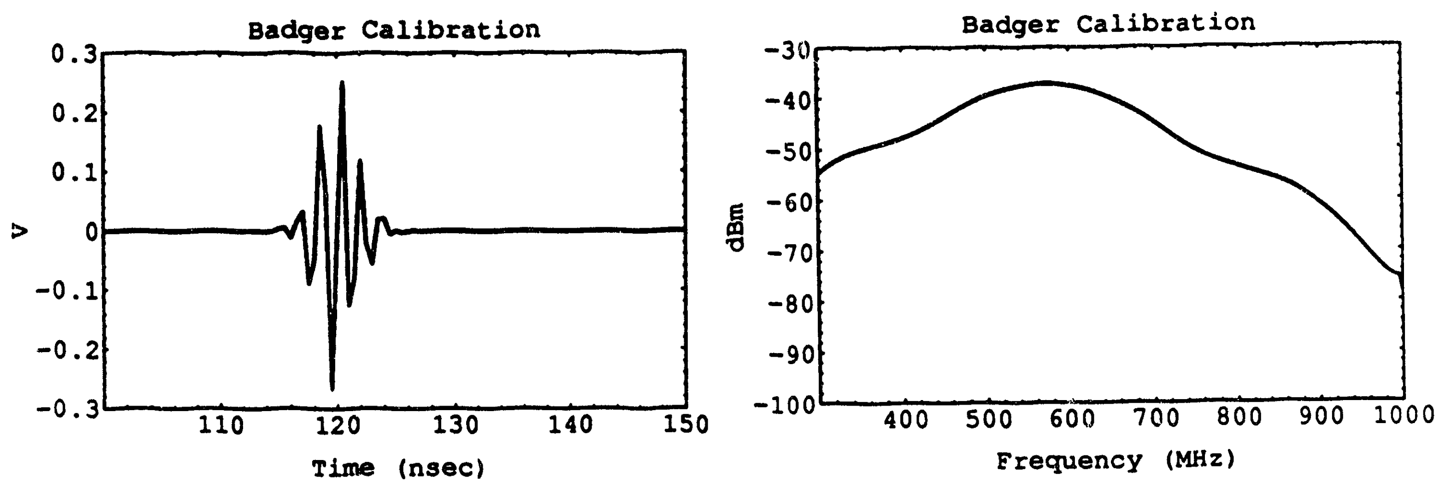


Figure 6.23. Windowed Voltage Waveform/Spectrum for Badger Calibration Target

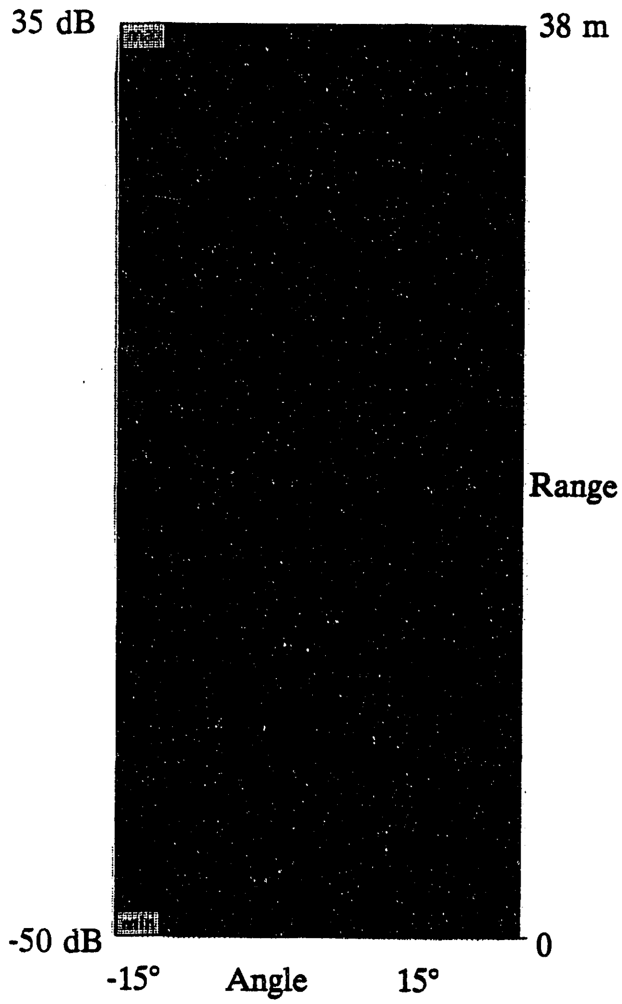


Figure 6.24. Pseudo-Color Calibrated SAR Image of Badger Calibration Target Area

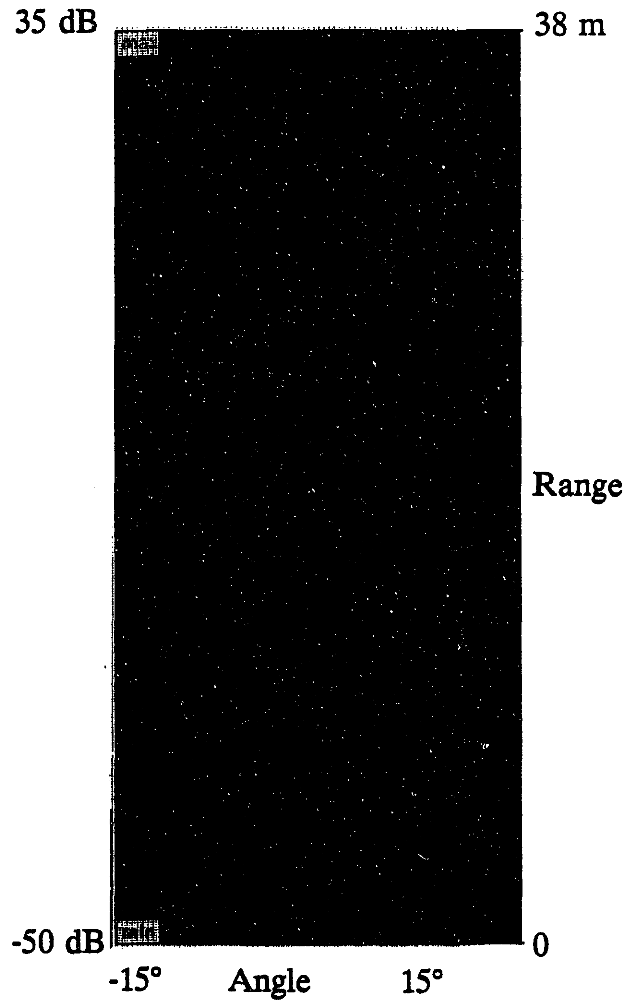


Figure 6.25. Pseudo-Color Calibrated SAR Image of Badger Clutter Region Showing Essentially Noise (RFI)

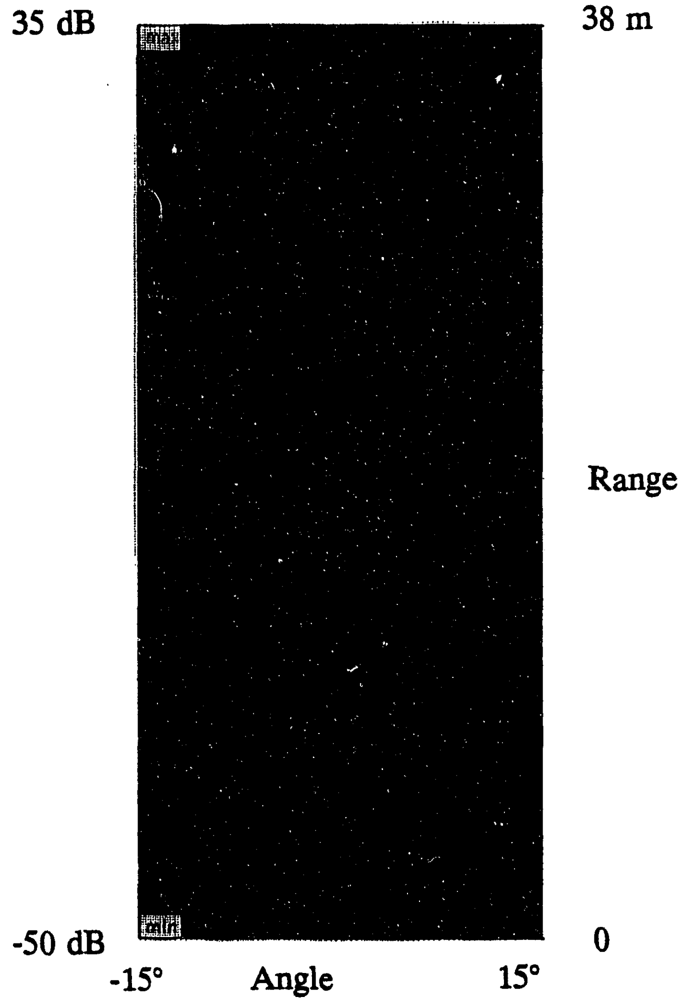


Figure 6.26. Pseudo-Color Calibrated SAR Image of Badger Clutter Region Showing Discrete Scatterers over a Noise (RFI) Dominated Background

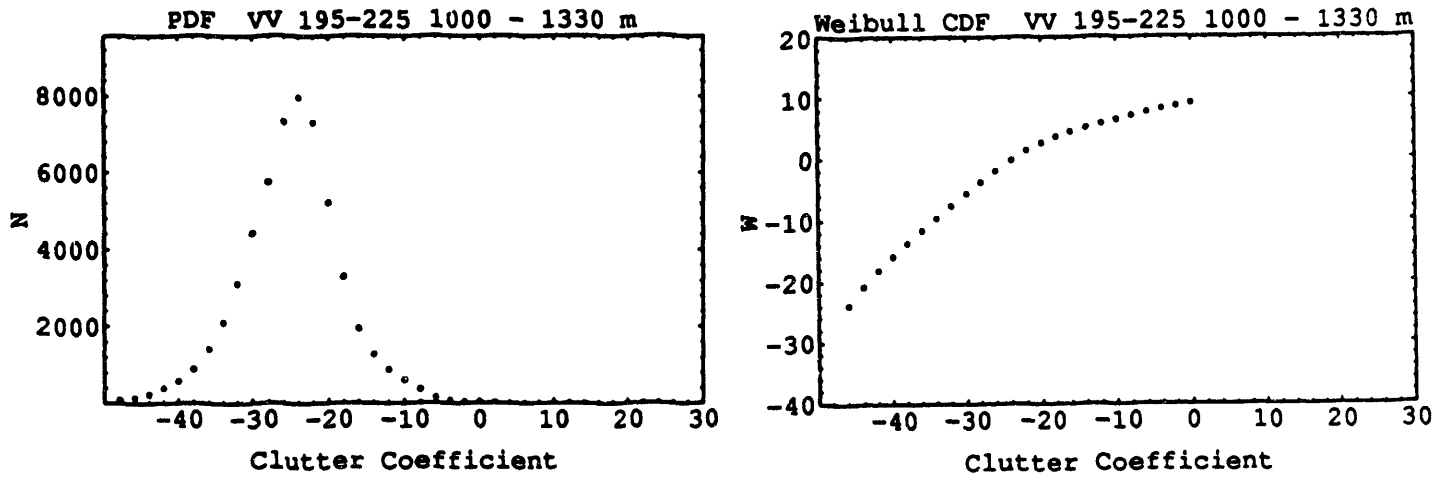


Figure 6.27. Distributions of the RFI Dominated Clutter Coefficient Measured at Badger Canyon

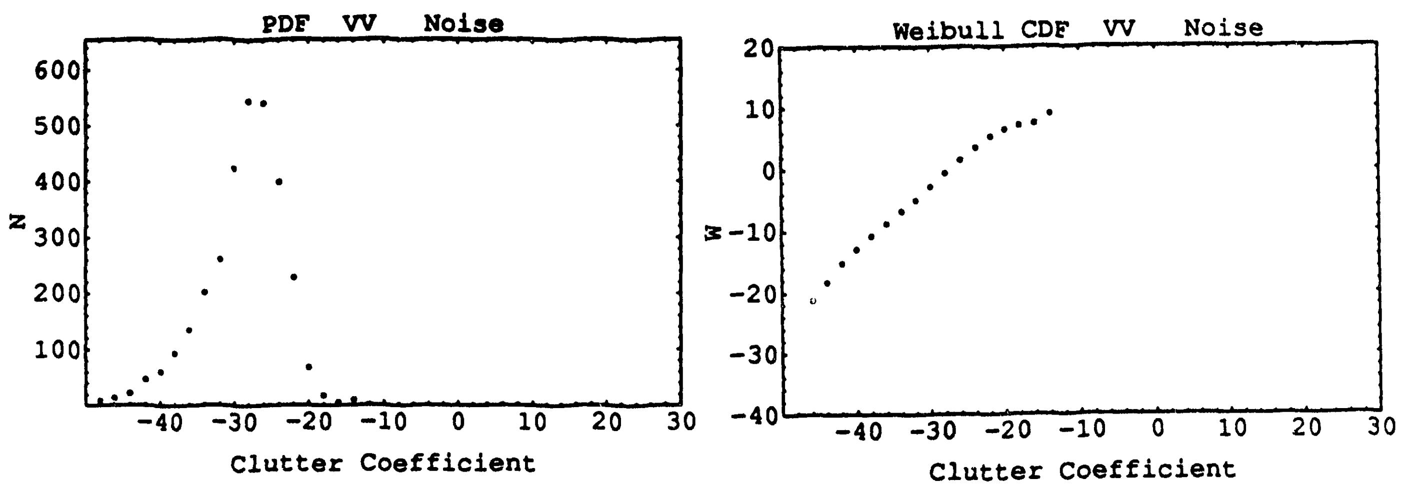


Figure 6.28. Distributions of the Noise Equivalent Clutter Coefficient Measured at Badger Canyon

7.0 1992 Impulse Forest Measurements

Forest clutter measurements were also taken using the impulse radar system at an additional site near Sequim, WA. This site is referred to as the Maynard Site and is described in more detail in Section 5.3. This site is located approximately 2.2 km southwest of Bear Mountain in the Olympic National Forest near Sequim, WA. Figure 7.1 is a panoramic collage of photographs looking outward from the scanner position. Figure 7.2 is a photograph of the scanner and radar set-up at the Maynard Site. Figure 7.3 shows a topographic map of the area surrounding the site. Figure 7.4 is an aerial photograph of the site and surrounding terrain.

7.1 Calibration and Verification

To ensure that the radar system was operating as expected, a radar equation closure experiment was conducted at PNL prior to the 1992 measurements. A typical impulse waveform from the DSA 602A digitizer was captured to disk and its Fourier spectrum was computed as shown in Figure 7.5. A small (3' by 4' flat plate) calibration target was then placed 3 meters above the ground at a range of 35 meters from the scanner. The received waveform was then digitized and stored as shown in Figure 7.6. The transient waveform in this figure was then time gated to reduce multipath using a raised cosine window with full width of 7.2 nsec. The gated waveform and its spectrum are shown in Figure 7.7. Closure with the radar equation is shown in Table 7.1 at 400, 600, and 800 MHz. Note that closure is reasonable given that the multipath signal cannot be completely removed by time gating. The area of the 3' by 4' flat plate target is 1.115 m^2. The gain of the antennas is assumed to be 10 (10 dBi). The range to the target is 35 meters. Note that the assumed gain of the antennas may be as low as 8 dBi which would improve the closure error.

Table 7.1. Radar Equation Closures (3' by 4' Target at 35 Meters)

	400 MHz	600 MHz	800 MHz
P_r/P_t (dB) calc	-62.8 dB	-62.8 dB	-62.8 dB
P_r (dBm) meas	-20	-15	-23
P_t (dBm)	41	39	37

	400 MHz	600 MHz	800 MHz
Net Receiver Gain (dB)	Recvr 53.3 Cable -5.6 Attn -40 Net 7.7	Recvr 54 Cable -6.9 Attn -40 Net 7.1	Recvr 54.4 Cable -8.3 Attn -40 Net 6.1
P_r/P_t (dB) meas	-68.7	-61.1	-66.1
Closure Error (dB)	5.9	1.7	3.3

At the Maynard site a simpler means of checking for closure with the radar equation was desired. Experience has shown that calculations using the peak transient amplitude yield reasonable results. For this calculation the center frequency (650 MHz) is assumed in the radar equation. The first calibration measurement was conducted with the large target placed at a range of 940 meters with the small target placed approximately 30 meters to the right at a range of approximately 928 meters. The HVTP pulser generates a peak amplitude of approximately 2000 V at the output of 35 feet of coaxial cable used to connect the pulser to the transmit antenna. This corresponds to a peak transmitted power of approximately 80 kW. The RCS of the 6' by 12' flat plate calibration target is 34.2 dBsm (2654 m^2) at 650 MHz. The gain of the antennas is approximated at 10 dB (10). The wavelength is 0.461 meters at the center frequency. The expected power at the receive antenna output is

$$P_r = P_t \frac{G^2\lambda^2\sigma}{(4\pi)^3 R^4} = 800 \frac{(10)^2(0.461)^2(2654)}{(4\pi)^3(940)^4} = 2.9 \times 10^{-6} W$$

The gain of the receiver is 54 dB and cables losses are 8 dB. Thus, the power at the input of the digitizer is 2.9 μW times 39800 which equals 0.115 W. This represents a peak voltage of 2.4 volts. The peak voltage observed from the 6' by 12' target at 940 meters is approximately 1.25 volts. This represents a difference of approximately 5.6 dB between the expected voltage and the measured voltage. This level of difference is expected since the pulse spectrum is much more broad than the radar systems 300-850 MHz bandwidth. If the pulse were filtered its peak amplitude would decrease accordingly. Additionally, the gain of the antennas is not precisely known. The assumed gain of 10 dBi might in fact be as low as 8 dBi, which would cause the agreement to improve by 4 dB. This radar equation closure test is not highly accurate, however, it is very useful for immediate determination of proper operation of the radar system. Operational errors such as peaking on a sidelobe of the calibration target or a failure of a receiver component would be readily determined using this type of analysis.

At the Maynard Site, two calibration target positions were chosen. Both of these positions were at approximately the same elevation as the radar system and had a valley in between. The valley floor was roughly centered between the radar and the target positions. The height of the radar and target positions above the floor was approximately 100 meters. This height difference roughly corresponds to a one-way time delay on the order of 67 nsec at a range of 1 km. Furthermore, the valley floor was largely covered with foliage and in no way represented an ideal ground plane for multipath signals. Given these considerations, multipath was not expected to be a problem at either calibration position.

The validity of the calibration procedure is highly dependent on the propagation characteristics between the radar and the target. A free space model is assumed in the calibration. At real sites, this will never be strictly correct. Multipath is the dominant issue concerning calibration accuracy. Due to the very short transmitted pulse and high range resolution of the system, most multipath signals can be time gated from the calibration waveform prior to calibration.

An image of the raw A-scan data gathered from the calibration target is shown in Figure 7.8. Each vertical line in the image represents the average of 100 waveforms taken at each scanner position. The horizontal aperture is 19 meters, and the vertical scale represents 512 waveform samples for 256 nsec or 38 meters of range.

The calibration process described in Section 4.5 is shown graphically in Figures 7.9 to 7.11. The focused waveform and is spectrum at the angle of the calibration target peak are shown in Figure 7.9. This waveform is time gated and calibrated to RCS and is shown in Figure 7.10. A full calibrated range-angle image of the target and its surrounding clutter is shown in Figure 7.11.

Thorough measurements were taken to ensure that the free-space calibration model was accurate at both calibration positions. Two calibration targets were deployed at each position. A 6' by 12' flat plate target was used as the main target. A 3' by 4' target was deployed simultaneously with the larger target. The small target was positioned approximately 10-15 meters closer to the radar and off to the right approximately 20-40 meters. A photograph of the target placement along the 28° line of sight at a range of approximately 1000 meters is shown in Figure 7.12. This placement ensured that the small target response could be isolated from the large target response and yet would be present in the same calibration image. The large target has an expected RCS of 34.2 dBsm. The small target has an expected RCS of 18.6 dBsm. Examination of four different calibration scans of the two targets at both positions (28° and 70°), and conversion from clutter coefficient to RCS yields a table of RCS measurements of known targets. This data is shown in Table 7.2 and is in agreement with the expected RCS values to within approximately 2 dB. The 6' by 12' target response in the "cal_e" file was used to calibrate the other measurements and is therefore not an independent measurement. The consistency of RCS measurements using two different targets at two different positions demonstrates that multipath effects are not present significantly in the calibration data.

Table 7.2. RCS Measurements of Known Targets

File	Pol	Angle	Range, m	Target	σ^o, dB	Area, m^2	σ_{meas}, dBsm	σ_{calc}, dBsm	Diff, dB
cal_d	VV	70°	940	6x12	24.8	6.64	33.0	34.2	1.2
cal_d	VV	70°	928	3x4	9.1	6.56	17.3	18.6	1.3
cal_e	HH	70°	940	6x12	24.6	6.64	32.8	34.2	1.4
cal_e	HH	70°	928	3x4	9.2	6.56	17.4	18.6	1.2
cal2_b	VV	28°	1277	6x12	23.9	9.03	33.5	34.2	0.7
cal2_b	VV	28°	1266	3x4	7.7	8.95	17.2	18.6	1.4
cal2_c	HH	28°	1277	6x12	23.7	9.03	33.3	34.2	0.9
cal2_c	HH	28°	1266	3x4	7.9	8.95	17.4	18.6	1.2

7.2 Clutter Measurements

Improvements to the radar system since the 1991 measurements have resulted in greatly increased data collection rates. Longer record lengths (8192 samples) have reduced the number of scans necessary to cover the illuminated area. Higher pulser power levels increased the effective range of the system. Internal averaging in the DSA602 also increased the data collection rate by removing the data transfer bottleneck.

Measurable terrain at the Maynard Site consists of an angular swath of 180° and a range swath up to 4 kilometers. This area was subdivided into six 30° sectors and five 600 meter range sections. Each range swath consists of 8192 sample points for 4096 nsec or 604.8 meters. The nearest range is approximately 0.3 km and the furthest range is approximately 3.3 km.

Vertical and horizontal polarization data were taken at each sector and range for a total of 60 clutter data scans. Additional calibration and noise measurement scans were also taken. Table 7.3 shows the filenames of each set of data taken and the sector and starting ranges covered. Each scan covers an angular swath of 30° and a range swath of 604.8 m.

Table 7.3. Sectors and Ranges Covered (30° by 604.8 m per scan)

Filename	Sector 1 Angle: 100°	Sector 2 Angle: 70°	Sector 3 Angle: 40°	Sector 4 Angle: 10°	Sector 5 Angle: 340°	Sector 6 Angle: 310°
Range 1 300 m	s1_r1	s2_r1	s3_r1	s4_r1	s5_r1	s6_r1
Range 2 904.8 m	s1_r2	s2_r2	s3_r2	s4_r2	s5_r2	s6_r2
Range 3 1509.6 m	s1_r3	s2_r3	s3_r3	s4_r3	s5_r3	s6_r3
Range 4 2114.4 m	s1_r4	s2_r4	s3_r4	s4_r4	s5_r4	s6_r4
Range 5 2719.2 m	s1_r5	s2_r5	s3_r5	s4_r5	s5_r5	s6_r5

7.3 Clutter Imaging Samples

Clutter range-angle images as shown in Figure 7.12 are not easily viewed for the full 8K record length clutter data files since the number of angles is relatively small (200) and the number of samples is high (8192). For examination on the computer screen, scrolling is used to allow examination of the data set at full resolution. For correlation of the data to the landscape or for a simple overview image of the clutter data, the range resolution must be effectively reduced. Furthermore a two-dimensional image in meters by meters (x-y image) is more useful that the range-angle images for this purpose. A data reduction/interpolation computer program was developed that reduces that data by computing the mean over typically 64 sample points, and interpolates the range-angle data onto a regular x-y image grid. Typical images including the calibration target from sector 2 range 2 are shown in Figures 7.13 and 7.14. Additional clutter images from sector 3 range 2 are shown in Figures 7.15 and 7.16.

7.4 Noise (RFI) Measurements

Noise measurements were taken at both calibration target positions by turning off the transmitter and gathering full scans. This data is then processed as though it were clutter data at a range of 1 km. The result of this processing is referred to as the "noise equivalent clutter coefficient." Typical statistical results are shown in Tables 7.4 and 7.5. Distributions are shown in Figures 7.17 and 7.18.

Table 7.4. Noise Equivalent Clutter Coefficient Statistics at 1 km for 300-800 MHz Processing Bandwidth and 70° Orientation

Polarization	VV	HH
Frequency Band	300-800 MHz	300-800 MHz
Aperture Window	Rectangular	Rectangular
Range	1000 m	1000 m
Number of Waveforms	25,600	25,600
Number of Cells	2208	2208
Mean σ^0	-50.8 dB	-48.7 dB
Median σ^0	-52.3 dB	-50.3 dB
Max σ^0	-41.4 dB	-40.0 dB

Table 7.5. Noise Equivalent Clutter Coefficient Statistics at 1 km for 300-800 MHz Processing Bandwidth and 28° Orientation

Polarization	VV	HH
Frequency Band	300-800 MHz	300-800 MHz
Aperture Window	Rectangular	Rectangular
Range	1000 m	1000 m
Number of Waveforms	25,600	25,600
Number of Cells	2208	2208
Mean σ^0	-47.7 dB	-42.5 dB
Median σ^0	-49.2 dB	-44.2 dB
Max σ^0	-39.2 dB	-33.5 dB

Composite images clutter data were formed using all 60 data scans (6 angular swaths * 5 range swaths 2 polarizations). These images appeared somewhat different than similar images formed soon after returning from Sequim, especially the vertically polarized data. In particular sectors 4 and 5 appeared to have a significant noise floor increase. Earlier the data had been processed using a 300-850 MHz bandwidth, so it was suspected that RFI from cellular phones in the 800-900 MHz frequency range was responsible for the increased noise floor. Further evidence of this is that sectors 4 and 5 are pointing in the general direction of Port Angeles, WA and Victoria, B.C. Noise data taken from two directions and two polarizations further confirms this result. Table 7.6 gives the noise equivalent clutter means values for different processing bandwidths.

Table 7.6. Noise Equivalent Clutter Coefficient at 1 km for Different Processing Bandwidths

Frequency Band	Mean Noise σ^0 V pol (dB)	Mean Noise σ^0 H pol (dB)	Orientation
300-800 MHz	-50.8	-48.7	70°
300-900 MHz	-34.8	-42.2	70°
300-800 MHz	-47.7	-42.5	28°
300-900 MHz	-31.4	-38.3	28°

Note that the vertical polarization noise floor is increased by about 15 dB by including the 800-900 MHz frequency band. Given this higher noise floor, the 1992 measurements have been processed using a 300-800 MHz bandwidth, which results in a significantly higher clutter to noise ratio. The data has also been processed with 300-900 MHz and 300-1000 MHz frequency bands for compatibility with the earlier 1991 measurements.

7.5 Forest Clutter Analysis

Due to improvements in the data collection rate of the impulse radar system for the 1992 measurements, a significantly larger amount of forest clutter data was obtained. Five range gates were used to cover 300 meters to 3300 meters. Six 30° sectors were used to cover a 180° angular swath. Both horizontal and vertical polarizations were used over the entire region.

A composite imaging program was used to combine all of the data from each polarization into composite images. Images were formed for the entire data sets for each polarization and are shown in Figures 7.19 and 7.20. The range resolution in these images was compressed using the mean of the clutter values over 64 sample points. The angular resolution of the clutter data is relatively coarse and did not need to be reduced. The gray scale in the images is scaled to be black at the minimum mean clutter level and white at the maximum mean clutter level. In between the minimum and maximum, the clutter coefficient levels (in dB) are mapped linearly to gray levels.

These composite images are of much higher resolution than those presented in Figure 6.17 and 6.18, although the technique used to generate the images is very similar. Examination of the composite clutter images shows strong correlation with the topography in the aerial photos and topographic maps. In particular, roads, clear-cut/tree lines, mountain sides, and ridges are discernible in the images.

Examination of the composite clutter images also shows which of the data scans are well illuminated. In forming the statistical data set certain sectors/ranges should probably not be used. The sectors are numbered from 1 to 6 counterclockwise from the bottom right side of the image. Ranges are numbered from 1 to 5 from near to far. The data set used to compute the overall statistics is: Sector 1 ranges 1 to 5, Sector 2 ranges 1 to 4, Sector 3 ranges 1 to 3, Sector 4 ranges 1 to 4, and Sector 5 ranges 1 to 5. Sector 6 was not used since it was largely shadowed by a low ridge near the radar site.

The overall statistics of the 300-800 MHz vertically and horizontally polarized clutter data were computed and are given in Table 7.7 and the distributions are shown in Figures 7.21 and 7.22. In Table 7.7 the statistics were computed in accordance with the formulas given in Section 4.6. The Weibull spread was calculated by numerically fitting a line to the Weibull distribution plots over the clutter values from -20 dB to +14 dB.

Table 7.7. Summary of 300-800 MHz VV and HH Polarization Clutter Data Taken in 6 Lines of Sight: 100°, 70°, 40°, 10°, 340°, and 310°

Polarization	VV	HH
Frequency Band	300-800 MHz	300-800 MHz
Aperture Window	Rectangular	Rectangular
Angle Coverage	115° to 0° to 295°	115° to 0° to 295°
Bandwidth (constant)	1.35°	1.35°
Range Coverage	300 m - 3300 m	300 m - 3300 m
Range Resolution	0.3 m	0.3 m

Polarization	VV	HH
Number of Cells	973,728	973,728
Mean	-6.4 dB	-9.3 dB
Median	-18.4 dB	-19.1 dB
Mean/Median Ratio	12.0 dB	9.8 dB
Std Dev/Mean	6.1 dB	6.5 dB
Skewness	13.4 dB	18.6 dB
Kurtosis	33.7 dB	43.5 dB
Max	22.9 dB	23.0 dB
Weibull Spread	2.97	2.83

The overall statistics of the 300-1000 MHz vertically and horizontally polarized clutter data were computed and are given in Table 7.8, and the distributions are shown in Figure 7.23 and 7.24.

Table 7.8. Summary of 300-1000 MHz VV and HH Polarization Clutter Data Taken in 6 Lines of Sight: 100°, 70°, 40°, 10°, 340°, and 310°

Polarization	VV	HH
Frequency Band	300-1000 MHz	300-1000 MHz
Aperture Window	Rectangular	Rectangular
Angle Coverage	115° to 0° to 295°	115° to 0° to 295°
Bandwidth (constant)	1.35°	1.35°
Range Coverage	300 m - 3300 m	300 m - 3300 m
Range Resolution	0.214 m	0.214 m
Number of Cells	1,298,304	1,298,304
Mean	-6.5 dB	-8.9 dB
Median	-14.2 dB	-15.5 dB
Mean/Median Ratio	7.7 dB	6.6 dB

Polarization	VV	HH
Std Dev/Mean	5.7 dB	6.2 dB
Skewness	20.8 dB	23.2 dB
Kurtosis	47.7 dB	50.9 dB
Max	26.4 dB	25.3 dB
Weibull Spread	2.39	2.40

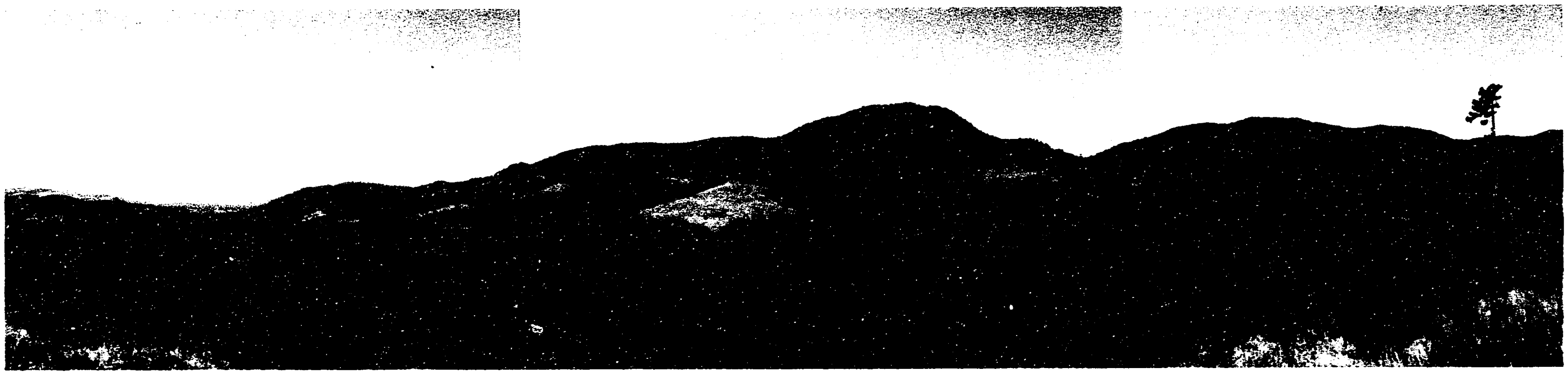


Figure 7.1. Panoramic Photograph Looking Outward from the Maynard Site

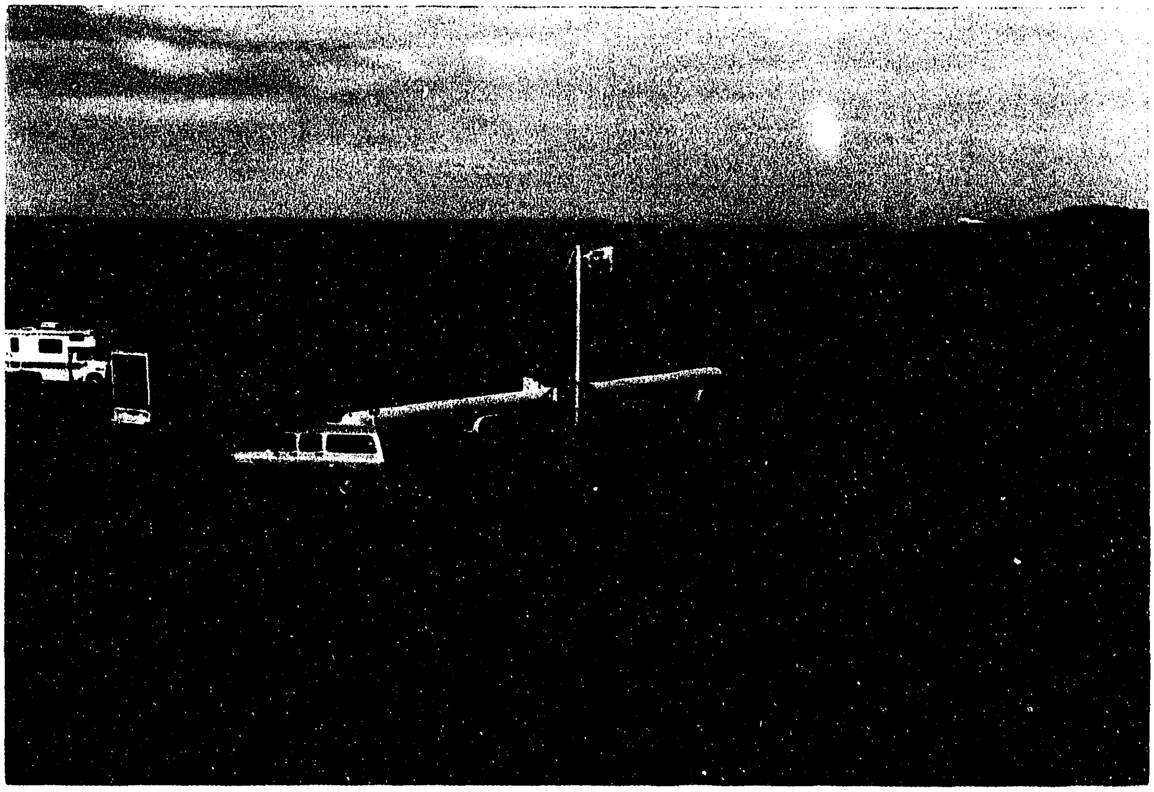


Figure 7.2. Photograph of the Scanner and Radar System at the Maynard Site

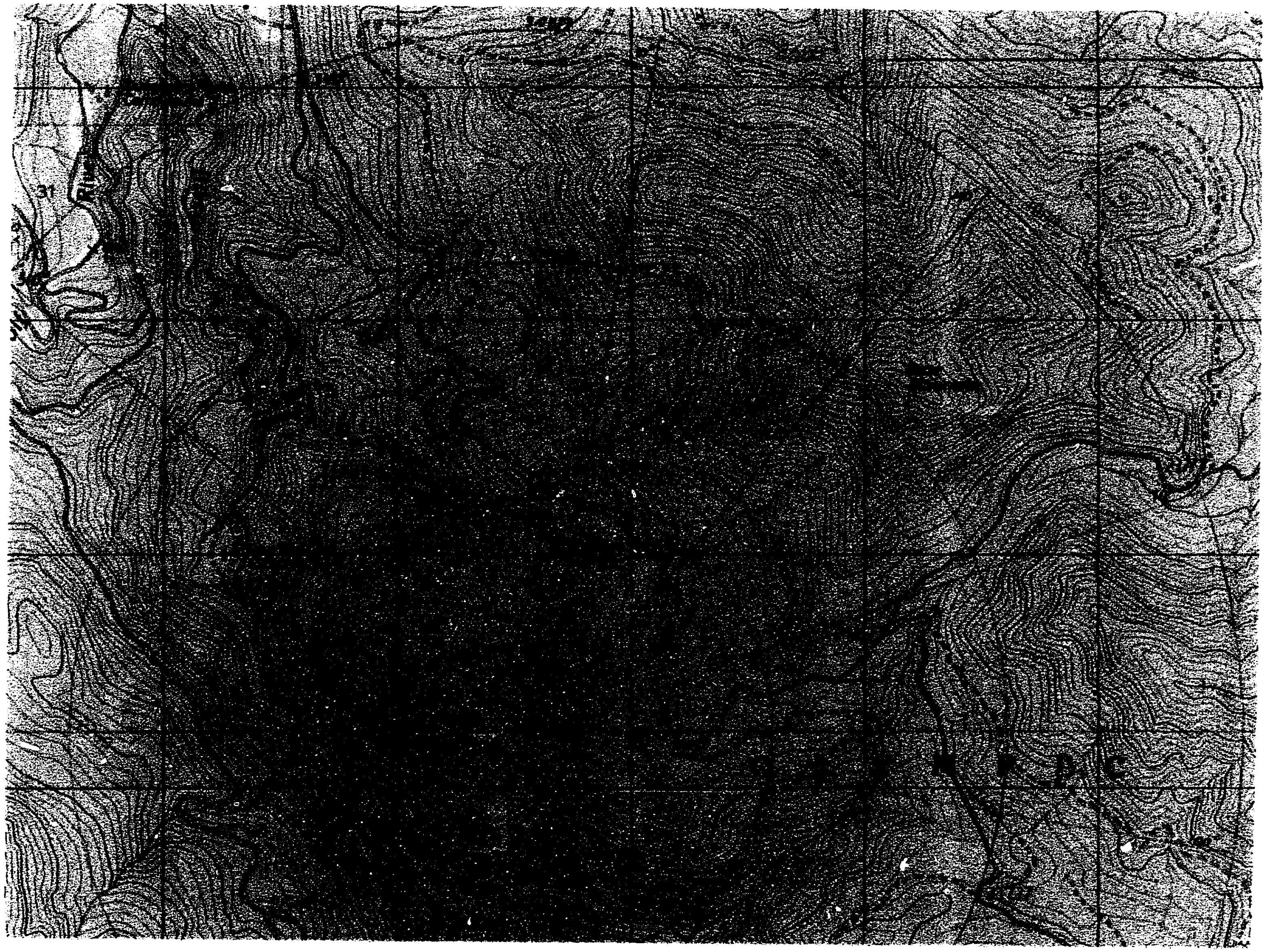


Figure 7.3. Topographic Map Showing the Maynard Site and Surrounding Terrain

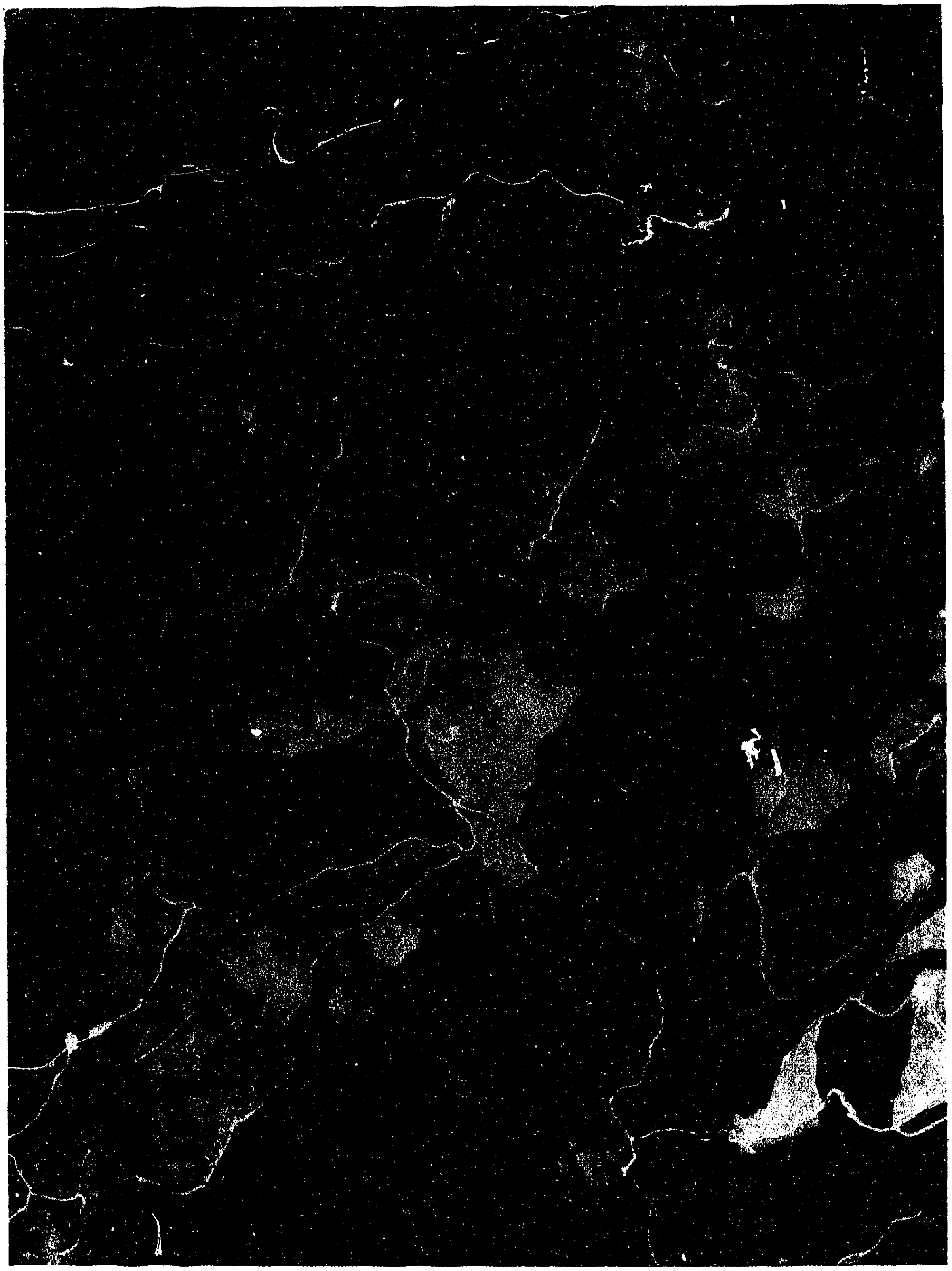


Figure 7.4. Aerial Photograph of the Maynard Site and Surrounding Terrain

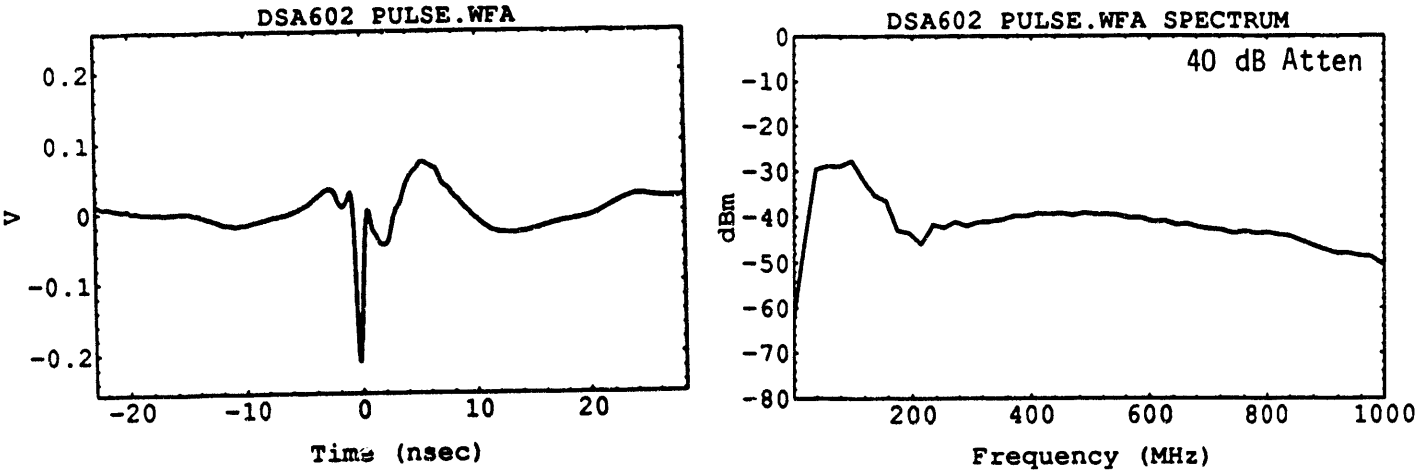


Figure 7.5. Pulser Output Waveform and Spectrum Attenuated by 40 dB

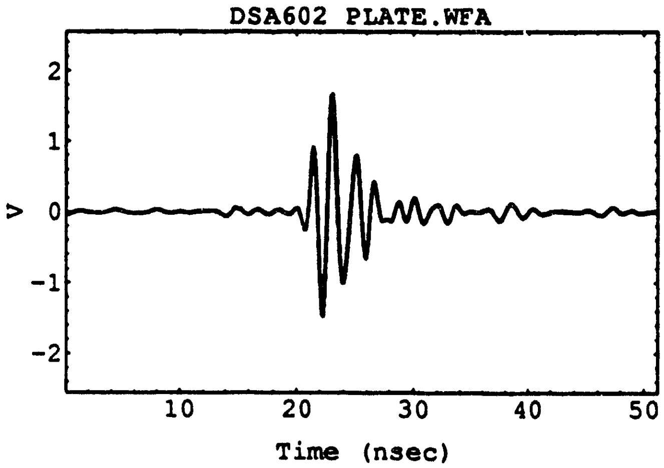


Figure 7.6. Waveform Received from 3' by 4' Target at 35 Meters

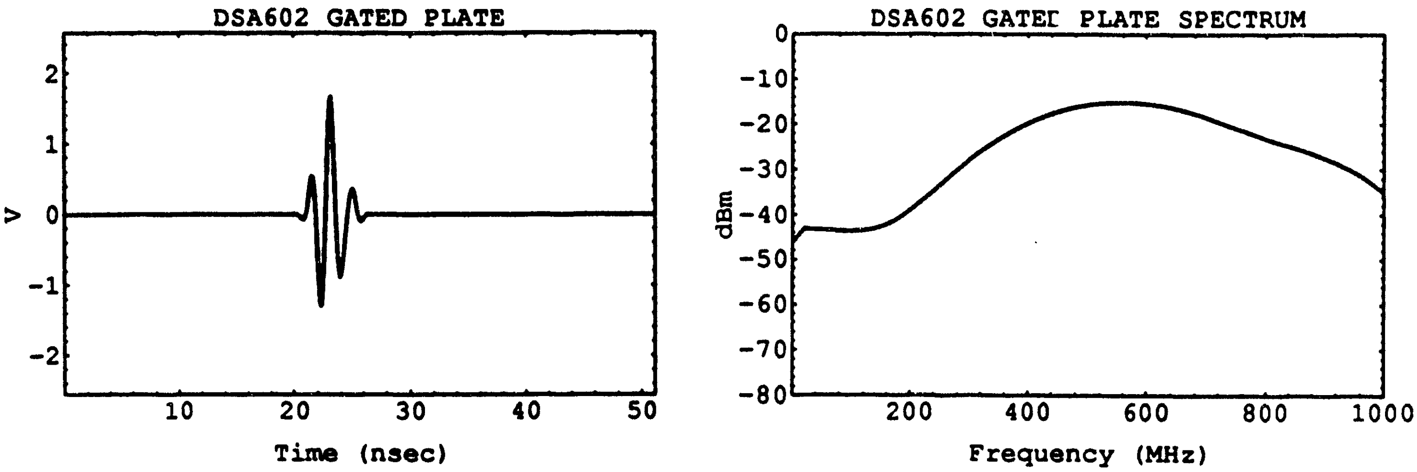


Figure 7.7. Gated Waveform and Spectrum Received from 3' by 4' Target at 35 Meters

Figure 7.8. Pseudo-Color Image of the A-scans Collected at the 256 Scanner Positions of the Calibration Target Area

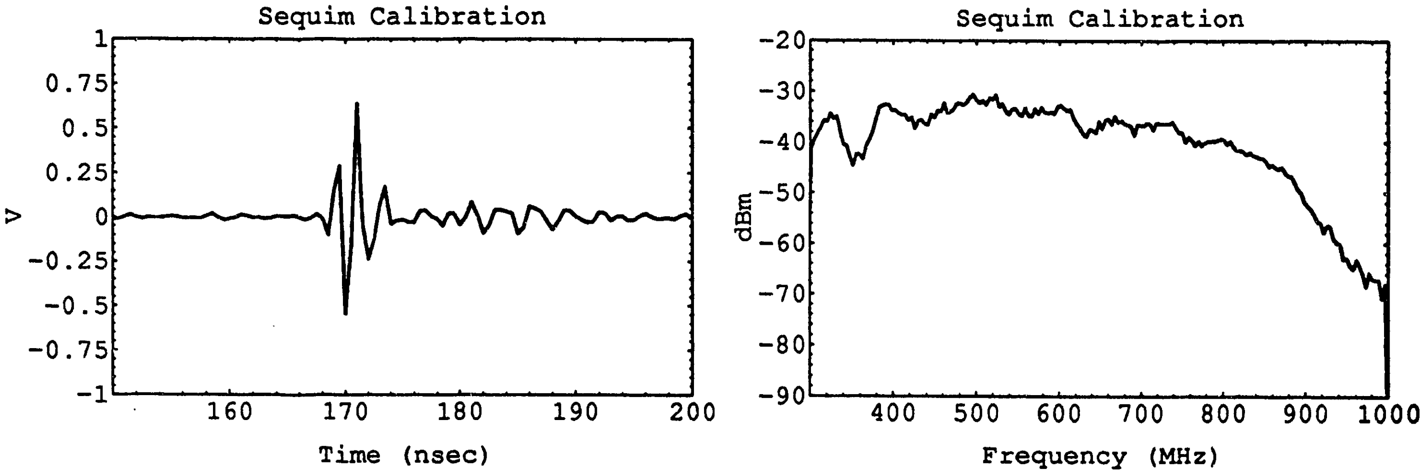


Figure 7.9. Focused Calibration Target Waveform and Spectrum

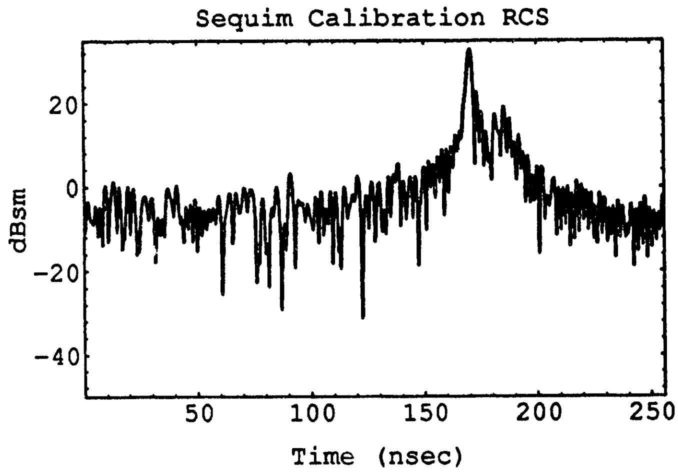


Figure 7.10. Focused Calibration Target Waveform Calibrated to RCS

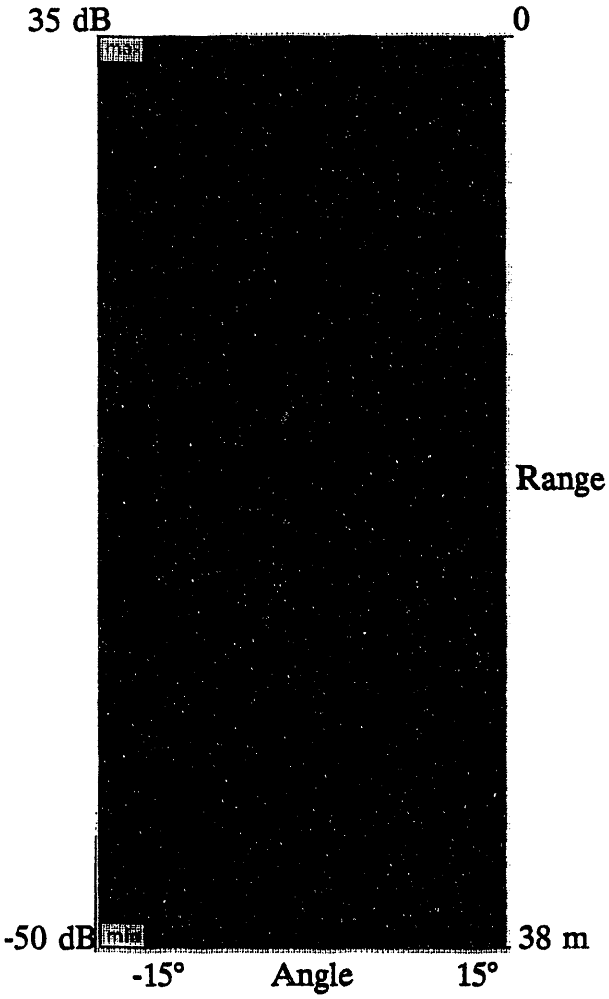


Figure 7.11. Calibration Target Image (located in clutter) Calibrated to RCS

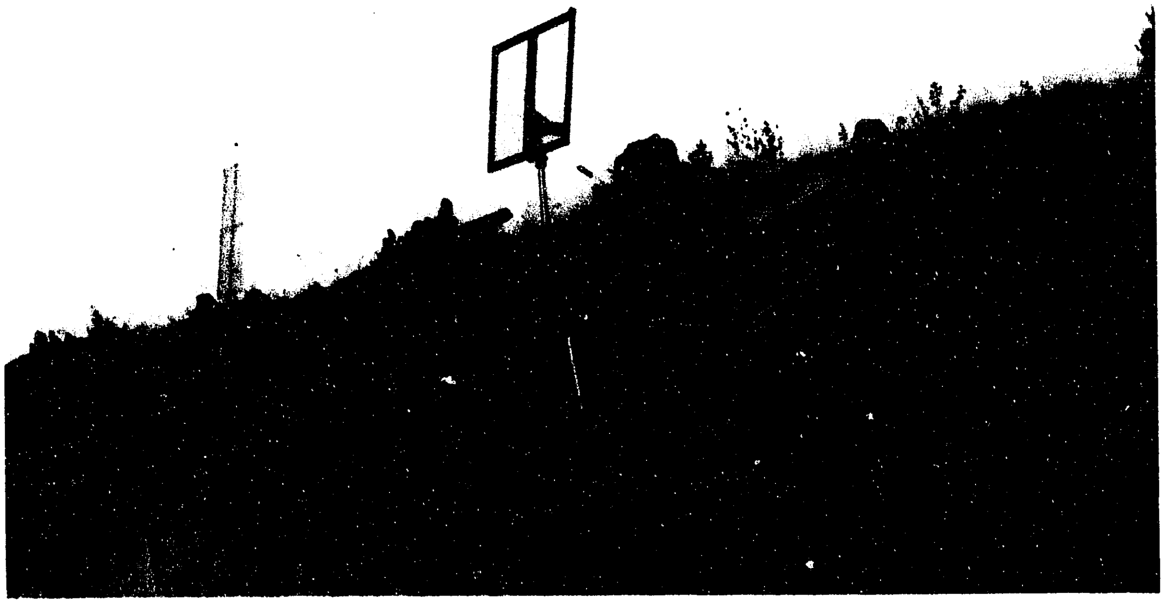


Figure 7.12. Photograph of 6' by 12' and 3' by 4' Calibration Targets along the 28° Line of Sight

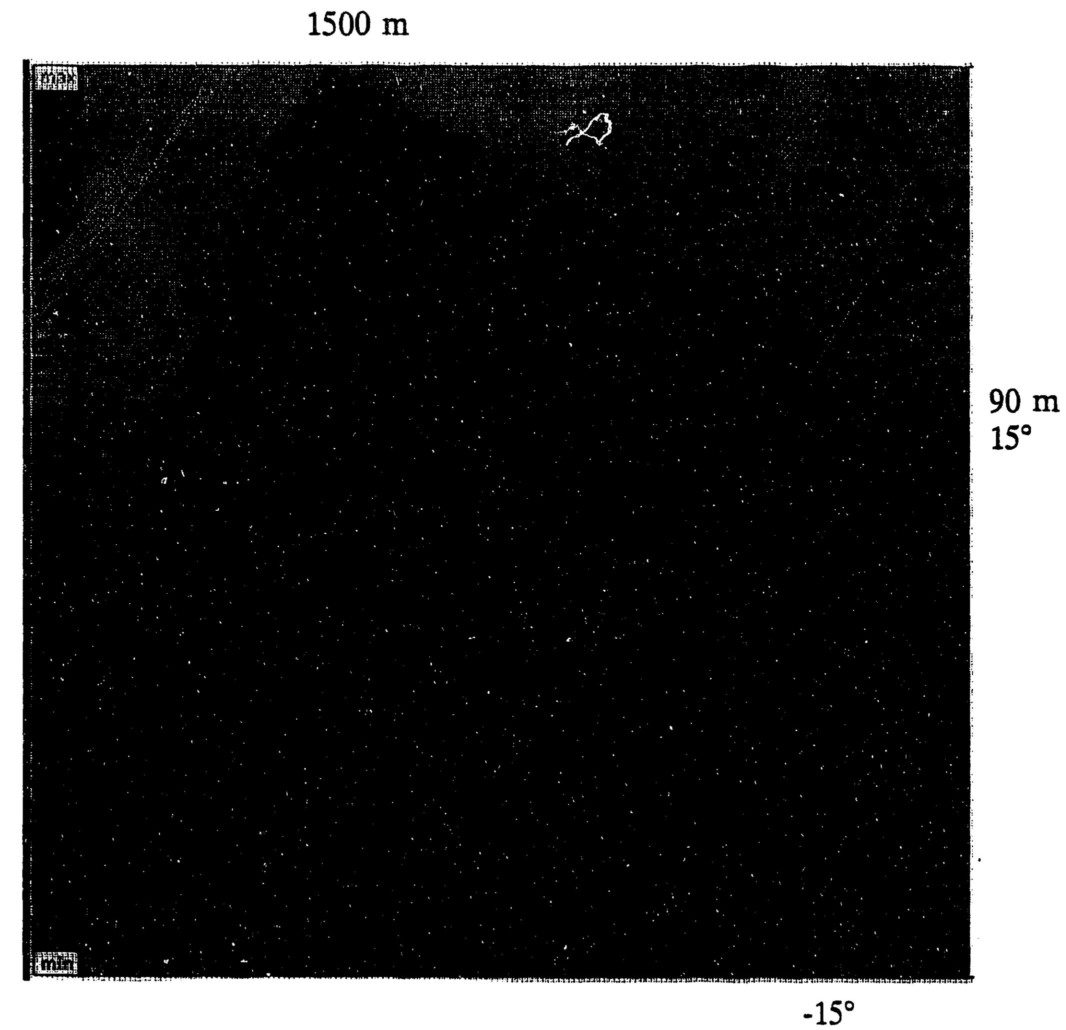
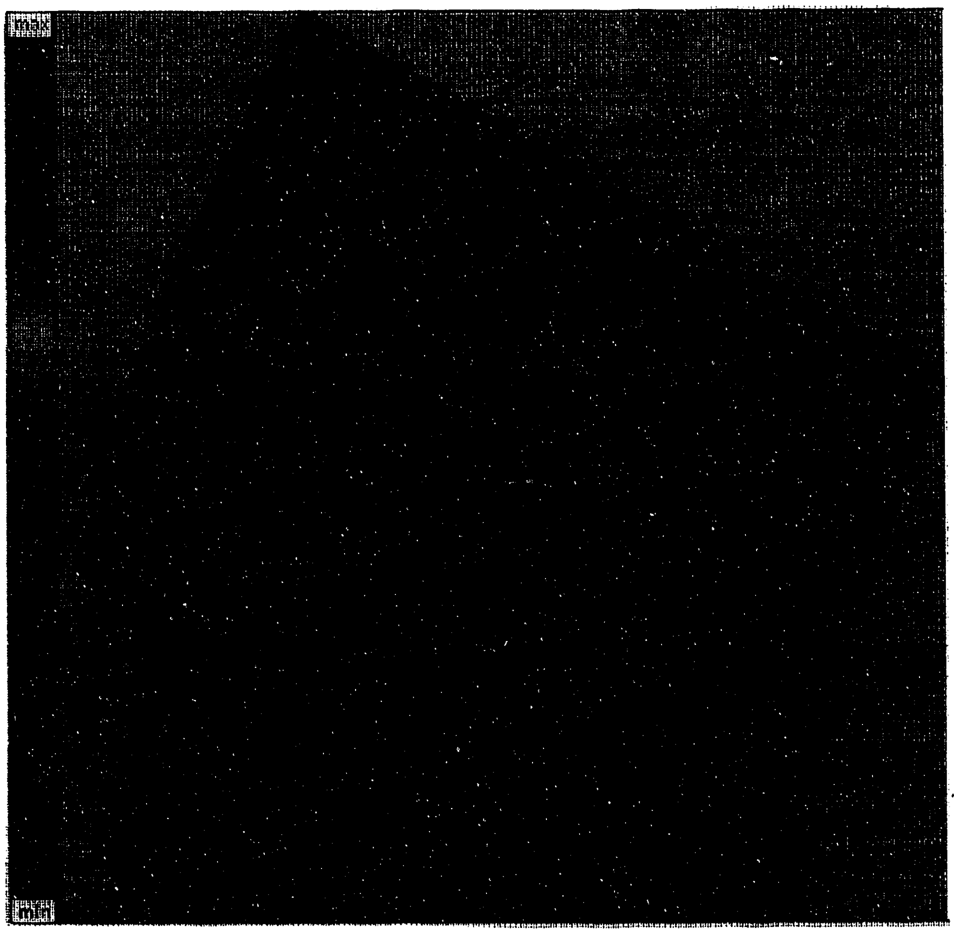


Figure 7.13. RCS Image of Clutter in Sector 2 (V pol.)

1500 m



900 m
15°

-15°

Figure 7.14. RCS Image of Clutter in Sector 2 (H pol.)

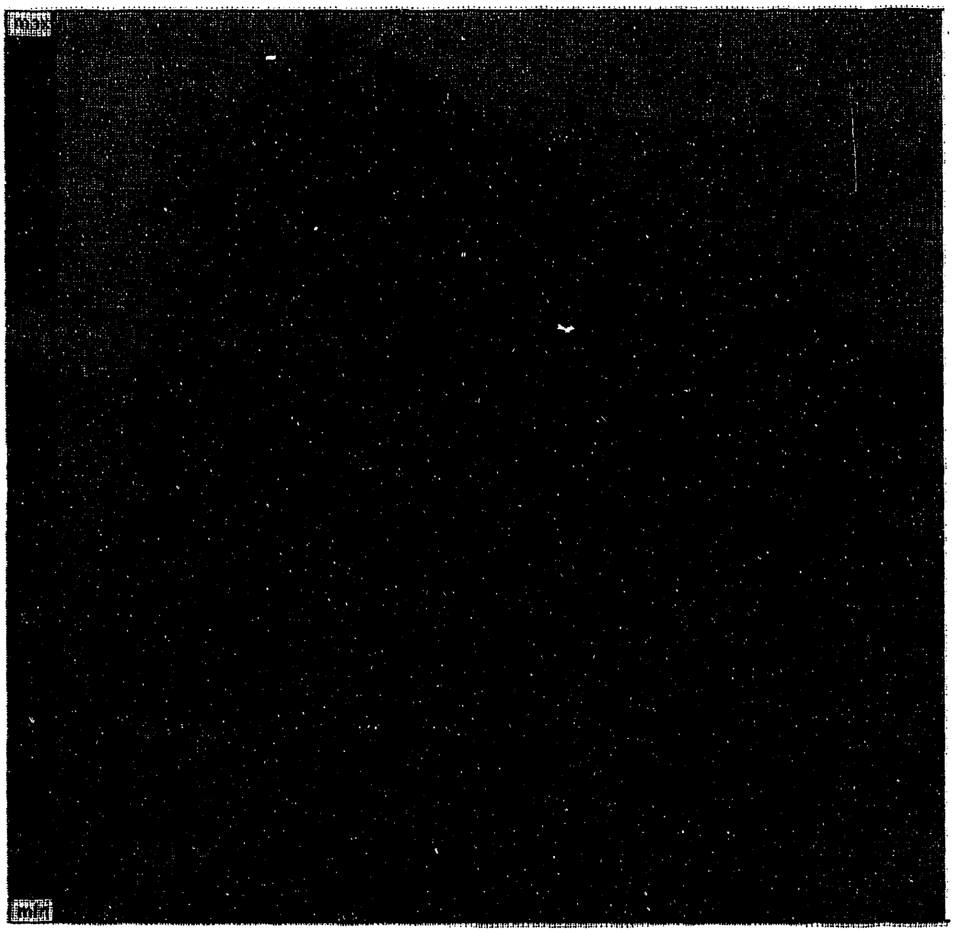


Figure 7.15. RCS Image of Clutter in Sector 3 (V pol.)

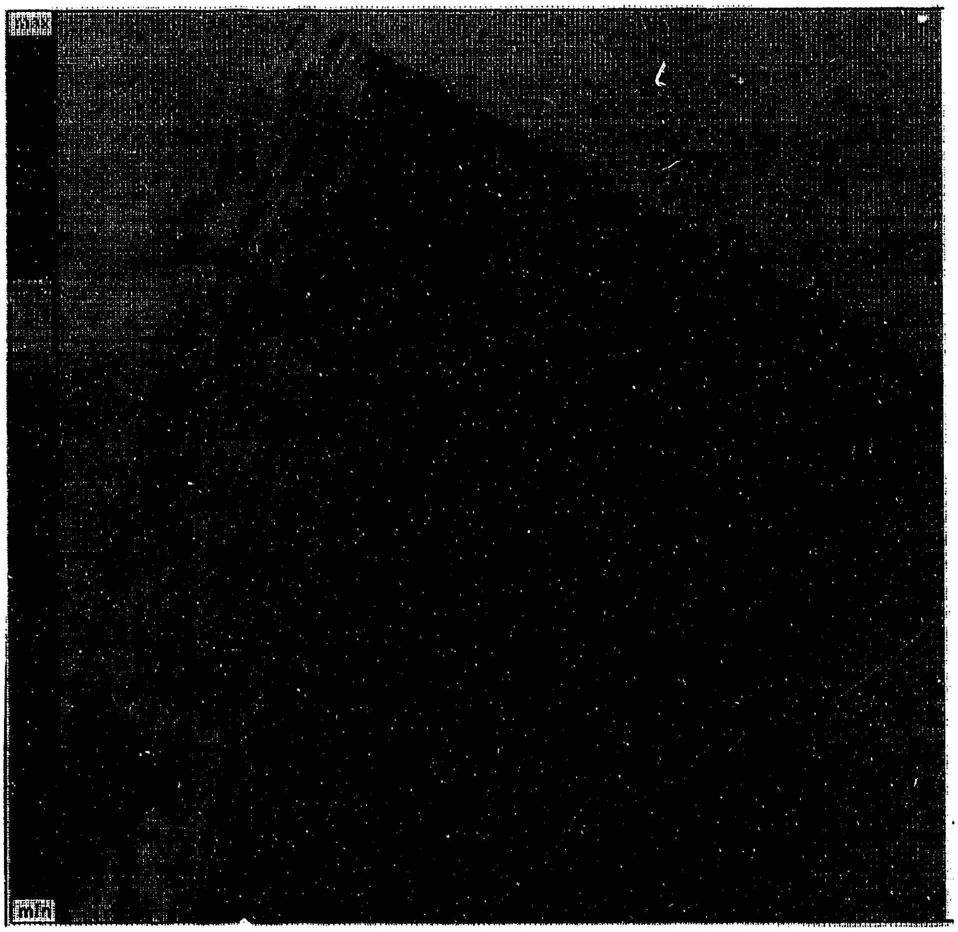


Figure 7.16. RCS Image of Clutter in Sector 3 (H pol.)

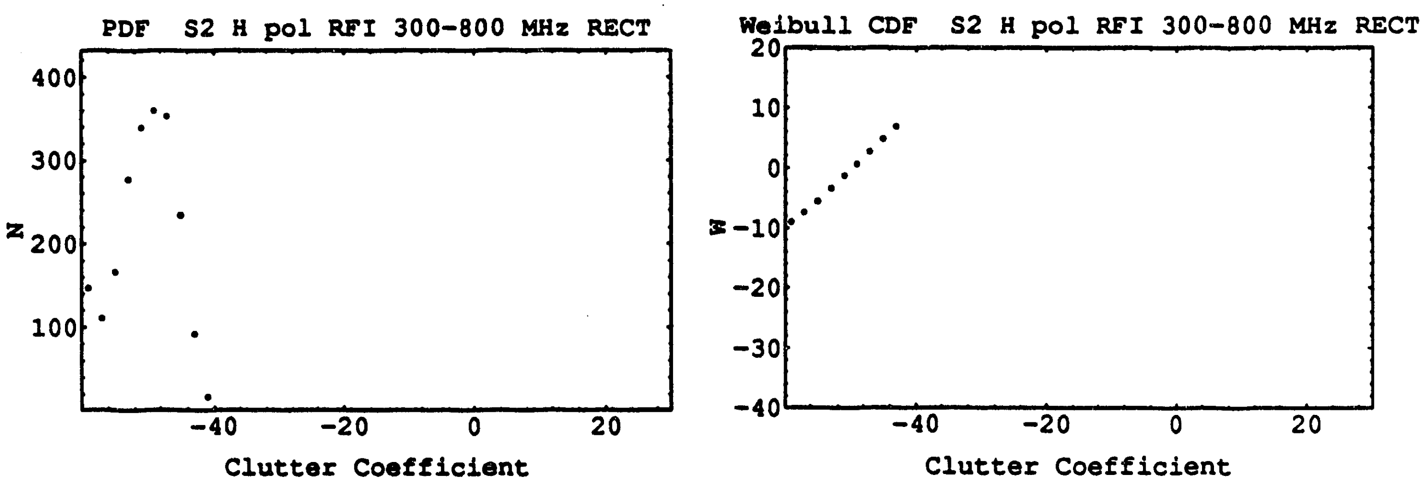


Figure 7.17. Noise Equivalent Clutter Coefficient Distributions for H Pol at 70° Orientation and at 1 km for 300-800 MHz Processing Bandwidth

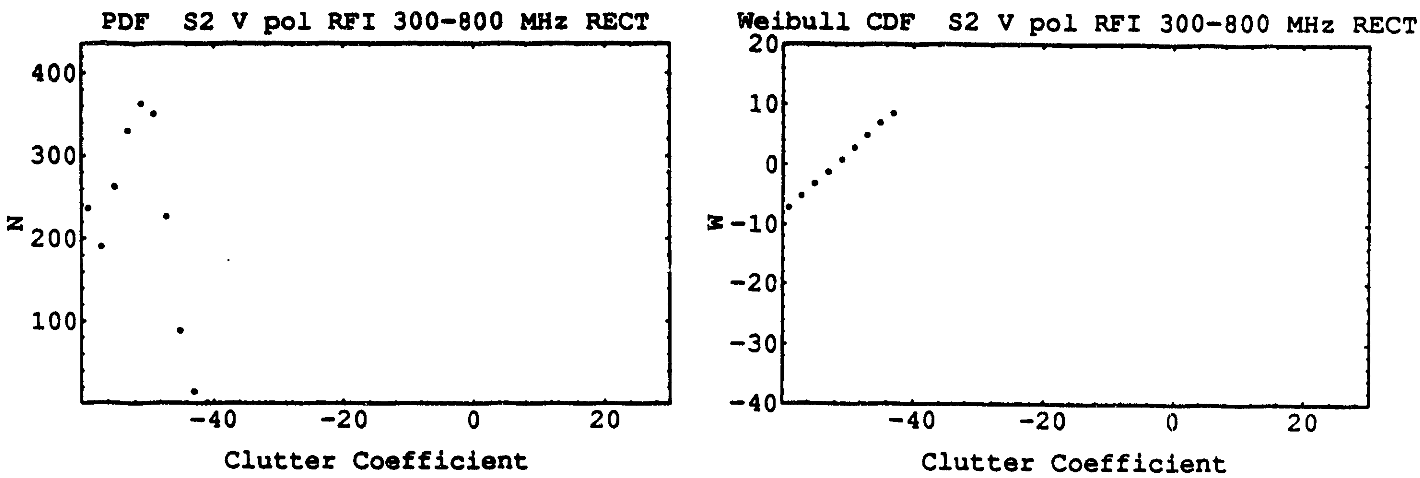


Figure 7.18. Noise Equivalent Clutter Coefficient Distributions for V Pol at 70° Orientation and at 1 km for 300-800 MHz Processing Bandwidth

Figure 7.19. Composite Clutter Image of the VV Data

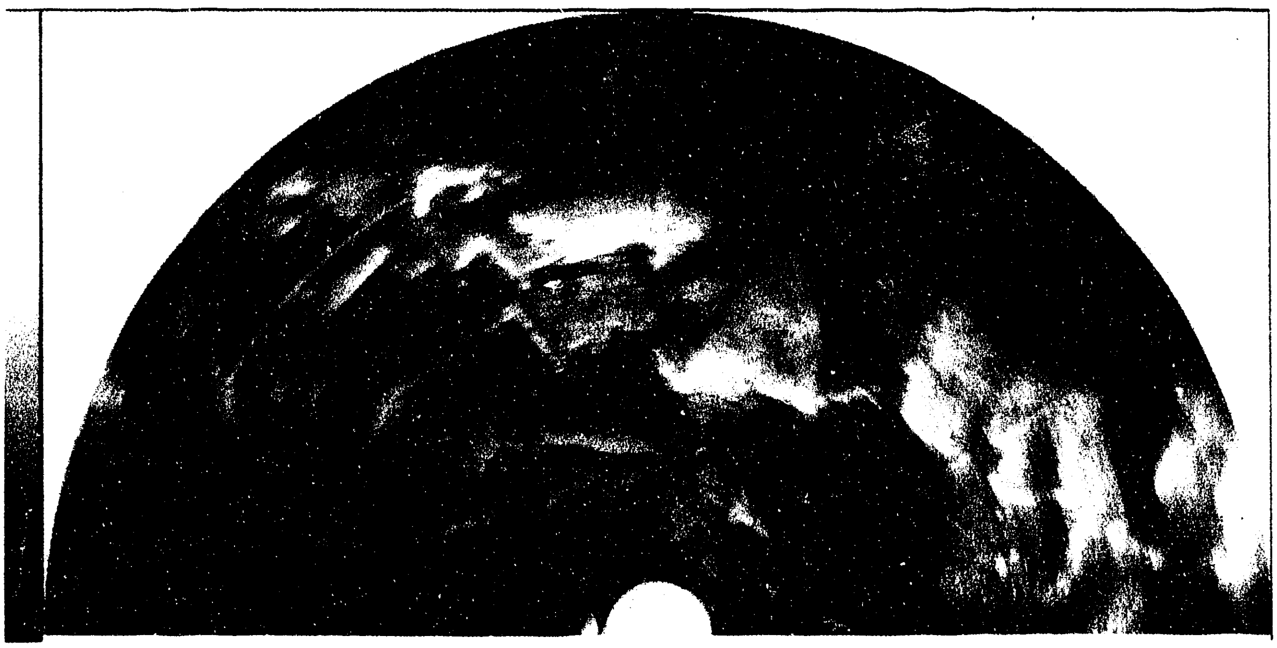


Figure 7.20. Composite Clutter Image of the HH Data

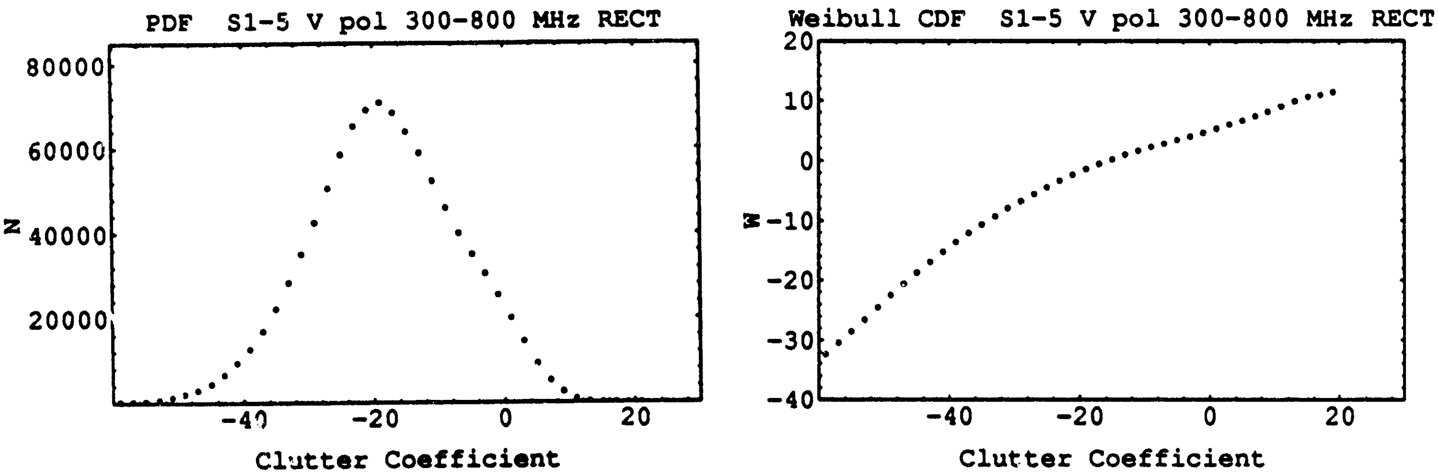


Figure 7.21. Distributions of 300-800 MHz VV Polarization Clutter Data Taken in 6 Lines of Sight: 100°, 70°, 40°, 10°, 340°, and 310°

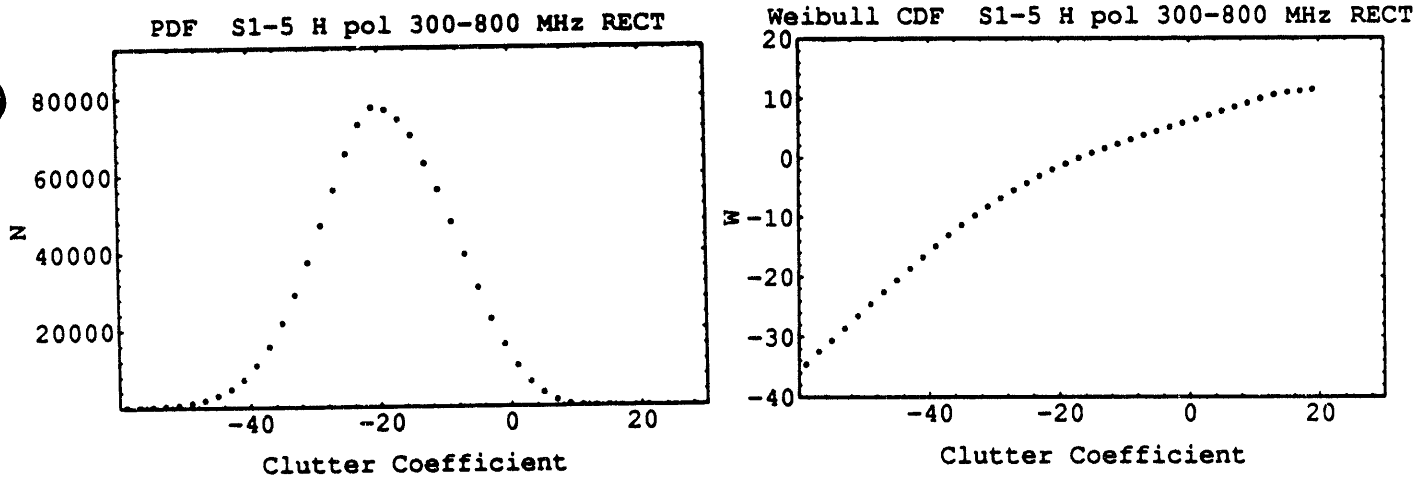


Figure 7.22. Distributions of 300-800 MHz HH Polarization Clutter Data Taken in 6 Lines of Sight: 100°, 70°, 40°, 10°, 340°, and 310°

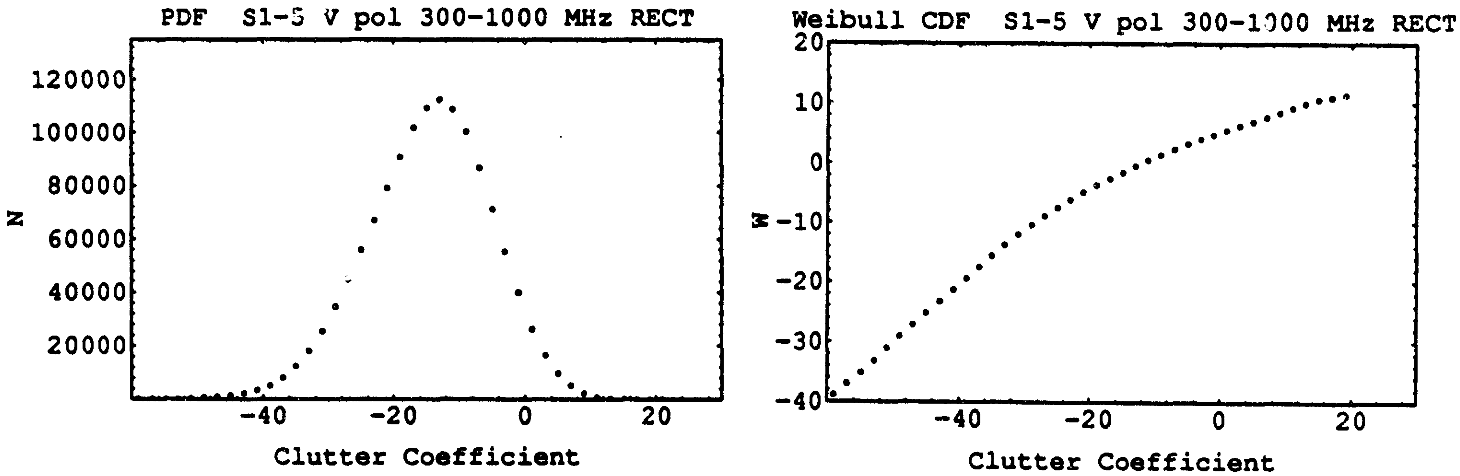


Figure 7.23. Distributions of 300-1000 MHz VV Polarization Clutter Data Taken in 6 Lines of Sight: 100°, 70°, 40°, 10°, 340°, and 310°

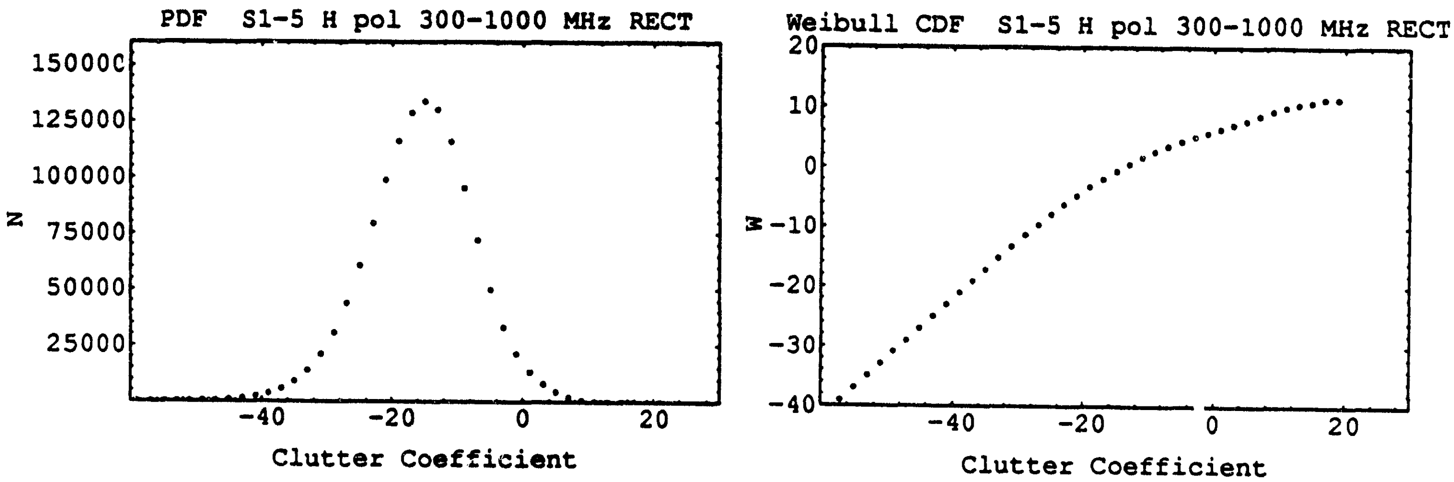


Figure 7.24. Distributions of 300-1000 MHz HH Polarization Clutter Data Taken in 6 Lines of Sight: 100°, 70°, 40°, 10°, 340°, and 310°

8.0 Comparison with Existing Data and Conclusions

One of the most important aspects of the UWB clutter project was to determine if more widely available narrowband clutter data could be successfully used in the UWB case. An additional goal was to determine the dependence of the clutter statistics on the frequency content and resolution of the UWB data. The following sections summarize the clutter statistics obtained in the 1991 and 1992 measurements and compare these results with existing narrowband data.

8.1. Overall Summary of Clutter Statistics

Three separate sets of UWB forest clutter data have been obtained. The first two sets are from the 1991 measurements using both the impulse and the step-chirp systems. These measurements both used the 300-1000 MHz frequency band and were taken simultaneously. The step-chirp measurements covered a significantly larger area than the impulse measurements. The 1992 impulse measurements were taken at a similar site to the 1991 measurements and yielded similar results. The 1992 measurements covered a vastly larger area than did the 1991 impulse measurements. Mean clutter values obtained from these three sets of data agree to within 3 dB. This is exceptional agreement, but may be somewhat coincidental since the terrain covered is different in each case. A summary of the UWB clutter data is given in Table 8.1.

Table 8.1. Summary of UWB Clutter Values

Polarization	Frequency Band, MHz	Mean, dB	Median, dB	Std Dev/ Mean, dB
1991 Impulse UWB Forest Clutter Measurements				
HH	300-1000	-9.0	-16.8	--
VV	300-1000	-5.4	-12.4	--
1991 Step-Chirp UWB Forest Clutter Measurements				
HH	300-1000	-11.5	-18.8	4.7
VV	300-1000	-7.4	-14.0	4.2
1992 Impulse UWB Forest Clutter Measurements				
HH	300-800	-9.3	-19.1	6.5
VV	300-800	-6.4	-18.4	6.1

8.2 Range Resolution and Frequency Content Effects

The step-chirp data set from the 1991 forest measurements was also processed to determine the effects of range resolution reduction by decreasing the bandwidth (Appendix A). Note that the narrower frequency range could be defined anywhere within the 300-1000 MHz total bandwidth. Typically the narrower bandwidths were chosen for a constant center frequency of 650 MHz. Table 8.2 shows the result of resolution (bandwidth) reduction for x1, x2, x4, and x8 for the 186° sector of data. Note that there is a significant decrease in clutter levels from the 0.214 meter resolution to the 0.429 m resolution with little subsequent change. This appears to be due to the elimination of the low frequency content of the 300-1000 MHz frequency band. This was determined by reprocessing the x2 data using the center frequency of the lower and upper halves of the 300-1000 MHz spectrum, which showed that the lower frequency content has significantly higher reflectivity (Sager and Schultheis 1992).

Table 8.2. Range Resolution Effects on σ^0 Statistics
(Sager and Schultheis and Appendix A)

Polarization	Range Res, m	Mean, dB	Median, dB	Std Dev/ Mean, dB
HH	0.214	-11.5	-18.8	4.7
VV	0.214	-7.4	-14.0	4.2
HH	0.429	-15.4	-22.6	4.7
VV	0.429	-11.1	-18.0	4.6
HH	0.857	-16.5	-23.4	4.5
VV	0.857	-12.0	-19.0	4.7
HH	1.714	-16.6	-23.0	4.4
VV	1.714	-12.0	-18.9	4.7

8.3 Comparison with Existing Narrow Band Data

An analysis comparing the UWB clutter data gathered during the 1991 measurements was written by Mike Tuley and was presented in Tuley et al. (1993) and is summarized here. The UWB clutter data was compared with existing narrowband data primarily from two sources. The first source is Nathanson (1991). The constant gamma model was used in which $\sigma^0 = \gamma \sin(\psi)$, where γ is a constant and ψ is the grazing angle. Nathanson provides a value of -16 dB for γ for wooded hills with grazing angles of 15° to 70°. Assuming an average local grazing angle of 20° for the 1991 Sequim measurements results in a predicted median σ^0 of -20 dB. This is on the order of 5 dB below the median levels (average of HH and VV) observed for the 1991 measurements. The predicted value agrees quite well with the 1992 impulse measurements which have a median σ^0 values of approximately -19 dB.

The main source of narrow band clutter data is the MIT Lincoln Laboratory data (Billingsley and Larrabee 1991). This data was gathered using five radar systems operating over narrow bandwidths. Three of these frequencies are of interest to the UWB measurements. These include a VHF system operating a 167 MHz (13° azimuth beamwidth and 36 m or 150 m range resolution), a UHF system operating at 435 MHz (5° azimuth beamwidth and 36 m or 150 m range resolution), and an L-band system operating at 1230 MHz (3° azimuth beamwidth and 15 m or 150 m range resolution). Table 8.3 provides a summary of the MIT/LL data of interest for the UWB forest and desert clutter measurements. Comparison of the UWB clutter data from the 1991 and 1992 measurements with the MIT/LL UHF data shows that mean and median clutter levels are consistent with the Mountains terrain data set. The agreement with the Forest/High Relief data set is not nearly as close. This is likely due to lower slopes for the Forest/High Relief data set than for the Sequim data.

Table 8.3. MIT/LL Narrowband Radar Data (Billingsley and Larrabee 1991)

	Mountains	Forest/ High Relief	Desert/Marsh/ Grasslands
Mean (dB)			
VHF	-7.6	-10.5	-38.2
UHF	-10.6	-16.1	-39.4
L-band	-17.5	-18.2	-39.6
Median (dB)			
VHF	-13.0	-15.0	-49.0
UHF	-16.0	-26.0	-59.5
L-band	-28.0	-25.5	-48.5
Std Dev/Mean (dB)			
VHF	3.4	4.2	5.5
UHF	5.4	4.3	8.2
L-band	2.8	6.1	9.2

8.4 Conclusions

The results from the 1991 and 1992 UWB forest clutter measurements and subsequent analyses lead to a number of conclusions, as drawn in Tuley et al. 1993.

The calibrations of these experiments are believed to be accurate to within 2 dB. The impulse and step-chirp systems gathered data that is essentially equivalent which was shown by a detailed comparison of data from one sector (Tuley et al. 1993)

Mean clutter coefficient values are typically -5 dB to -7 dB for vertical polarization and -9 dB to -11 dB for horizontal polarization. Median clutter values are typically -12 dB to -18 dB for vertical polarization and -17 to -19 for horizontal polarization. Thus, mean and median values are typically 3-5 dB higher for VV than for HH polarization.

The clutter statistics do not depend strongly on range resolution for the range resolutions considered (0.214 m to 1.714 m). Note that this conclusion can only be drawn for the system configurations and terrain types that were examined.

Mean and median values are similar to the MIT/LL UHF (435 MHz) mountain terrain data (Billingsley and Larrabee 1991).

9.0 References

Billingsley, J. B., and J. F. Larrabee, "Multifrequency Measurements of Radar Ground Clutter at 42 Sites," *Lincoln Laboratory Technical Report 916*, November 15, 1991.

Nathanson, F. E., *Radar Design Principles*, Second Edition, McGraw-Hill, New York, 1991.

OSD/DARPA Ultra-Wideband Radar Review Panel, "Assessment of Ultra-Wideband (UWB) Technology," July 13, 1990.

Sager, E. V., and A. C. Schultheis, "Description of Clutter Data Collected at a Forested Site," *SPC Final Technical Report 1432*, October 1992.

Skolnik, M. L., *Introduction to Radar Systems*, McGraw-Hill, New York, 1980.

Tuley, M. T., D. M. Sheen, H. D. Collins, E. V. Sager, and A. C. Schultheis, "Ultrawideband Radar Clutter Measurements and Analysis," Proceedings - Ultrawideband Radar, SPIE, January 1993.

APPENDIX A:

SPC Report on 1991 Sequim Measurements

SPC Log No. 92-1722
Cy001

DESCRIPTION OF CLUTTER DATA COLLECTED AT A FORESTED SITE

SPC REPORT 1432

October 1992

Earl V. Sager
Andreas C. Schultheis

Prepared for
Battelle Pacific Northwest Laboratories
Battelle Boulevard
P.O. Box 999
Richland, WA 99352

Subcontract 127158-A-T2

CONTENTS

I. TEST OBJECTIVE

In November of 1991, System Planning Corporation (SPC) participated with Battelle Pacific Northwest Laboratories (PNL) in collecting high range resolution clutter RCS data. The main purpose for using the SPC MKIV step-chirp radar was to provide a complementary set of data to compare to results obtained from the PNL impulse radar. Data sets for both radar systems were collected from the same clutter scenes at closely spaced periods in time. The MKIV was operated over a bandwidth consistent with the range resolution of the impulse system and high range resolution was obtained by Fourier processing the step chirp data. Synthetic aperture beam forming techniques were applied to both data sets to generate narrow azimuth beams. The body of data collected by the MKIV was larger than that of the impulse system because of better throughput and longer range sensitivity. Because of this, the data set produced with the MKIV is a valuable asset for clutter statistics. In addition, the step chirp waveform permits the use of data processing to reduce the radar bandwidth to study the effects of variable range resolution. Interference from narrow band RFI could also be conceivably filtered from the data.

PNL was responsible for the collection and processing of all impulse radar data. SPC was similarly responsible for the step chirp radar data.

Dr. Michael Tuley of Georgia Tech Research Institute (GTRI) was responsible for assessing the correlation between the step chirp radar and impulse radar sets of data based on contributions provided by SPC and PNL.

II. TEST DESCRIPTION

Data was collected from a forested site near Sequim, Washington in November of 1991. The radar was sited at a clearing on the side of a hill overlooking a valley and across to tree covered slopes. The trees were pines in the 30 to 50 foot height range. The weather was generally humid with temperatures in the 50-70 degree F range during the daytime data collection periods.

Data was collected as follows. A horizontal antenna positioner (scanner) 19 meters in length was located .5 to 2.5 km from the clutter areas of interest. Horizontally and vertically polarized log-periodic antennas were mounted on the mast of the scanner. The two-way horizontal 3 dB beamwidth of the antennas was predicted to be 26 degrees at .3 GHz and 20 degrees at 1. GHz. The antenna mast moved continuously along the track so that 127 azimuth positions were sampled at each of the 1024 step chirp frequencies that were collected from .3 to 1.0 GHz. The objective is to process the data so that high range resolution clutter statistics can be obtained from a frequency independent patch size. The use of a fixed 19 meter synthetic aperture antenna results in a beam profile that would diminish by a factor of about three from the low frequency to the high frequency ends of the chirp. Synthetic aperture reduction techniques were used to process the data so that a constant beam profile (equivalent to the low frequency end) is maintained.

For RCS backscatter measurements, the two-way 3 dB beam profile is related to frequency f and aperture size D by:

$$\theta_{beam} = \frac{c}{2D}$$

where: *c = speed of light*
D = aperture width
f = frequency

In order to maintain a constant beam width, the synthesized aperture at 1.0 GHz must be .3 the size at .3 GHz. To form equivalent beams at 1.0 GHz and at .3 GHz, only (.3)(127) contiguous elements (a subaperture) are used at the high end while the full 127 elements are used at the low end. Once a constant beam size is synthesized at each frequency (1024 of them), an FFT is performed to generate a high resolution profile for each subaperture. Prior to the FFT, weighting can be applied to reduce sidelobes. A phase calibration is required of the 1024 frequency elements prior to the FFT to correct for dispersion and to properly align the output range bins. The calibration constants are obtained from a calibration target erected at a convenient location relative to the radar. This calibration procedure assumes that a uniform frequency response is desired for the chirp data.

A data set is described by the following parameters:

N_c = number of chirp frequencies
N_a = number of aperture samples
D = aperture length
R_0 = center range
f_0 = base frequency
B = chirp bandwidth
PRF= constant

A complete data set consists of N_c x N_a data points. The antenna was continuously moved at a slow rate while the data was collected. The PRF of the radar, the number of coherent integrations at each frequency in the step chirp, and the scan speed of the positioner were selected to coincide with the required spatial sampling interval. A typical run took about 11 minutes to complete. The run was duplicated for both HH and VV polarization.

All data points were extracted from the file and stored in an N_c x N_a array, where N_c = 1024 and N_a = 127. Every element was amplitude and phase calibrated according to normal chirp calibration procedures. The data analysis program takes as input the aperture spacing d, the number of aperture points N_a, the operating range R_0, and a set of angles at which beams are to be formed. Complex beamforming weights were determined by the trigonometry of the problem which depends on D and R_0. The output is a file consisting of RCS (amplitude and phase) versus range versus beam steering angle. This file can be processed for statistical analysis of the clutter cells.

The aperture function to steer the array to a particular angle for a particular frequency is given by:

$$A(\theta_s, f) = \Sigma_i [a(x_i, f) e^{i\delta\phi(x_i, \theta_s, f)}]$$

The phase shifts at each aperture position x used to steer the array are:

$$\delta\phi(x, \theta_s, f) = -[R(x, \theta_s) - R_0] [4\pi \frac{f}{c}]$$

where:

$$R(x, \theta) = \sqrt{R_0^2 + x^2 - 2xR_0 \sin(\theta)}$$

At each frequency, a single complex data value will be generated from a subset of the N_a collected values. A different value will be computed for every required steering angle.

At higher frequencies the beam width created by this aperture function will be narrower than at lower frequencies. In order to maintain a constant beam width for all frequencies which will give a constant clutter patch size, the beam formed at higher frequencies will use fewer elements in proportion to the ratio $(f_{low}/f)N_a$. If a smaller array is created around the center of the full array, the fewer elements result in less gain (reducing the SNR). In order to obtain high range resolution, an FFT is applied to chirp sets representing each synthesized beam angle.

The results of the beam steering and range compression operation is a matrix of RCS values associated with discrete clutter patches determined by the range and angle resolution of the processing. The RCS of each patch is normalized by the area of the patch to produce the clutter reflectivity coefficient. The array of reflectivity values spanning the range azimuth sector can be displayed as a beam map and processed for statistics.

III. CALIBRATION

Calibration could not be conducted within one of the range azimuth sectors viewed by the scanner. Insufficient signal-to-clutter power was available to properly peak the calibration target and to provide a meaningful amplitude and phase calibration. Instead the calibration target was positioned in a cleared area at about 1000 feet from the antenna. Because of irregularities in the frequency response of the calibration target, significant multipath effects were indicated. As a result, calibration data collected from another site at near Richland, Washington was used instead for a calibration reference to process the Sequim clutter data.

Calibration was performed using a rectangular screen 6 feet wide by 12 feet high mounted with the center seven feet above ground. The antenna horn was dismounted from the scanner and mounted on a tripod at a seven foot height so that the antenna could view the screen at a convenient location. A sighting scope was mounted on the screen so that the face could be approximately pointed at the antenna. The return from the screen was peaked at the highest frequency by hand in elevation and azimuth. The screen was secured with ropes while the data was collected. No capability existed to ascertain the multi-path propagation factor. The cable path to the horn was maintained at a constant length for data collection and calibration. An RF cable segment equal in length to the piece fixed to the scanner was made use of during the calibration.

The principal uncertainties deal with the multipath propagation factor. The relief of the ground between the antenna and target was generally gently rolling with irregularities of the order of a few inches. There was a downslope to the left of the target and an upslope to the right. No dramatic nulls were observed in the response of the target as the frequency was swept across the band. The external response of the plate was very similar to the internal loop mode response of the radar.

The output of the RF converter was measured at SPC and an estimated power to be received from the cal target based on gains and losses was calculated as a function of frequency.

Table 1
Factors Affecting Calibration

polarization	H	V	H	V
frequency (GHz)	.3	.3	1.	1.

measured power in (dBm)	-77.85	-76.05	-60.35	-62.75
estimated power in (dBm)	-78.12	-77.12	-71.75	-73.55
measured - estimated (dB)	.28	1.08	11.41	10.81

There appears to be a substantial power excess. A difference of 10 dB in power received between .3 and 1.0 GHz can originate from the propagation factor. However, the propagation factor cannot account for a 10 dB excess over the estimated value at the cal target range of about 950 feet for the antenna and target heights that were involved. No enhancement should be possible at 950 feet. As the ground reflection coefficient decreases from 1, the differences between the propagation factors for .3 and 1. GHz converge from a maximum of about 20 dB. At this point there is no clue as to the source of the apparent excess power. However, since the calibration is a relative one and multipath does not appear to be a significant contributor, the calibration performed on the clutter data should be valid.

IV. RF ENVIRONMENT

RF contamination was readily detectable at multiple locations within the .3 to 1. GHz spectrum. This contamination is shown in Figure 1 relative to the noise floor. As can be seen in Figure 2, which compares the RF contamination to the typical clutter levels, the measurements of clutter reflectivity are not significantly degraded by the amount of RF contamination that is present.

V. DATA COLLECTION

The scanner was manually moved to view four different sector angles: 186, 216, 246, and 276 degrees. At each sector angle the scanner made four passes as the MKIV radar collected data at HH and VV polarization at near and far ranges. The near and far ranges covered .5 to 2.5 km in two segments. Each data consisted of 5 collected range delays with a spacing increment of 1330 ns. The basic radar collection parameters are listed in Table 2. Coherent integration was used to improve SNR. At each of the 1024 frequency steps, 256 pulses were summed before storing to tape. Pseudorandom coding was applied to the waveform to avoid contributions from range ambiguous clutter.

Table 2
SPC MKIV Radar Parameters

	CAPABILITY	USED
Frequency	.3 to 18 GHz	.3 to 1 GHz
Power	2w to 1 kw	2w
PRF	< 1 MHz	55 KHz
Pulsewidth	> 1 ns	1330 ns

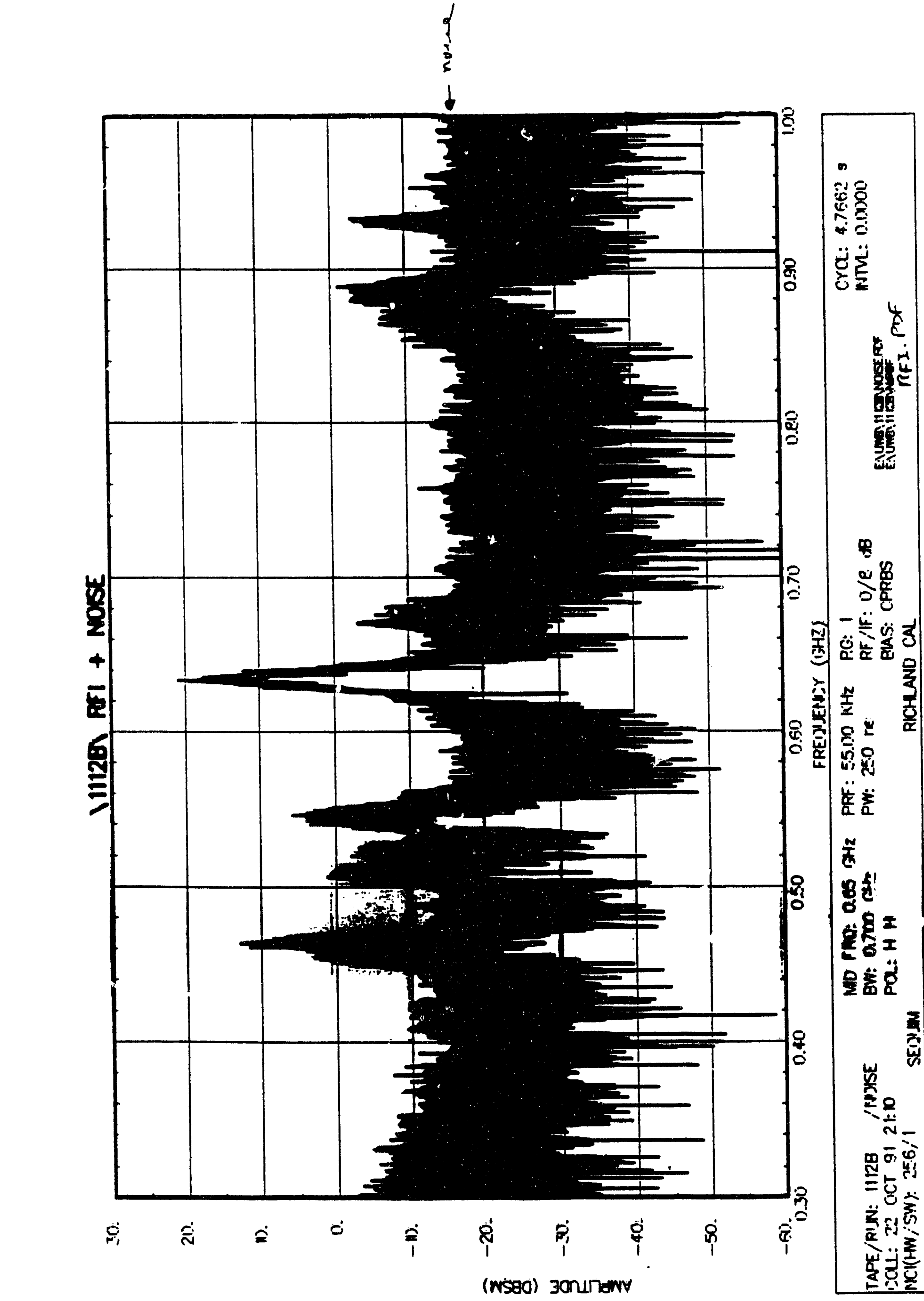


Figure 1
RFI + Noise

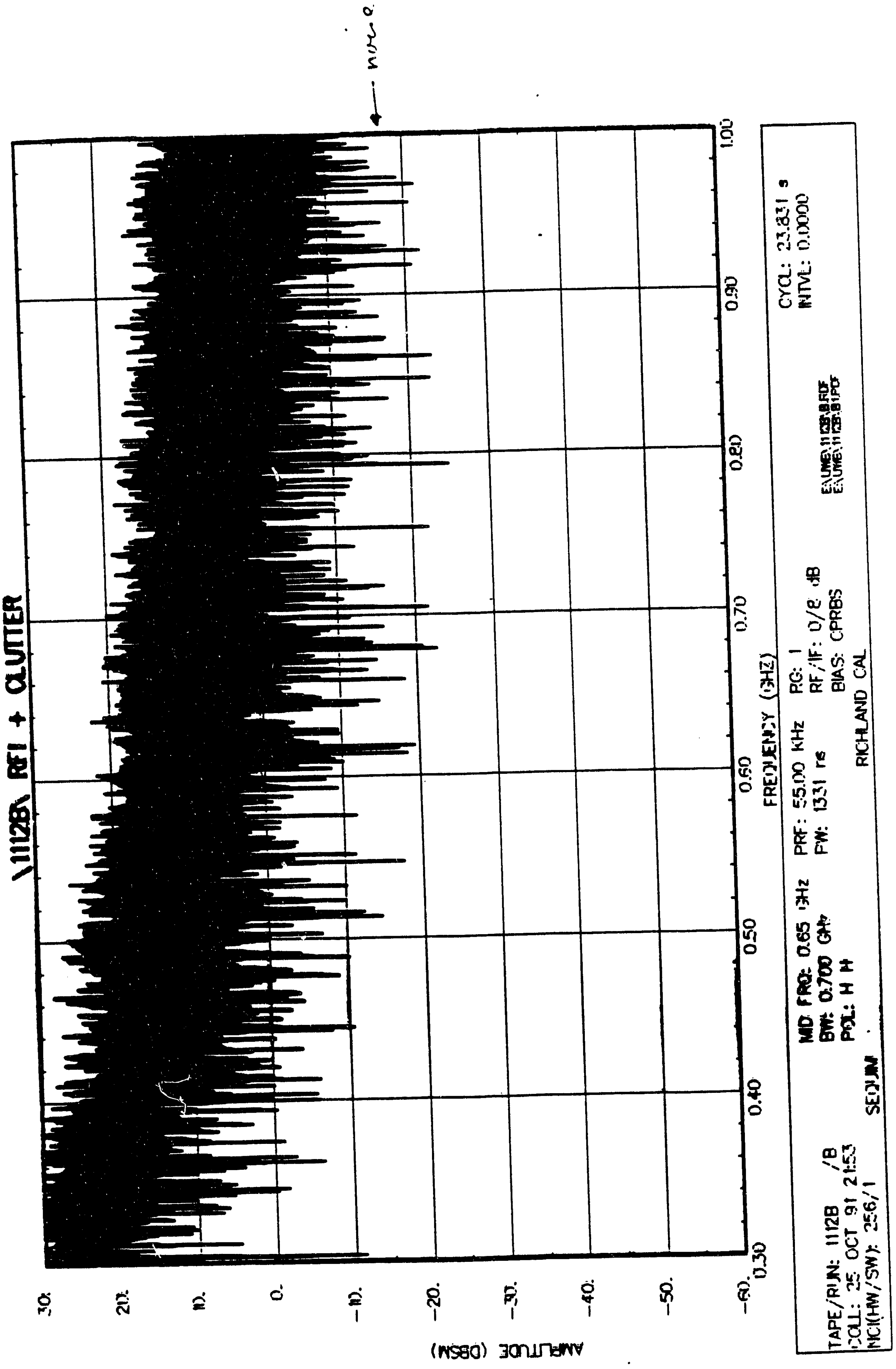


Figure 2
RFI + Clutter

	CAPABILITY	USED
Polarization	HH VV HV VH	HH VV
A/D Resolution	12 bits	12 bits
Coherent Integration	< 64,000	256
Bias Compensation	Pseudorandom	Pseudorandom

VI. DATA PROCESSING

Data was collected and processed over a range interval of 500 meters to 2500 meters. The cell size is given by R(dR)(dA). The processed beam angle dA is .0255 radians. The fundamental range resolution of .214 meters is obtained for 700 MHz of bandwidth. Cell area as a function of range for different range resolutions is shown in Figure 3.

File designation -

Histogram files are identified with six characters as illustrated below:

AAAPRC - six character file name
- AAA - sector angle [186, 216, 246, 276 or ALL]
- P- polarization H or V
- R- range resolution
  - B: .214m
  - C: .214m X4= .86m
  - D: .214m X2= .43m
  - E: .214m X8= 1.71m
  - F: .214m X16 = 3.42m
  - G: .214m X32= 6.85m
- C- a processing code

Beam map files are identified with five character file names as illustrated below:

TDRCA - five character file name
- T- tape file identifying principal range and polarization as follows

Character	Sector	Pol	Range
A	186	H	far
B	186	V	far
C	186	H	near
D	186	V	near
A	216	H	far
B	216	H	near
C	216	V	far

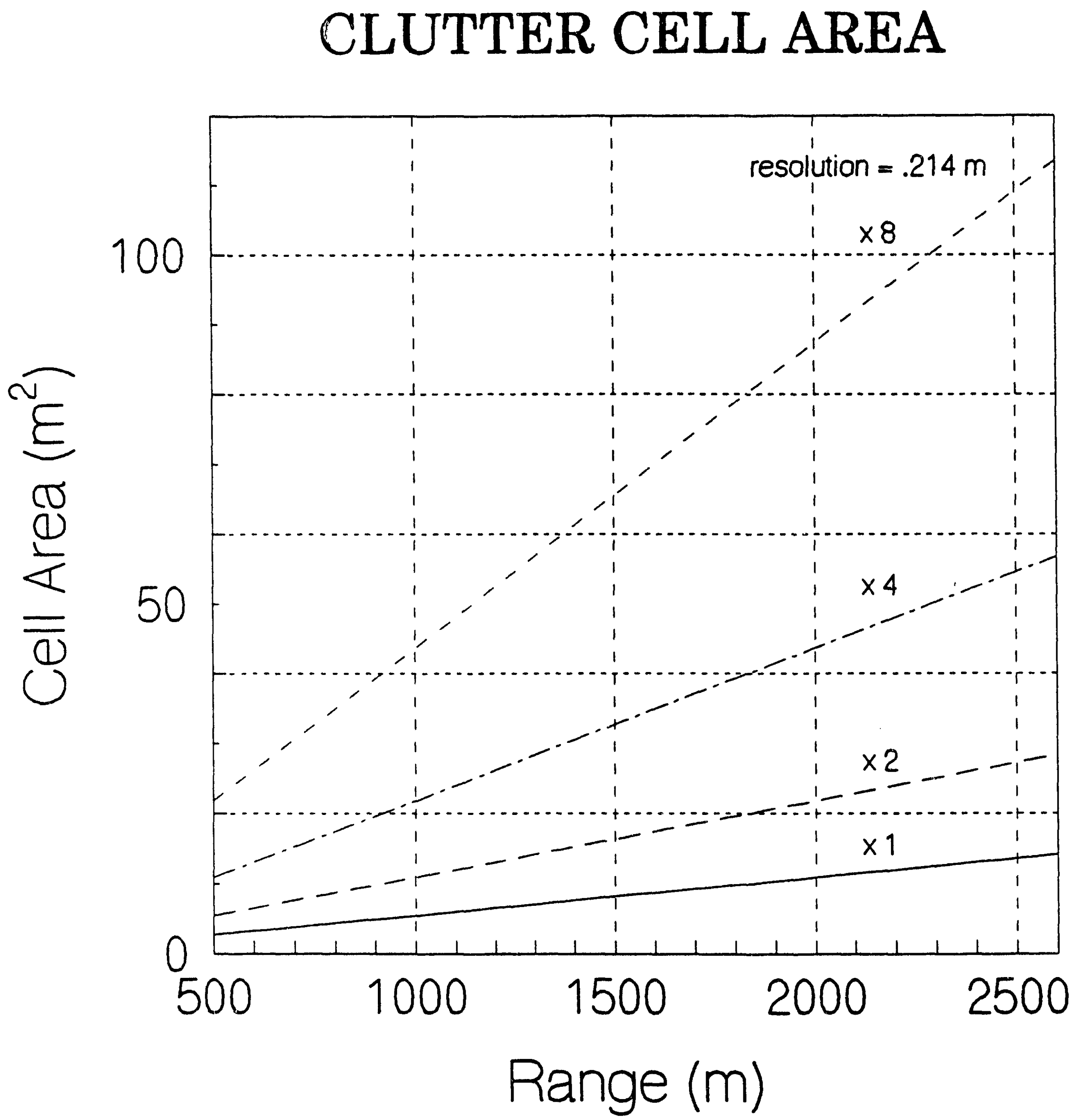


Figure 3
Clutter Cell Area vs Range

E	216	V	near
A	246,276	H	far
B	246,276	H	near
C	246,276	V	far
D	246,276	V	near

D - range delay adjustment

1: 0 ns
2: -1330 ns
3: -2660 ns
4: -3990 ns
5: -5320 ns

R - range resolution (as indicated above)
C - processing code
A - type of output (D for displayable in dB, L for linear)

High resolution

Data for each of the 10 range intervals at each of the four sector angles were processed individually for both HH and VV polarization. The result of the first stage of processing was a beam map composed of 21 azimuth beams of nominal 1.5 degree beamwidth covering the 30 degree sector. Each beam contained 929 range cells. The difference between the 1024 input frequencies and the 929 output range cells results from deleting those processed range cells not covered by the radar pulse. No weighting function was used to generate the range cells. Thus, the nominal range resolution is .214 meters. Each beam map was prepared as a linear ASCII file for further statistical processing and as a separate file suitable for display.

The second stage of the processing consisted of collecting all range intervals within a given sector and preparing a set of statistics. The statistical measures consist of:

- mean (dB)
- median (dB)
- standard deviation (dB)
- standard deviation/mean (dB)
- maximum (dB)
- minimum (dB)
- skew
- kurtosis
- weibull spread - estimated as

$$-2.23077 -/+ .1538(337.+65*MMR)^{1/2}$$

where MMR is mean/median in dB

Values were histogrammed in 1 dB bins from -50 to +30 dB. In addition, all clutter cells were aggregated as a group for each polarization and the same set of statistics generated. Distribution and cumulative plots were prepared.

High range resolution color beam maps displaying reflectivity as a function of range and beam angle are to be found in Appendix A. Each sector angle contains ten maps for each polarization. Each map represents approximately 200 meters and 30 degrees.

Variable resolution

The maximum bandwidth of 700 MHz was collected in 1024 step frequencies. Resolution was degraded by reducing the processed bandwidth with a constant center frequency of 650 MHz. Degradation was performed at steps of 1, 2, 4 and 8 for the complete data set. A summary of the varied resolution characteristics is given in Table 3. In addition, the data for the 186 degree sector was further degraded to 16 and 32. The results of the degradation on means and medians is plotted in Figure 4 and Figure 5 for the aggregate data and in Figures 6 and 7 for the four separate sector angles. The plots appear to show a steep drop off when degrading by a factor of two. Further steps show a rapid leveling off. Figures 8 to 19 are beam maps for a particular segment of the data within the 186 degree sector. This segment was selected for the presence of high levels and low levels within the map. The number of high levels, identified as red, are sharply reduced as resolution is degraded. However, the change in levels is not really due to the change in resolution, but is due to the different parts of the frequency spectrum included to produce the necessary bandwidth. The same range-angle sector was reprocessed to utilize the same bandwidth, but instead of centering the frequency at the center of the full bandwidth, the center of the lower and upper halves was used. The results are shown in the beam maps of Figures 20 to 23. Obviously the reflectivity is much greater for the map produced from the lower spectral half than from the higher spectral half.

Table 3
Composition of a Processed Data Set

Resolution (m)	Bandwidth (MHz)	# of frequencies	# of clutter cells	# of cells in data
.214	700	1024	929	19.5K

.428	350	512	464	9.7K
.856	175	256	233	4.9K
1.71	87.5	128	116	2.4K
3.42	43.75	64	58	1.2K
6.84	21.88	32	29	.6K

<u>Summary</u>

A summary of the statistical parameters obtained for the aggregated data is provided in Table 4. A similar summary for the data segregated by sector is found in Table 5. Plots of distributions and cumulatives along with histogram and statistical listings are provided in Appendices B, C and D.

Table 4
STATISTICAL SUMMARY of
REFLECTIVITY at SEQUIM

File	Pol	Res	Mean (dB)	Median (dB)	SD/Mn (dB)	Max (dB)	Weib	Num
ALLHB1	HH	1	-11.5	-18.8	4.7	10	2.14	780K
ALLVB1	VV	1	-7.4	-14.	4.23	16	2.02	780K
ALLHD1	HH	2	-15.4	-22.6	4.66	7	2.13	390K
ALLVD1	VV	2	-11.1	-18.	4.57	11	2.08	390K
ALLHC1	HH	4	-16.5	-23.4	4.52	40	2.08	195K
ALLVC1	VV	4	-12.0	-19.0	4.67	9	2.10	195K
ALLHE1	HH	8	-16.6	-23.0	4.39	4	2.00	97K
ALLVE1	VV	8	-12.	-18.9	4.69	90	2.08	97K

Table 5
STATISTICAL SUMMARY of
REFLECTIVITY at SEQUIM
SEPARATED BY SECTOR

File	Pol	Res	Mean (dB)	Median (dB)	SD/Mn (dB)	Max (dB)	Weib	Shad (%)	Num
186HB1	HH	1	-11.	-18.1	5.1	10	2.12	10	195K
186VB1	VV	1	-6.9	-13.4	4.2	13	2.01	10	195K
216HB1	HH	1	-13.	-17.3	3.3	5	1.69	5	195K
216VB1	VV	1	-8.5	-12.9	2.9	9	1.62	5	195K
246HB1	HH	1	-10.8	-17.7	3.8	10	2.08	25	195K
246VB1	VV	1	-7.2	-13.5	3.5	12	1.97	25	195K
276HB1	HH	1	-11.5	-23.3	5.2	9	2.89	50	195K
276VB1	VV	1	-7.2	-17.1	5.1	16	2.58	50	195K
186HD1	HH	2	-15.4	-22.2	4.68	7	2.07	10	97K
186VD1	VV	2	-10.5	-17.4	4.26	10	2.02	10	97K
216HD1	HH	2	-16.6	-21.3	3.23	2	1.65	5	97K
216VD1	VV	2	-12.1	-16.8	3.2	6	1.66	5	97K
246HD1	HH	2	-14.9	-21.8	3.89	3	2.09	25	97K
246VD1	VV	2	-11.1	-17.6	3.68	9	2.02	25	97K
276HD1	HH	2	-14.9	-26.6	5.44	6	2.78	50	97K
276VD1	VV	2	-10.8	-21.4	5.63	11	2.78	50	97K
186HC1	HH	4	-16.4	-23.4	4.56	4	2.1	10	49K
186VC1	VV	4	-11.3	-18.2	4.68	9	2.07	10	49K
216HC1	HH	4	-17.6	-22.2	3.2	1	1.64	5	49K
216VC1	VV	4	-12.9	-17.7	3.3	5	1.69	5	49K
246HC1	HH	4	-16.	-22.6	3.89	3	2.04	25	49K
246VC1	VV	4	-12.	-18.7	3.81	6	2.04	25	49K
276HC1	HH	4	-16.1	-25.8	5.27	4	2.59	50	49K
276VC1	VV	4	-11.9	-22.9	5.58	8	2.76	50	49K
186HE1	HH	8	-16.5	-23.6	4.46	2	2.11	10	24K
186VE1	VV	8	-11.4	-18.2	4.65	9	2.06	10	24K
216HE1	HH	8	-17.8	-22.2	2.94	-1	1.62	5	24K
216VE1	VV	8	-12.9	-17.6	3.25	3	1.68	5	24K
246HE1	HH	8	-16.1	-22.3	3.75	2	1.95	25	24K
246VE1	VV	8	-12.	-18.4	3.7	5	2.	25	24K
276HE1	HH	8	-16.2	-24.4	5.1	4	2.3	50	24K

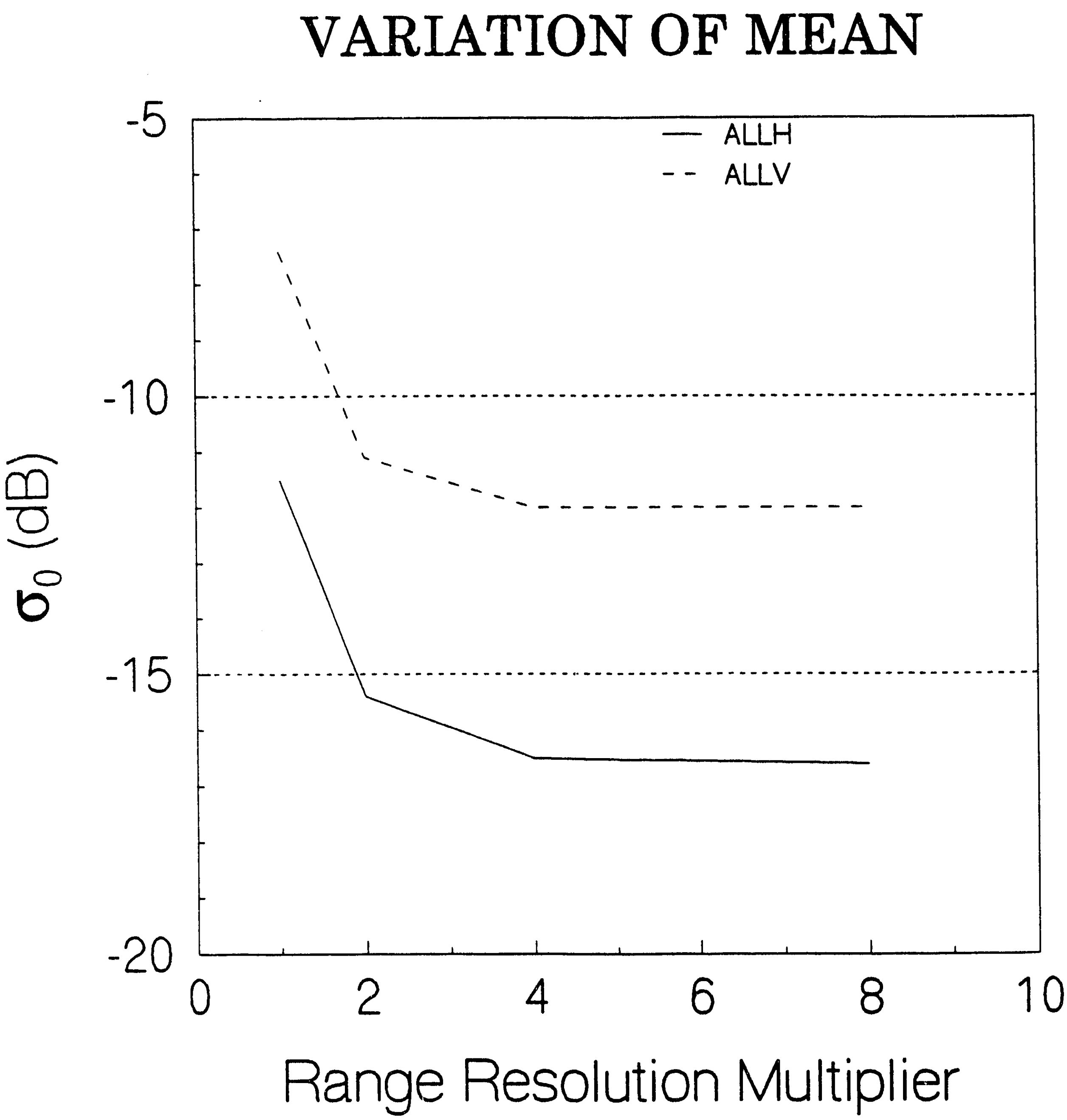


Figure 4
Variation of Aggregate Mean with Range Resolution

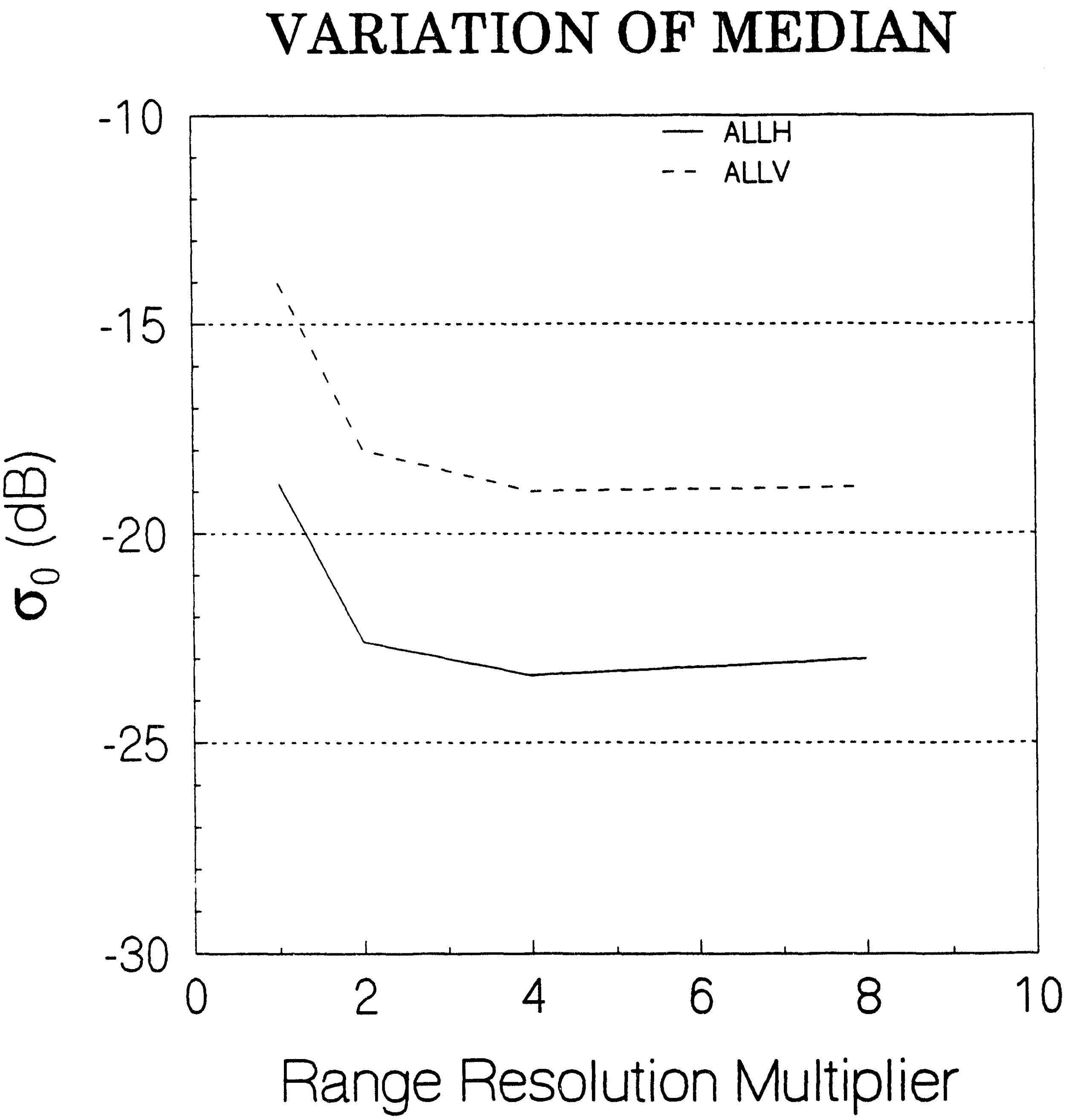


Figure 5
Variation of Aggregate Median with Range Resolution

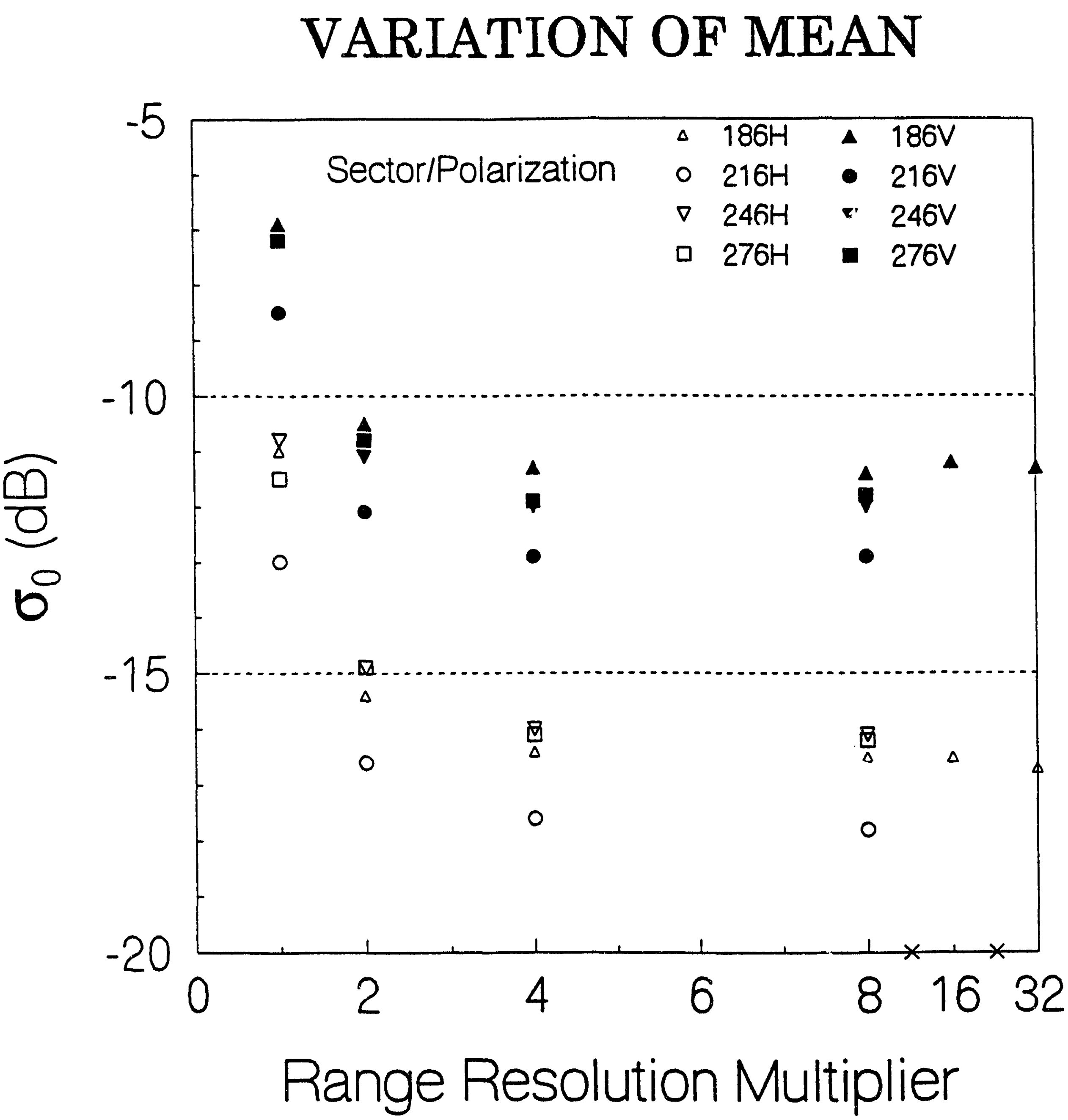


Figure 6
Variation of Sector Mean with Range Resolution

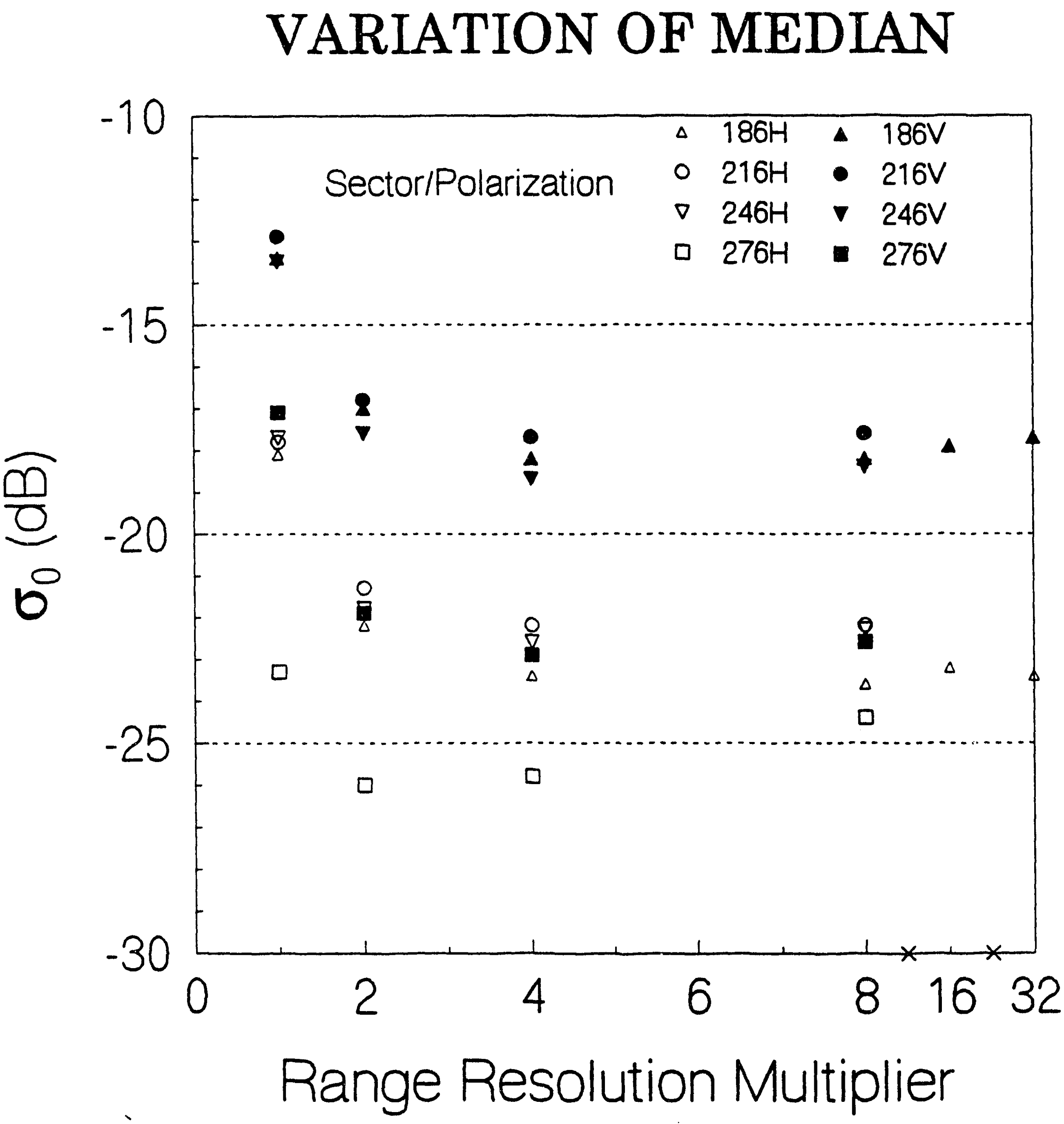


Figure 7
Variation of Sector Median with Range Resolution

276VE1	VV	8	-11.8	-22.6	5.76	9	2.72	50	24K

VII. CORRELATION OF CHIRP AND IMPULSE DATA

A portion of the data from the 186 degree sector was processed to produce a file of high resolution range-azimuth reflectivity values. This file was provided to Dr. Michael Tuley of GTRI to correlate with the PNL processed data collected for the same general region. His work indicated a high degree of correlation with an offset of 72.4 meters. The means and median values, when scaled for the apparent offset, were within about 1 dB. A subsequent examination of the SPC processing algorithms uncovered an improper range slide of about 200 feet. Removal of that range brings the spatial assignments of the two data sets within close agreement. All data was processed with the corrected range.

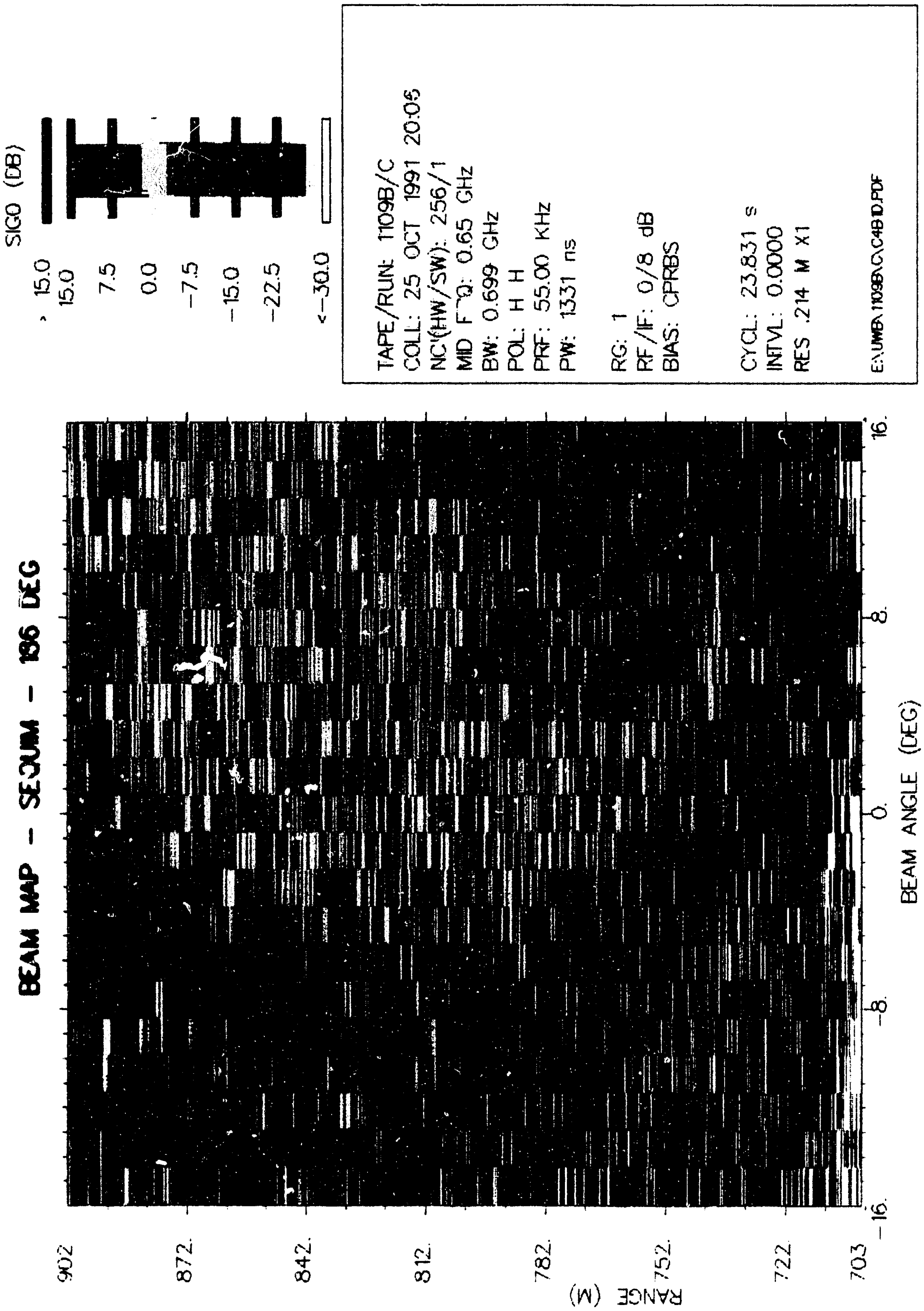


Figure 8.
Resolution: .214m x1 Center Frequencies - H polarization

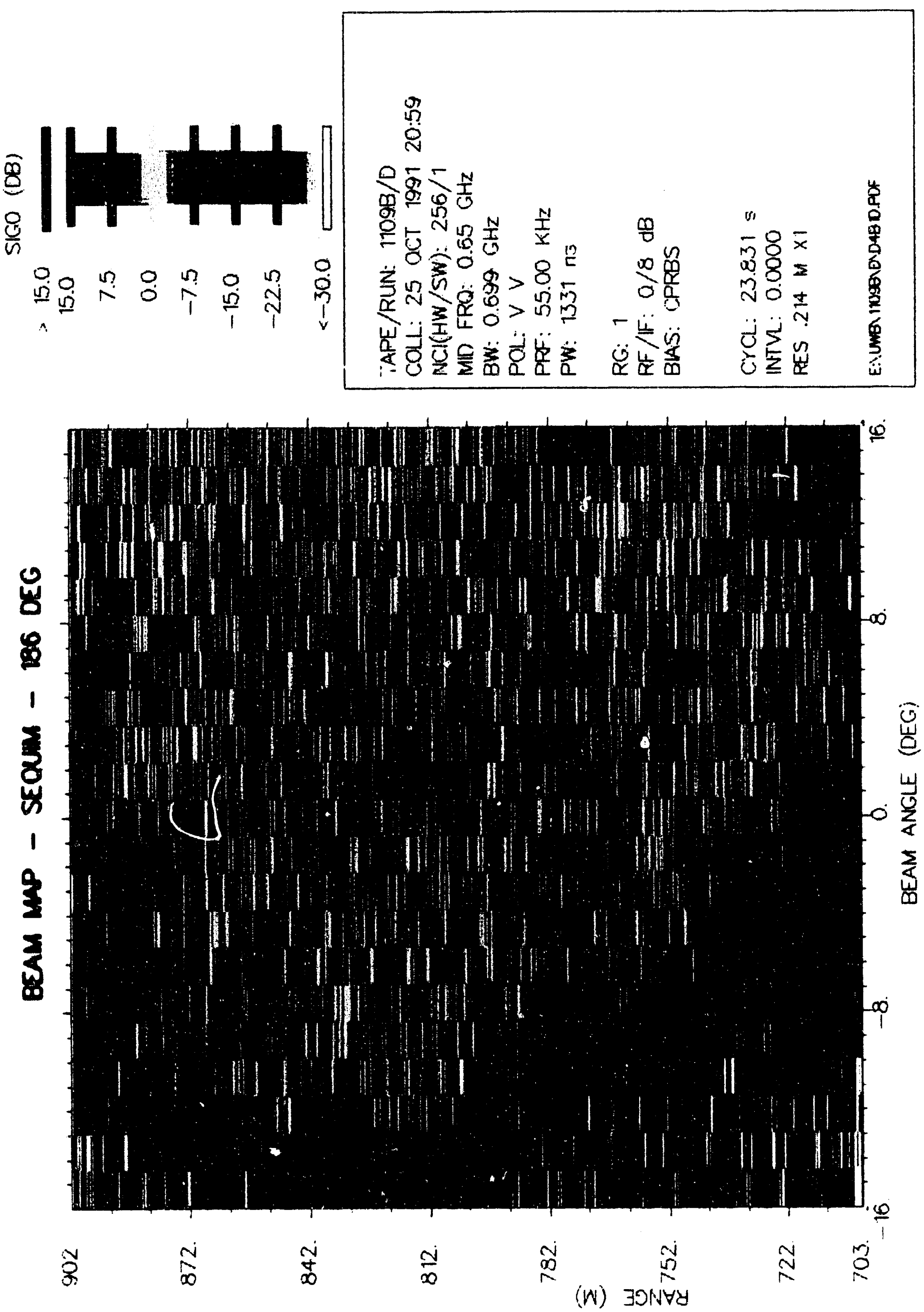


Figure 9.
Resolution: .214m x1 Center Frequencies - V polarization

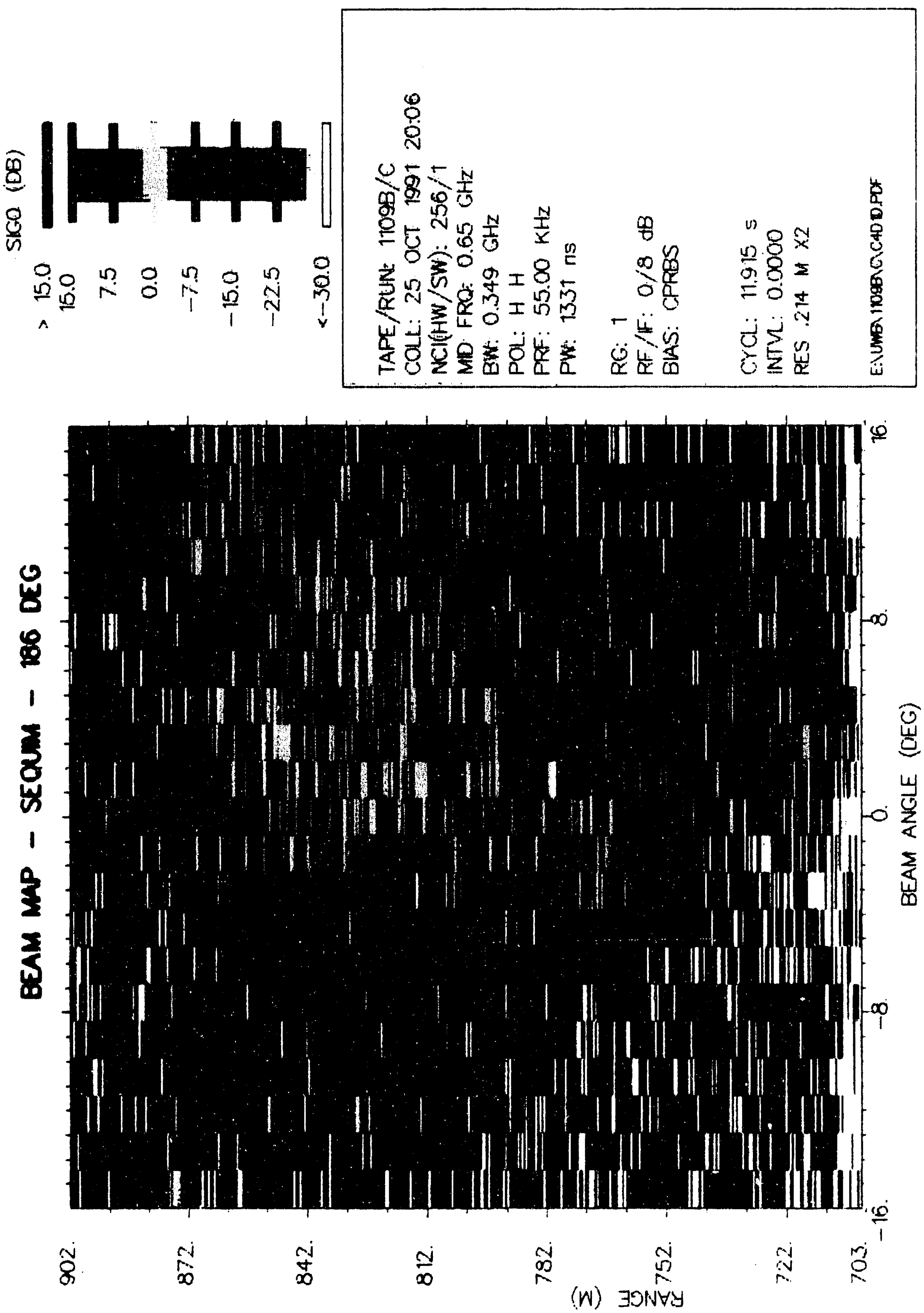


Figure 10.
Resolution: .214m x2 Center Frequencies - H polarization

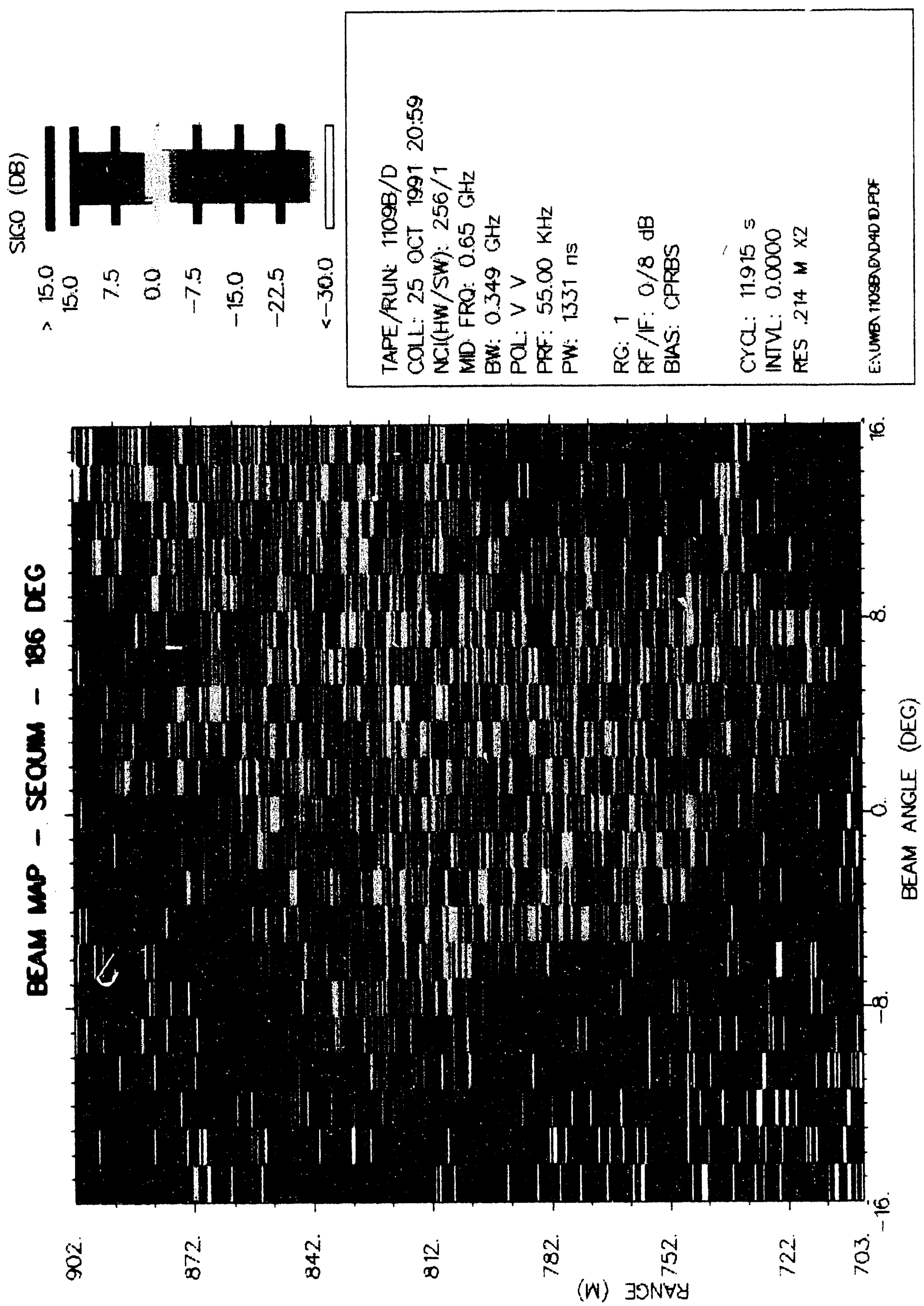


Figure 11.
Resolution: .214m x2 Center Frequencies - V polarization

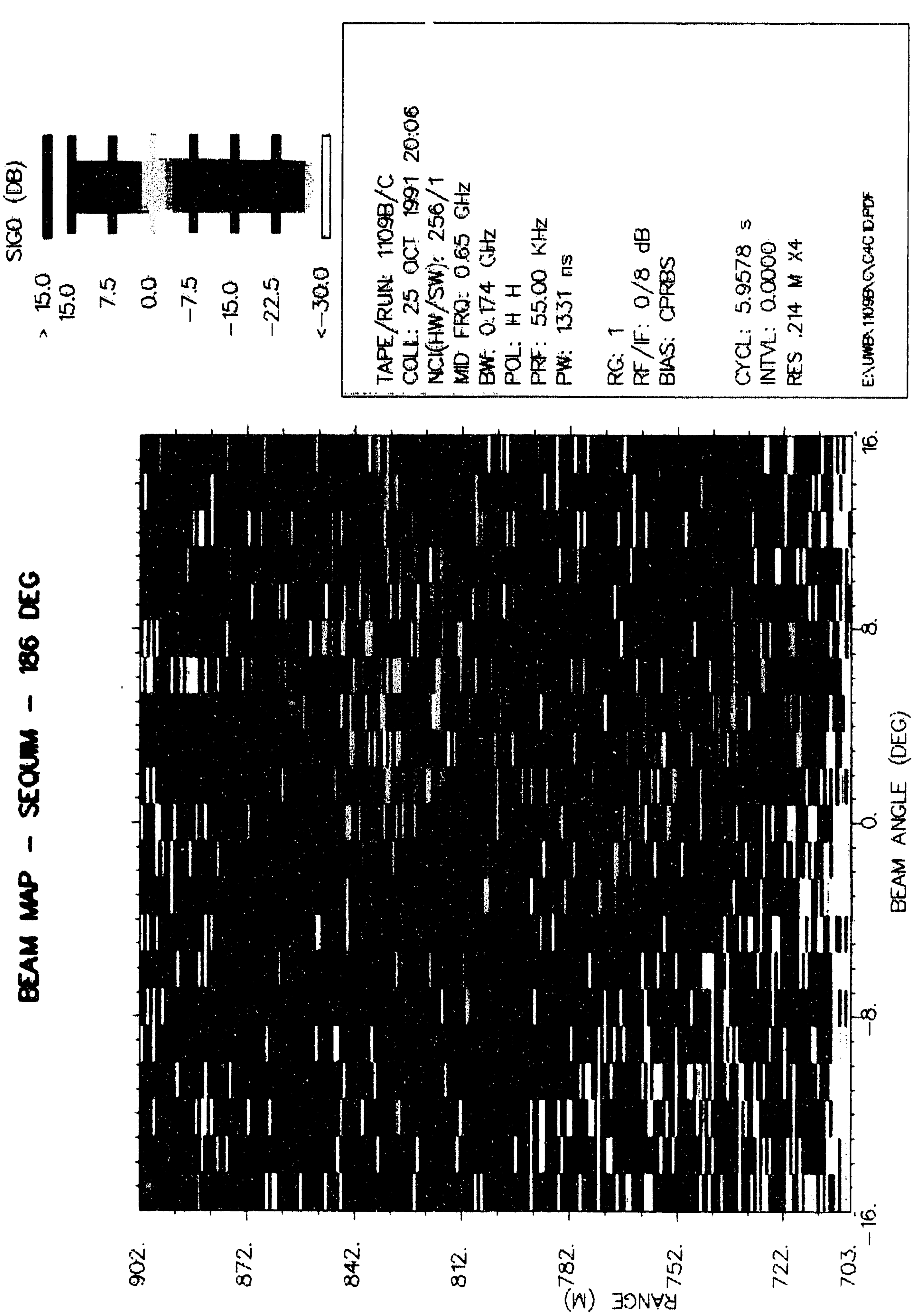


Figure 12.
Resolution: .214m x4 Center Frequencies - H polarization

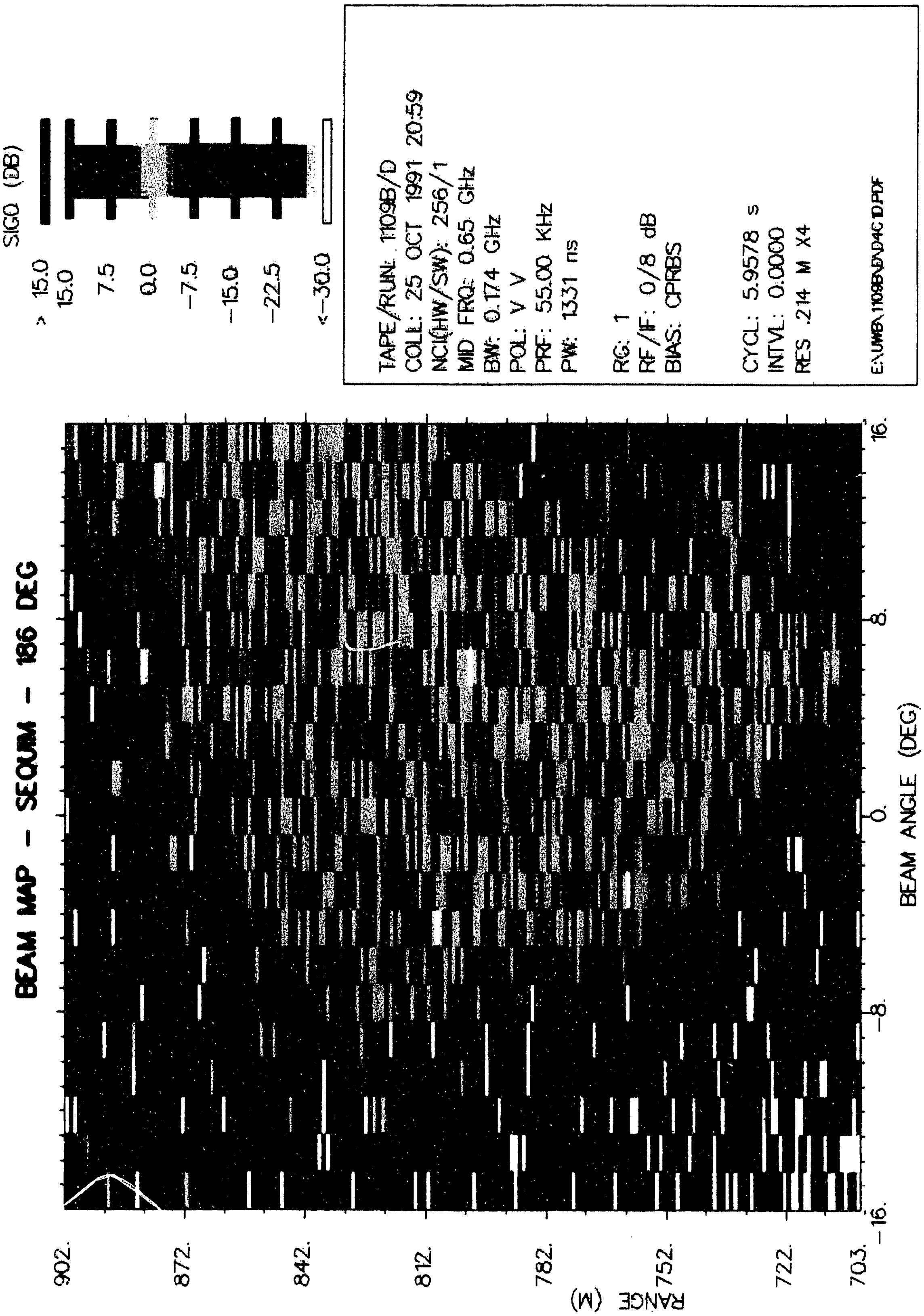


Figure 13.
Resolution: .214m x4 Center Frequencies - V polarization

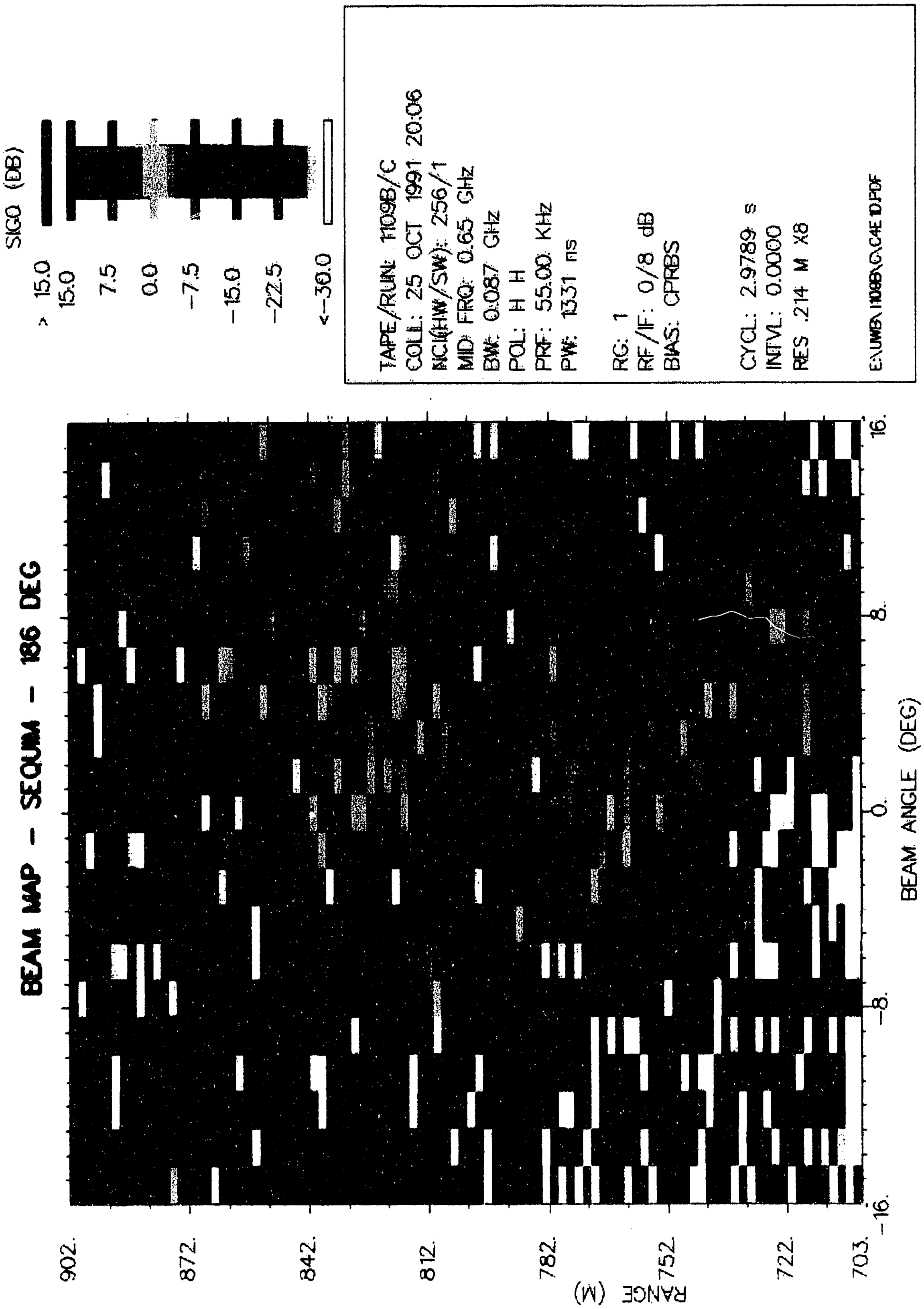


Figure 14.
Resolution: .214m x8 Center Frequencies - H polarization

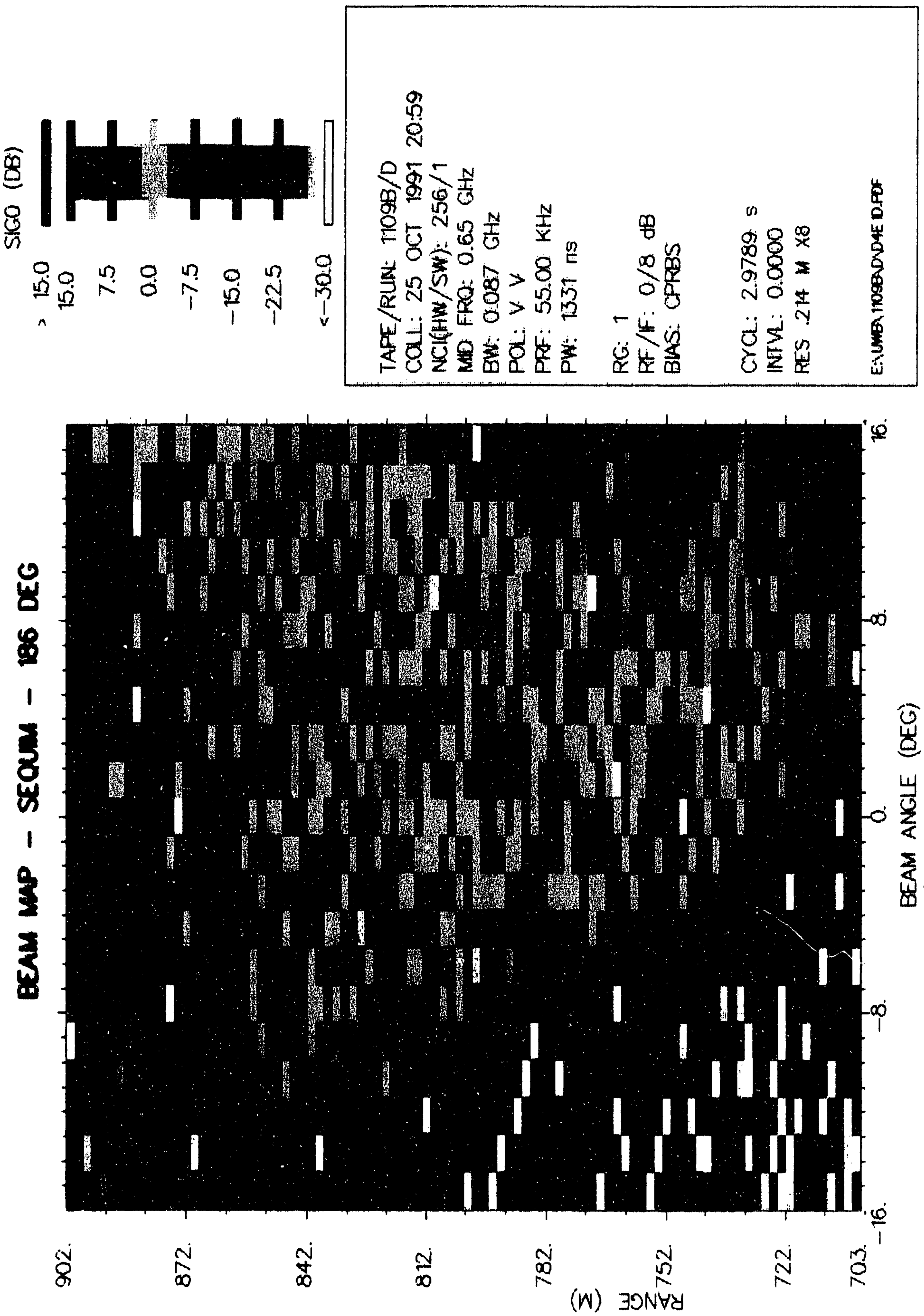


Figure 15.
Resolution: .214m x8 Center Frequencies - V polarization

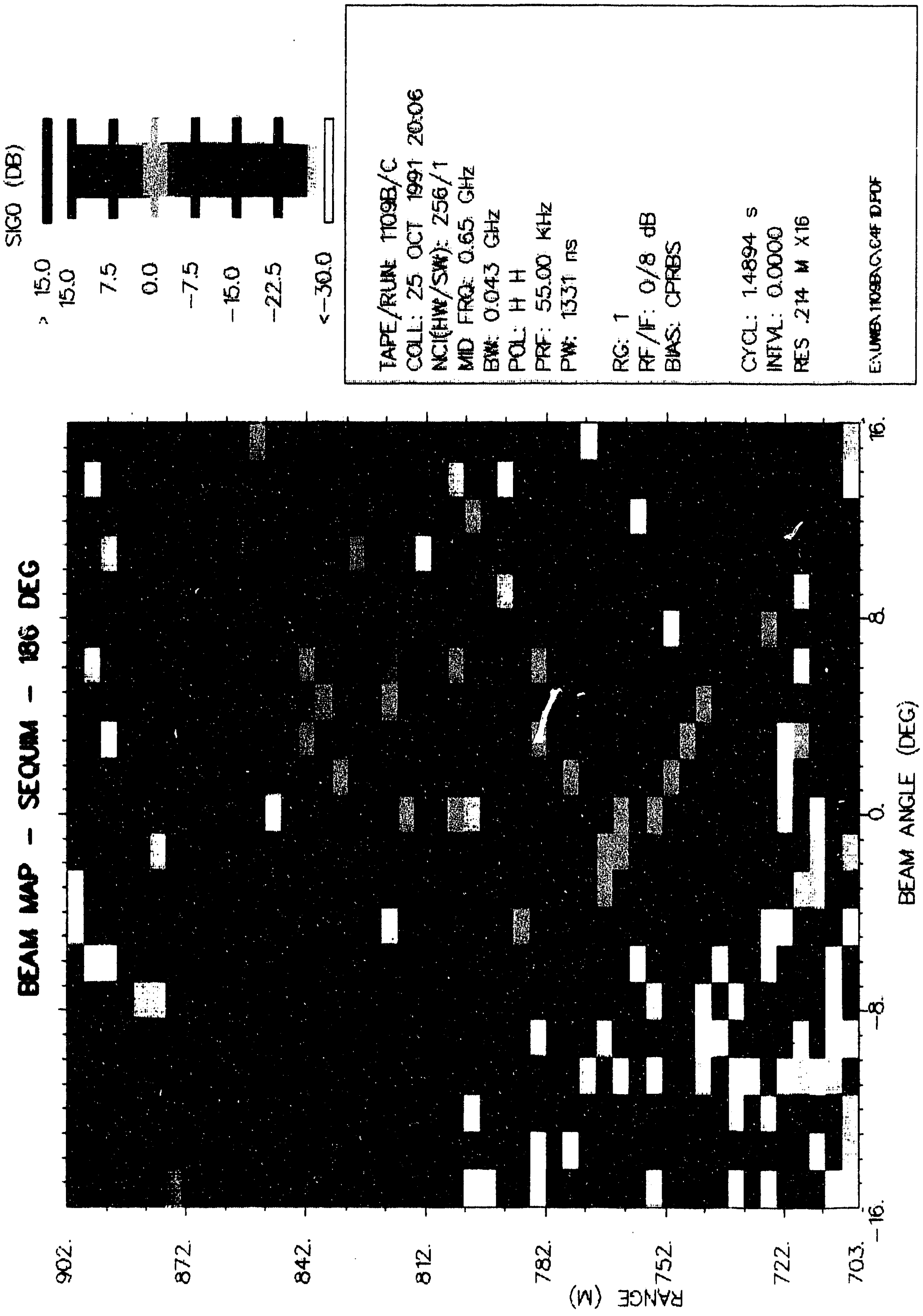


Figure 16.
Resolution: .214m x16 Center Frequencies - H polarization

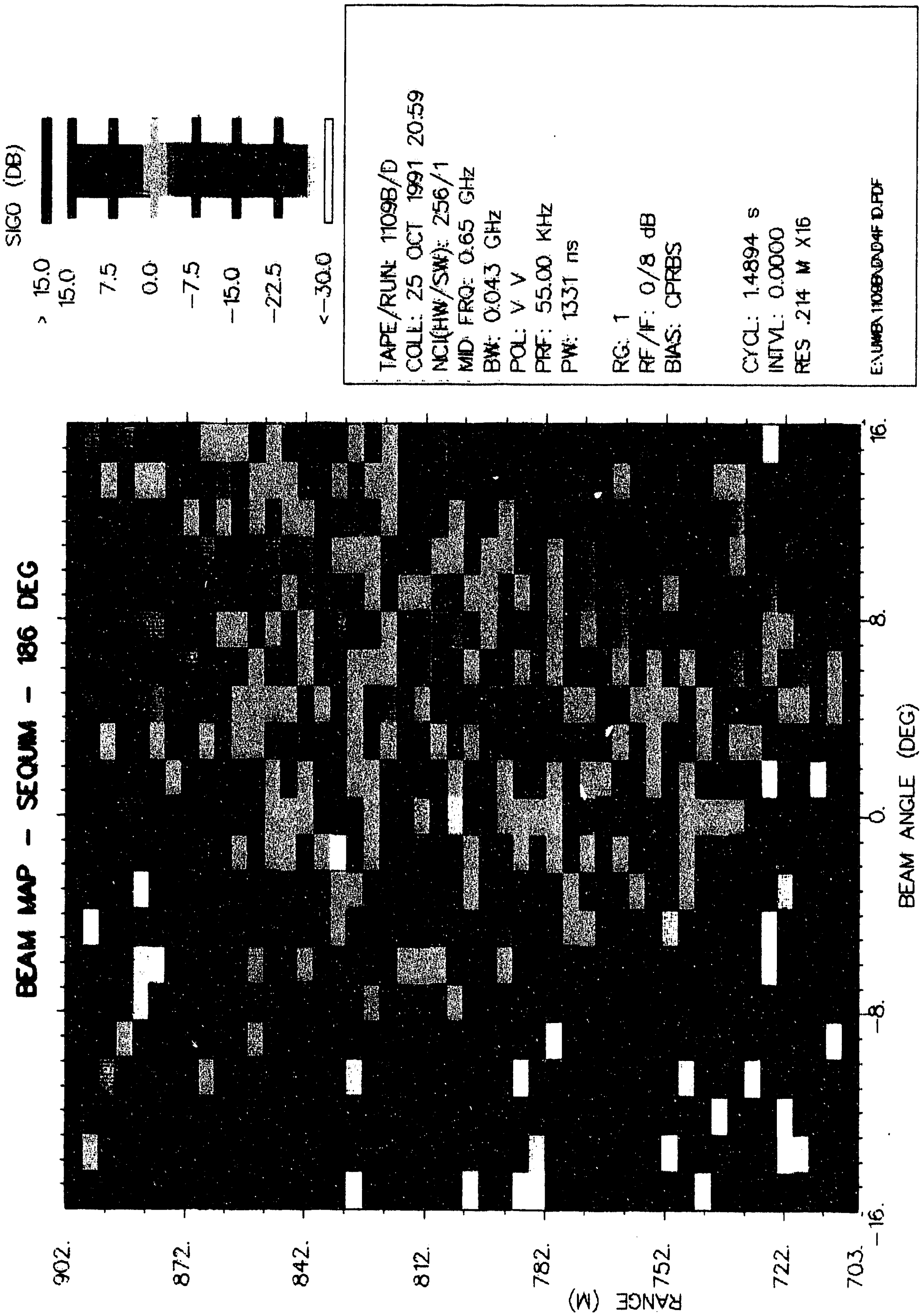


Figure 17.
Resolution: .214m x16 Center Frequencies - V polarization

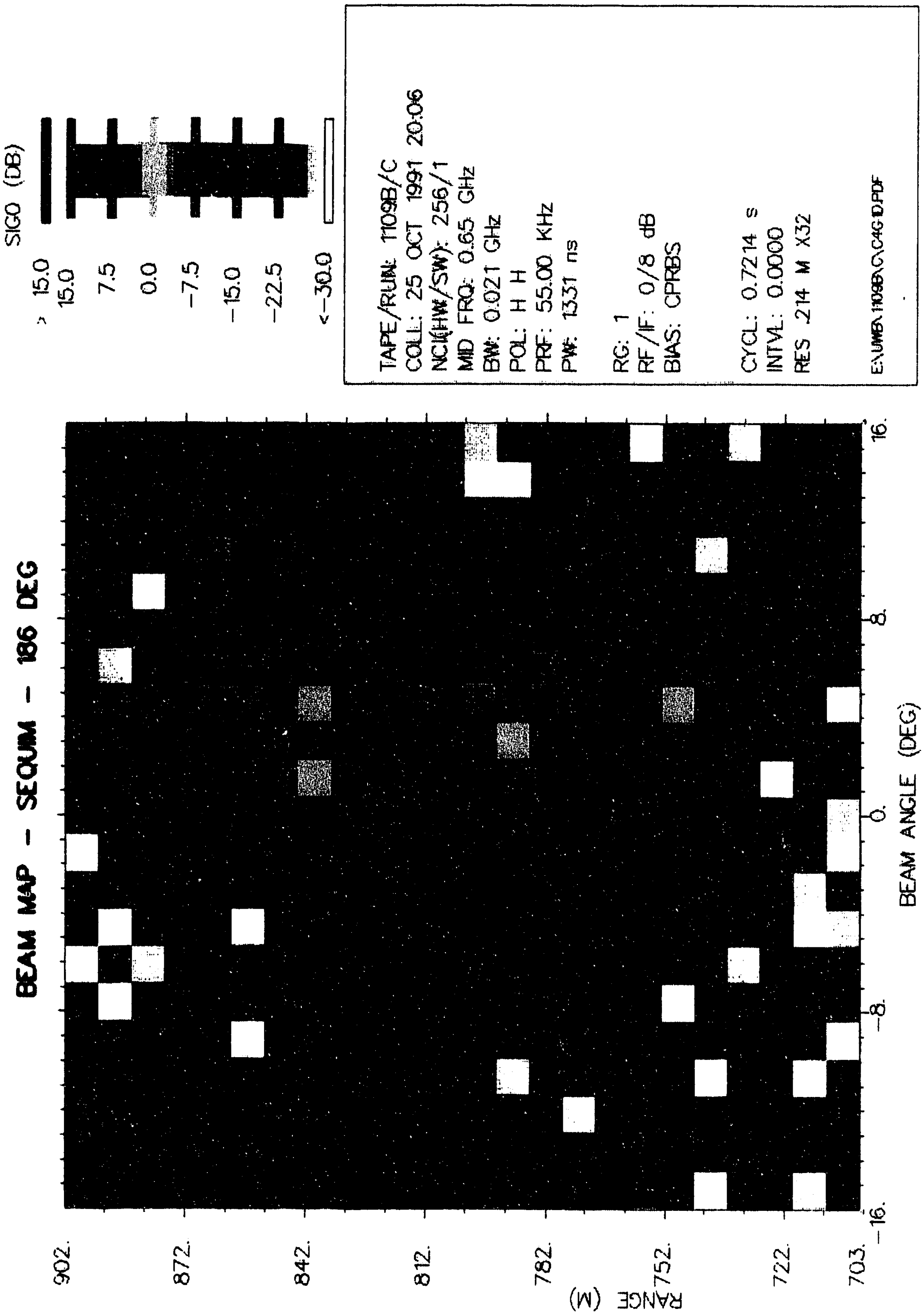


Figure 18.
Resolution: .214m x32 Center Frequencies - H polarization

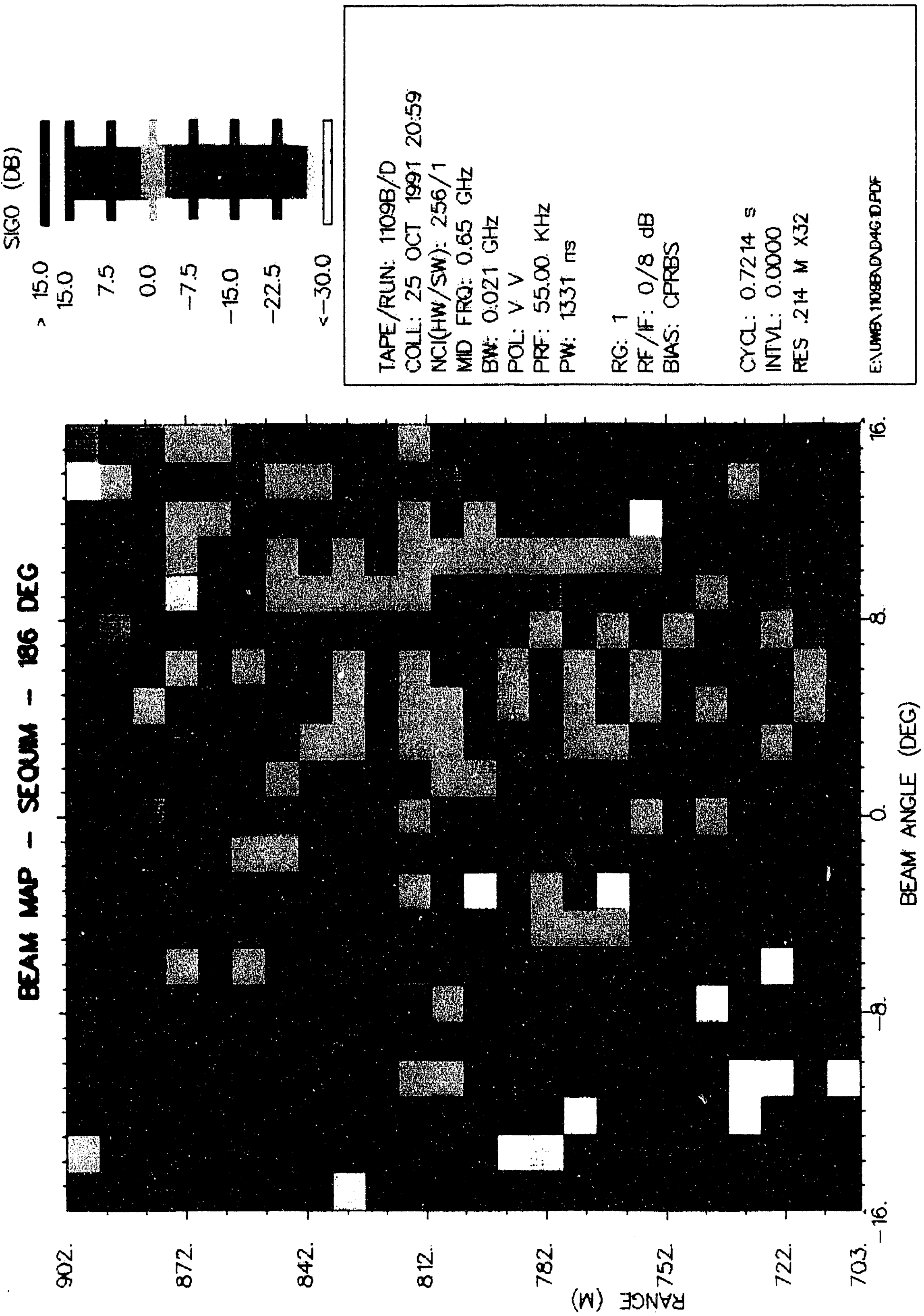


Figure 19.
Resolution: .214m x32 Center Frequencies - V polarization

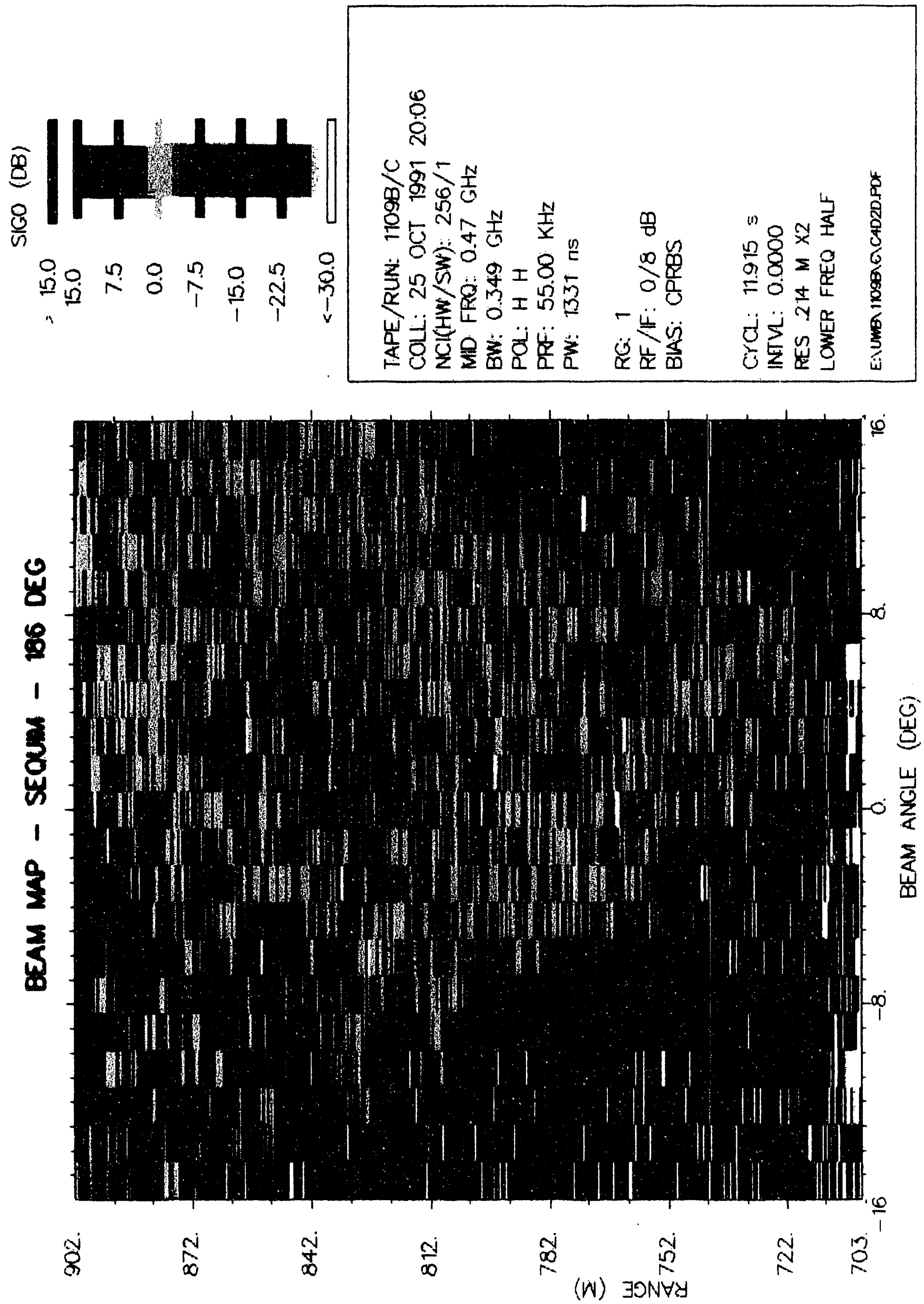


Figure 20.
Resolution: .214m x2 Lower Frequencies - H polarization

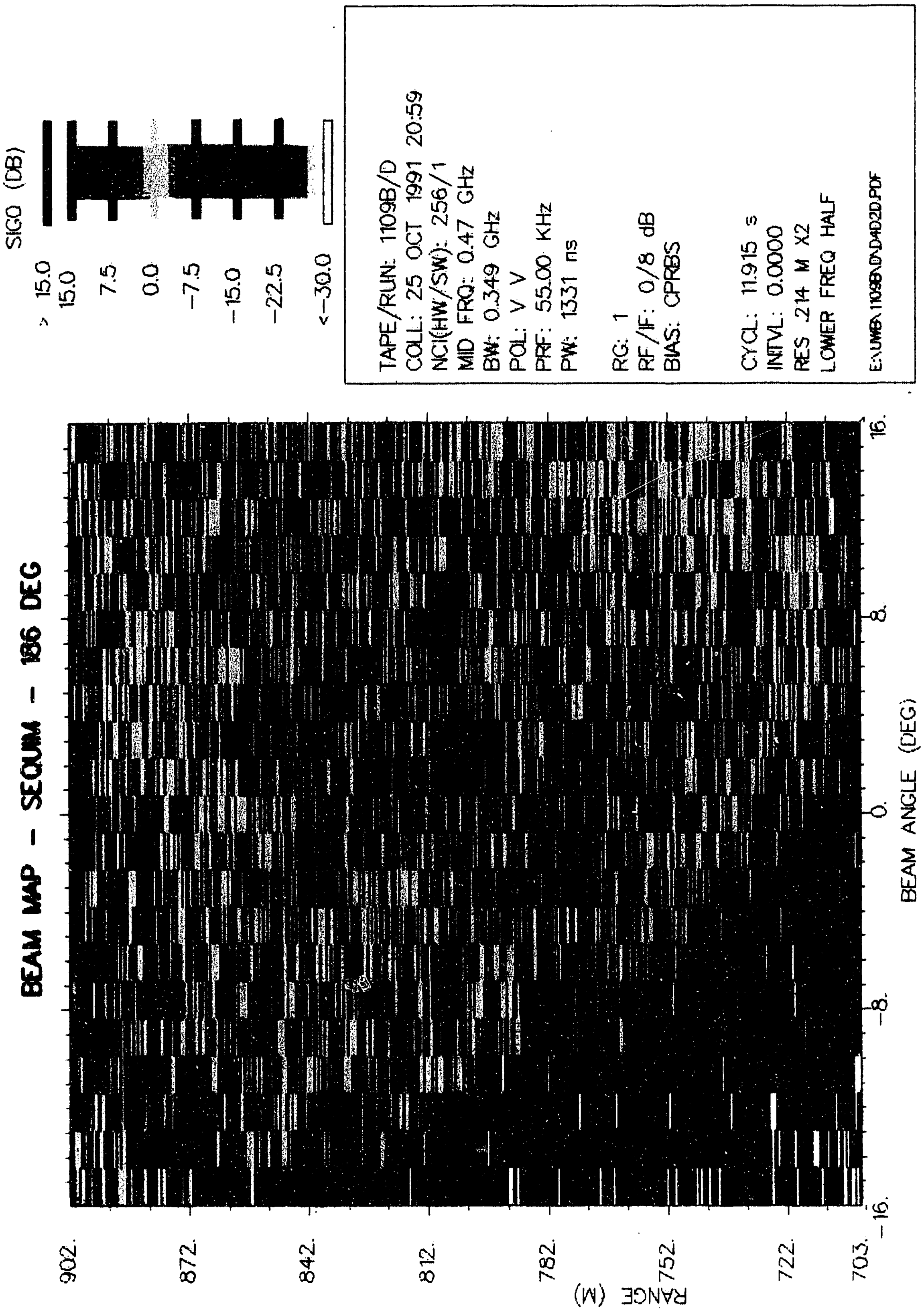


Figure 21.
Resolution: .214m x2 Lower Frequencies - V polarization

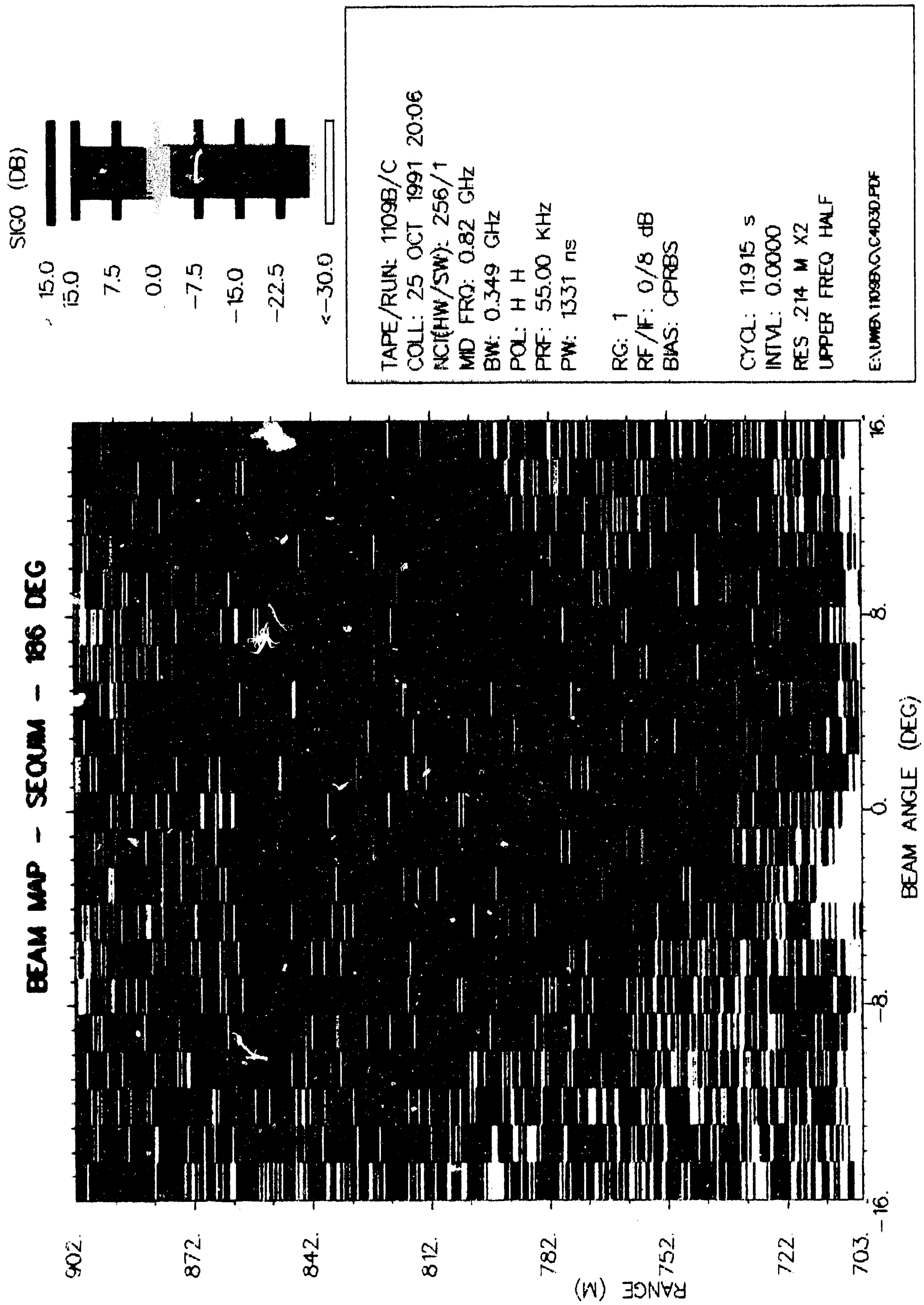


Figure 22.
Resolution: .214m x2 Upper Frequencies - H polarization

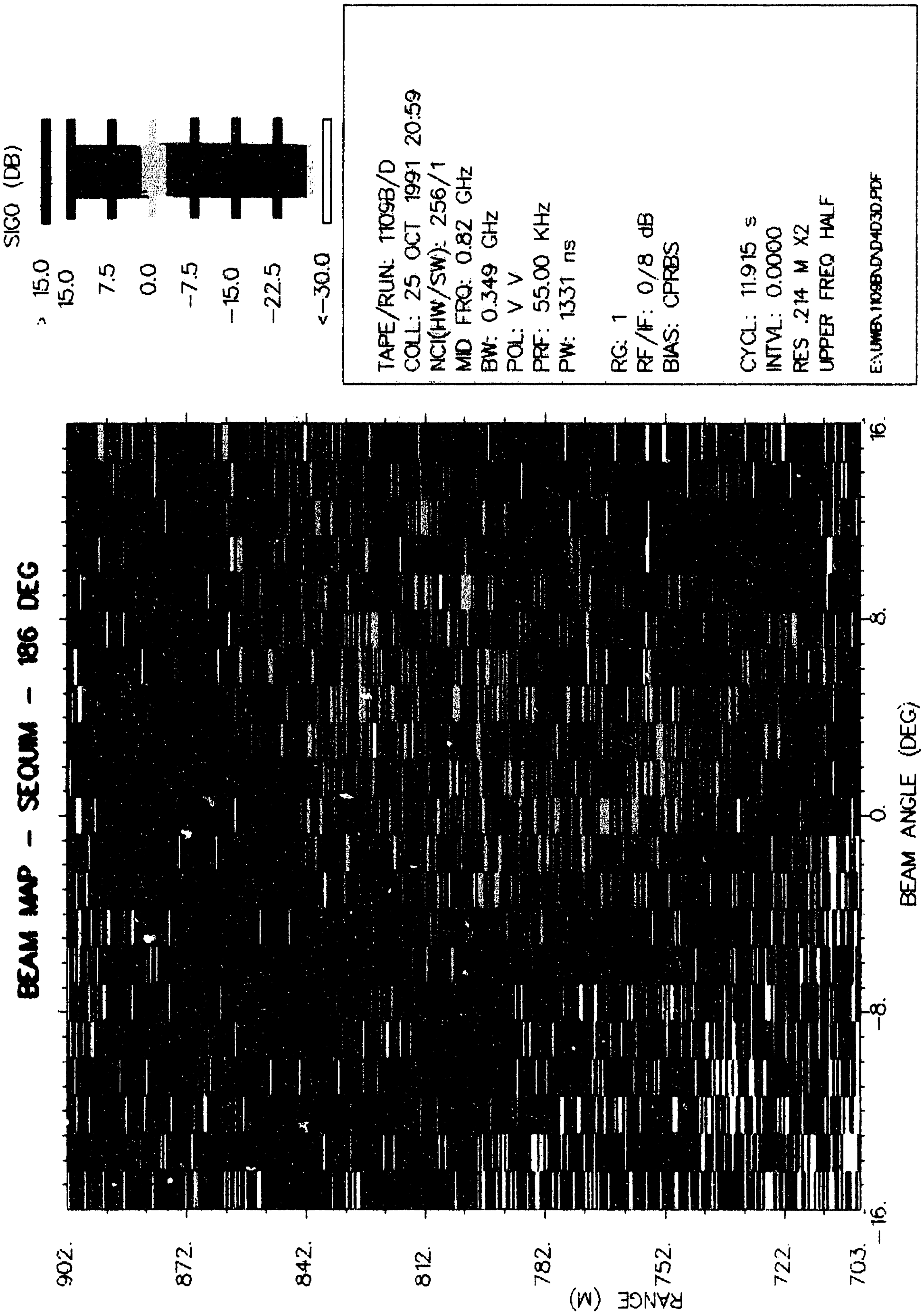


Figure 23.
Resolution: .214m x2 Upper Frequencies - V polarization

APPENDIX B:

Ground Truth for Original Site 1991 Sequim Measurements

UWB CLUTTER EXPERIMENT GROUND TRUTH DATA FOR A FORESTED SITE

V. I. Cullinan
E. Telenick

November 1991

Letter Report prepared for
Pacific Northwest Laboratories

INTRODUCTION

Battelle, Marine Sciences Laboratory was requested to participate in the collection of ground truth data in association with the UWB Clutter Radar Experiment conducted for the Defense Advanced Research Projects Agency through a contract with the Department of Energy. The data collection criteria for the radar experiment were to determine the general vegetative and environmental characteristics along 3 transect lines of illumination from a pre-selected site in the Quilcene Ranger District, Olympic National Forest, Washington.

Historically, radar clutter measurement efforts have been planned and sized so that large areas have fallen within the measurement zone. Consequently, ground truth measurements have often consisted only of general descriptions of terrain type (e.g., wheat fields, forest canopy, desert). This experiment however, was designed to target a much smaller area, thereby allowing the scope of the ground truth data to be expanded from the historical level of data acquisition. The goal of data collection in this experiment was to balance the qualitative and quantitative environmental descriptions to allow for a greater understanding of the reflective radar scatter without providing excessive detail superfluous to the radar designer.

METHODS

Field surveys were conducted at a pre-selected "forested" site within the Olympic National Forest. Data collection was designed to characterize the landscape in a general manner for the following parameters: 1) stand type including size, spacing, and dominant species; 2) canopy profile and coverage; 3) understory vegetation type and amount; 4) forest litter accumulation and description; and 5) moisture level. Details of the survey including transect location, field methods, statistical analysis, and photographic records of the specific sites have been included and provide a database useful to ground-truth the forest cover types within the site. Ancillary documentation in the form of aerial photographs plus Geographical Information System (GIS) data on specific timber stands within the radar illumination path will be included as a supplement to this document (Supplement 1).

Transect Location

The ground truth sampling area was limited to a 2 km radius from the radar site, eliminating the area of negative slope which extends approximately 0.5 km from the radar site counterclockwise in a north to east direction. Within the sampling area three transect line azimuths were predetermined as potential lines of radar illumination and were used for the ground truth data collection. These transects, as viewed from the radar site from south to west, are referred to as the Mount Zion, One-K, and Bear Mountain transects and face 167, 216, and 261 degrees, respectively (Figure 1) (Supplement 2).

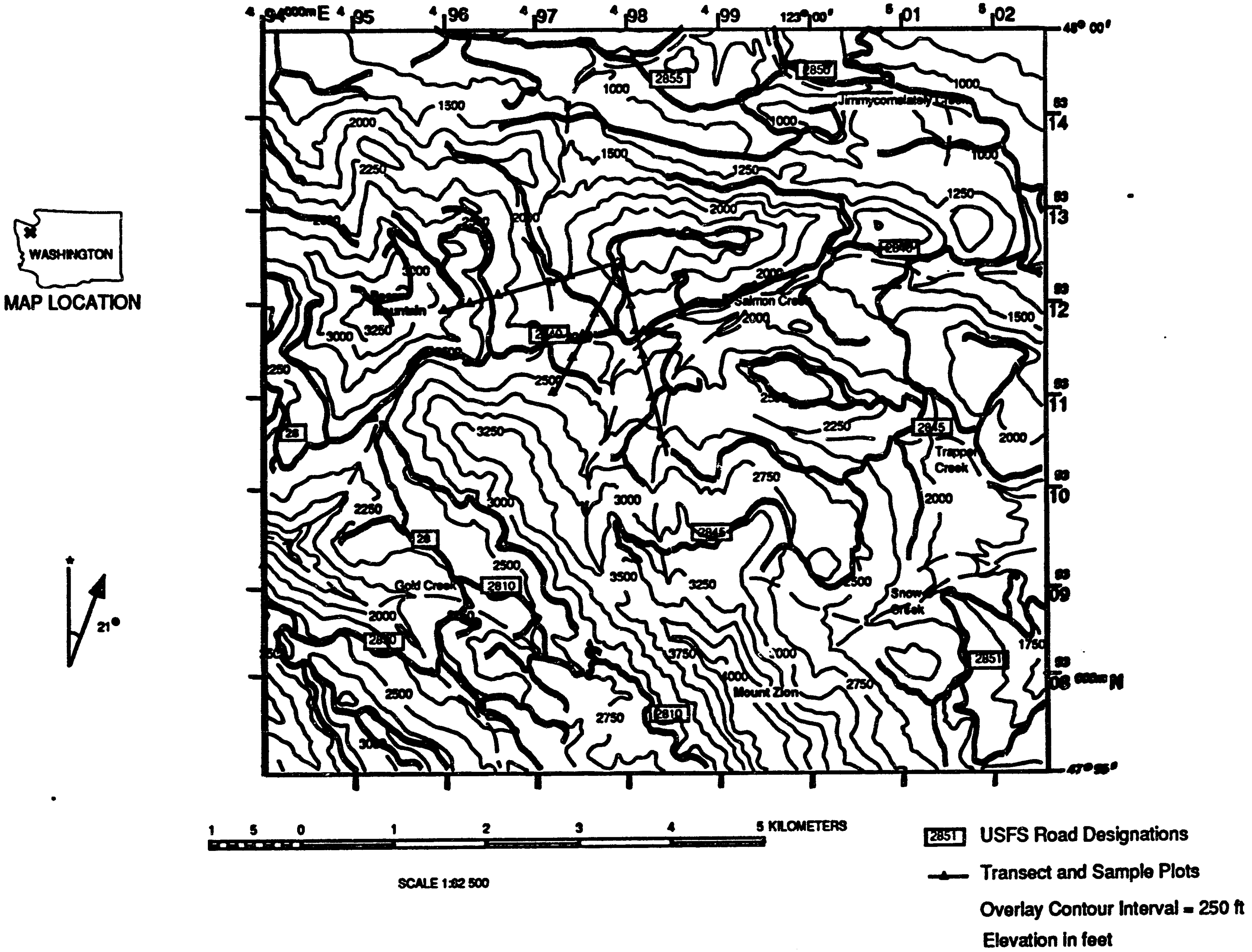
Location of the transect lines was accomplished with a hand held compass, aerial photographs, helium balloons, and an observer at the radar site. Using two-way radios, the observer guided a second technician equipped with the balloons to points along the transects which intersected accessible roads. The center lines of illumination were approximated with two balloons per transect plus a final target zone. Photographs were used to document the location of the three transects as seen from the radar site (Appendix A).

Once the transect lines were located, color aerial photographs were used to delineate potential timber stands and clearcuts for sampling. Stand types were verified along each transect during an initial field survey, and sample points were selected based on gross differences in stand composition. A total of 14 sample plots were selected for the three transects, with 4 to 5 sample plots per transect (Figure 1).

Field Methods

Due to the cursory nature of the stand surveys, a single sample plot was chosen to describe each stand. Each plot was carefully selected to be representative of that stand type. For example, plot centers were placed away from the edges of clearcuts or logging roads to minimize the effects of blowdown or logging construction. A plot radius of 16.7 ft, which represents 1/50 of an acre on level ground, was selected because it was large enough to accommodate minor site variability yet small enough to allow a single surveyor to efficiently inventory the site. Both general stand conditions and specific site conditions as defined by the boundaries of the plot were described for each sampling plot on a field form (Figure 2).

Figure 1. UWB Experiment Ground Truth Sampling Plot Locations as Adapted from A Custom Correct Map, Little River Enterprises, 1990


WASHINGTON
MAP LOCATION
21°
4 94 000m E
4 95
4 96
4 97
4 98
4 99
123° 00'
5 01
5 02
48° 00'
47° 55'
T4
T3
T2
T1
T0
09
08 000m N
Jimmycomelately Creek
Salmon Creek
Trapper Creek
Gold Creek
Snow Creek
Mount Zion
2855
2850
2810
2845
2851
28
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250
3500
3750
4000
1 5 0 1 2 3 4 5 KILOMETERS
SCALE 1:62 500
2851 USFS Road Designations
Transect and Sample Plots
Overlay Contour Interval = 250 ft
Elevation in feet

UWB CLUTTER EXPERIMENT

Observer ____________ Date ____________

Transect ____________ Sampling Station ____________

Site Description: ____________

Slope: ____________ Overall Canopy Cover: ____________

General Over/Under Story Description: ____________

(Major Species/Woody Fuels/Litter) ____________

Photo Log:
- N ____
- E ____
- S ____
- W ____
- C ____

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: ____________

Stand Data: Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover								
% Overstory								
Number/Class	.	.	.					
Average Height	.	.	.					
Major Species	.	.	.					
Minor Species	.	.	.					

Reviewed By: ____________

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

WH - Western Hemlock

WRC - Western Red Cedar

PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species

Figure 2. UWB Clutter Experiment Ground Truth Data Collection Form

The data taken at each plot included general stand characteristics of the site and photographs. The stand type at each sample plot was described in terms of its overall composition, slope, canopy cover, litter accumulation, and moisture characteristics. These descriptions provide an overview of the general area, not necessarily restricted to the plot perimeter. Photographs were taken from the center of each sample plot toward the cardinal compass points (North, East, South, West) plus the canopy to provide a visual record of the various sample plots (Appendix B).

Specific data was collected within the confines of the circular plot. The center point of each plot was marked with colored flagging, and plot perimeters were marked with tree marking paint. Overstory vegetation was categorized using 5 stem diameter classifications: 0-2, >2-6, >6-12, >12-16, and >16 inches. All diameters were measured at a standard height of 4.5 ft. Trees which did not have a measurable stem at this height were tallied as shrubs. Major and minor species represented in the plot were recorded along with an ocular estimate of the average tree height by stem size classification. Due to the variability of heights and multiple trees per class in many of the sample plots, these estimates should be considered very coarse. Occasional tree heights were measured using a clinometer to provide a "calibration" for the ocular estimates.

Each site was further described in terms of the vegetation for both ground cover and overstory coverage. Vegetation was classified as either litter/bare ground, grasses/forbs, shrubs, or one of the 5 tree stem classifications. The ground cover survey was defined as the percentage of the circular plot covered by each of these vegetative classifications. Because this survey dealt primarily with the ground cover composition, only the cross-sectional diameters of the woody stems of trees were evaluated as a percentage of the overall plot for this calculation. Shrubs were tallied as ground cover unless they were tall enough to be considered as a factor in the overstory. In these cases the shrubs were considered small trees and categorized by stem diameters. The percent overstory survey was conducted as if the plot was viewed from above. In areas where there was multiple overstory layering, the uppermost canopy was recorded in the appropriate stem diameter classification. Thus, for both surveys the overall coverage totalled, but did not exceed 100%.

Moisture conditions were described for each site in terms of overstory shading, aspect, and litter accumulation and their influence on the relative "wetness" of a stand. Rain gauges were set up at three locations along each transect, and at the radar site, in an effort to quantify microclimate variability within the study area. These gauges were monitored periodically throughout the duration of the radar field experiment.

Statistical Analysis

Data from the field survey forms were entered into an Excel spreadsheet (Excel Version 3.0, MicroSoft Corporation, One Microsoft Way, Redmond, WA 98052) for analysis. Plots were generated using both Excel and DeltaGraph software (DeltaGraph Version 1.5, DeltaPoint, Inc., 200 Heritage Harbor, Suite G, Monterey, CA 93940). Data were summarized by both stand classification and by individual transect. Individual sample plot data are listed in Appendix B.

For the purpose of analysis, three stand classes were used to characterize the 14 sampling plots. Stands were classified as Class 1 if the major tree component was absent or could be characterized as seedling/sapling with a diameter of ≤2 inches, Class 2 if the major tree component could be harvested as pole timber, or Class 3 if the major tree component could be harvested as saw timber. Pole and saw timber stands were identified as having trees with a diameter of ≤12 and >12 inches, respectively.

All sampling plots were categorized within one of the stand classes in order to estimate the mean and standard deviation for each of the stand parameters measured. Weighted means, using the number of trees observed in each stem diameter class as the weights, were calculated to estimate the mean tree spacing, tree diameter, and tree height. The moisture level at each site was ranked without ties from 1 (driest) to 5 (wettest) to produce an average relative moisture for each stand class.

RESULTS AND DISCUSSION

Using the individual plot and stand data summaries, transect vegetative and environmental parameters were described along with the general stand characteristics associated with the three stand classifications (Table 1).

Table 1. UWB Clutter Experiment Ground Truth Stand Summary of Vegetative and Environmental Characteristics

TRANSECT	SITE	OVERALL STAND TYPE	STAND CLASS	OVERALL LITTER DEPTH (INCHES)	OVERALL CANOPY (%)	10/24 -11/1 RAINFALL (INCHES)	MOISTURE LEVEL	TREE SPACING (FT)	DIAMETER (INCHES)	HEIGHT (FT)	UNDERSTORY COMPOSITION
BEAR MNT	M1	CLEAR/SEEDLING	1	18	0	0.9	3	29.52	1.00	5.00	1.33
BEAR MNT	M4	CLEAR/SLASH	1	18	0	0.9	1	0.00	0.00	0.00	1.39
BEAR MNT	M2	CLEAR/ALDER REGEN	2	3	15	-	2	25.58	1.30	11.50	1.92
BEAR MNT	M5	MIXED LRG. POLE/ DH	2	12	90	-	4	8.45	4.33	39.88	1.02
BEAR MNT	M3	SAW/LRG. POLE	3	24	60	0.7	5	25.30	7.33	47.78	1.24
MT ZION	Z1	OLD CLEAR/ MEADOW	1	1	5	0.86	2	22.60	3.00	22.00	1.87
MT ZION	Z5	CLEAR/ SLASH	1	12	0	-	1	0.00	0.00	0.00	1.21
MT ZION	Z2	LRG. POLE/ SM. SAW	2	2	80	-	3	24.61	5.11	32.22	1.53
MT ZION	Z4	SM. POLE/ DOGHAIR	2	18	95	0.96	4	19.91	5.83	32.83	1.33
MT ZION	Z3	MIXED LRG. SAW	3	32	30	-	5	27.88	3.05	21.82	1.41
ONE-K	S3	CLEAR/SEEDLING	1	4	0	0.94	1	17.04	1.00	10.00	2.30
ONE-K	S1	POLE	2	18	80	1.1	3	14.19	5.77	44.23	1.12
ONE-K	S2	MIXED SAW/POLE	3	24	90	-	4	13.90	8.17	80.00	1.07
ONE-K	S4	OLD GROWTH	3	32	85	0.66	5	18.76	11.29	111.43	1.03
		MEAN	CLASS 1	10.60	1.00	0.90	1.60	13.83	1.00	7.40	1.62
			CLASS 2	10.60	72.00	1.03	3.20	18.55	4.47	32.13	1.38
			CLASS 3	28.00	66.25	0.68	4.75	21.46	7.46	65.26	1.19
		STDEV	CLASS 1	7.86	2.24	0.03	0.89	13.38	1.22	9.15	0.45
			CLASS 2	7.80	32.52	0.10	0.84	7.23	1.87	12.58	0.36
			CLASS 3	4.62	27.50	0.03	0.50	6.33	3.40	38.91	0.18

Profiles of each stand class along the transect lines are shown in Figure 3. Distances within each stand type were calculated from aerial photographs using two points at a defined distance and estimated slope correction factors to compensate for uneven terrain (Table 2). Figure 4 and depicts the composition of each transect in terms of the three primary stand classifications.

General stand characteristics were averaged for all sample plots within a common stand class. Summary statistics are presented for litter depth, percent canopy, current rainfall, and relative moisture (Figure 5). As expected, the average litter depth, canopy cover, and relative moisture increased as the tree sizes increased. Increased canopy cover and litter depths tend to prevent sites from drying as fast. The litter depth was greater than expected in the class 1 areas because of residual debris from recent logging on several of the plots. Percent canopy cover was highest within the class 2 stands (pole) because of closer spacing and more fully developed crowns on several of the sample plots. Rainfall levels were based solely on rain gauge locations and could have been influenced by local variation as well as canopy obstructions preventing rainfall penetration.

Additional stand information, including average tree spacing, diameter, height, and the composition of the understory component, was also calculated by stand class (Figure 6). Tree spacing increased with stand class, indicating a trend toward wider spacing as trees matured. This trend is expected due to natural thinning as a result of competition for nutrients and available sunlight and due to commercial thinning operations. Tree diameters follow a similar trend; however, the overall averages are considerably smaller than the defined size classifications for pole and saw timber. This reduction in diameter can be explained by the few number of larger trees in each sample plot and many smaller trees downweighting the larger diameters. Average tree heights were calculated using the same weighting method; therefore, while the trends are representative, the actual height averages reflect mixed tree sizes within a class type. The average understory composition portrays the relative contribution of bare ground/litter, grasses/forbs, or understory shrubs (coded as 1, 2, and 3 respectively) ignoring the stem diameter classes. Less understory foliage (grasses, forbs, and shrubs) was represented in the larger diameter stands, primarily due to the heavy litter accumulation in these sites.

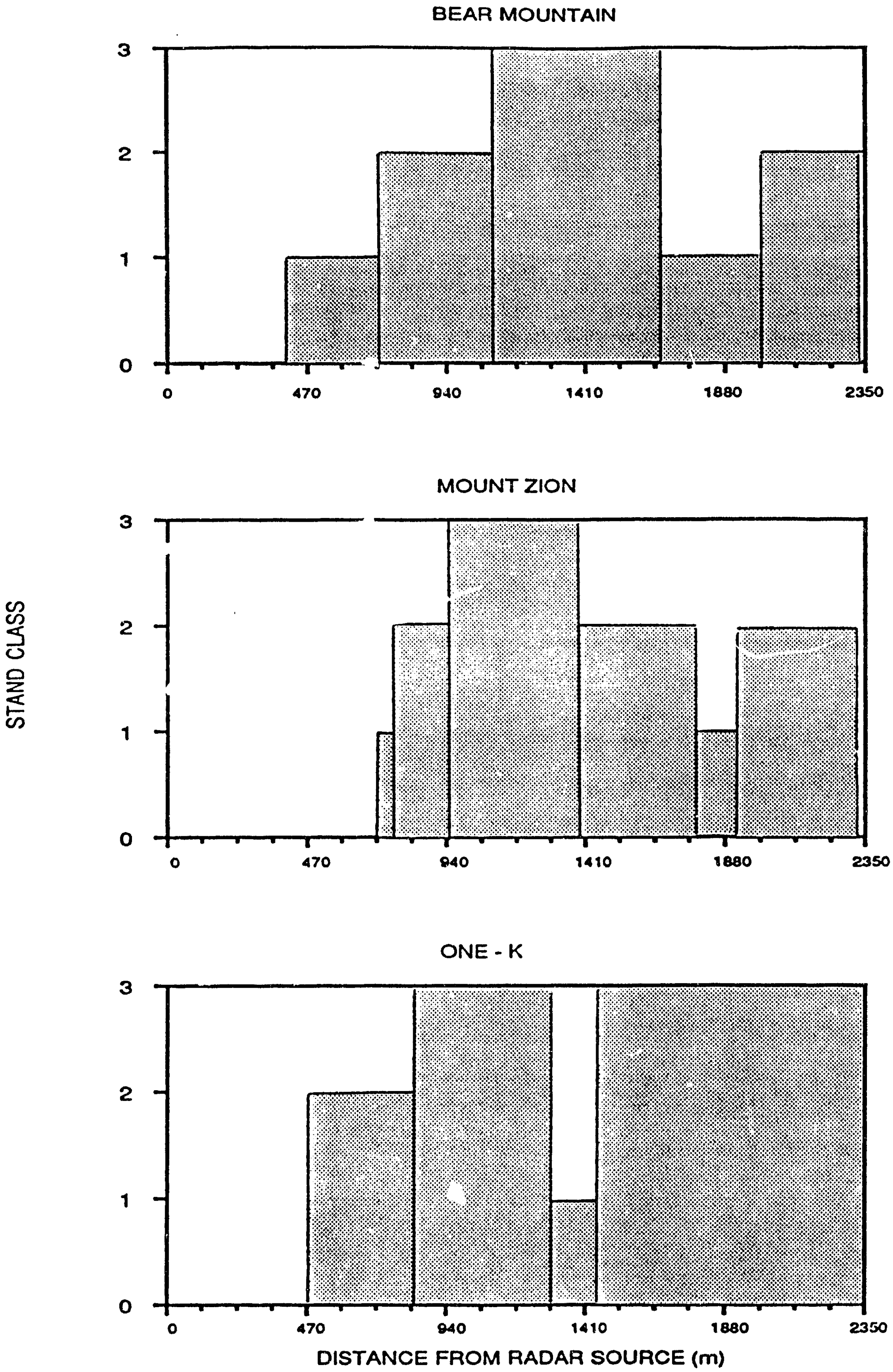


Figure 3. UWB Clutter Experiment Ground Truth Transect Profile by Stand Classification

Table 2. UWB Clutter Experiment Ground Truth Sample Plot Summary for Transect Profile

TRANSECT	SITE	OVERALL STAND TYPE	STAND CLASS	DISTANCE FROM RADAR (m)	STAND CLASS % OF TRANSECT	SLOPE [%]	ASPECT
BEAR MNT	M1	CLEAR/SEEDLING	1	393	13.52	NEG. 5	SW
BEAR MNT	M4	CLEAR/SLASH	1	1662	14.21	80	E
BEAR MNT	M2	CLEAR/ALDER REGEN	2	707	16.75	5	E
BEAR MNT	M5	MIXED LRG. POLE/ DH	2	1992	14.21	45	ESE
BEAR MNT	M3	SAW/LRG. POLE	3	1096	24.38	70	E
MT ZION	Z1	OLD CLEAR/ MEADOW	1	707	2.04	0	N/A
MT ZION	Z5	CLEAR/ SLASH	1	1814	4.93	15	W
MT ZION	Z2	LRG. POLE/ SM. SAW	2	746	10.27	5	WNW
MT ZION	Z4	SM. POLE/ DOGHAIR	2	1382	22.64	15	WNW
MT ZION	Z3	MIXED LRG. SAW	3	942	23.06	15	WNW
ONE-K	S3	CLEAR/SEEDLING	1	1277	7.36	85	NE
ONE-K	S1	POLE	2	471	14.72	5	NE
ONE-K	S2	MIXED SAW/POLE	3	817	19.57	70	NE
ONE-K	S4	OLD GROWTH	3	1450	38.30	50	ENE

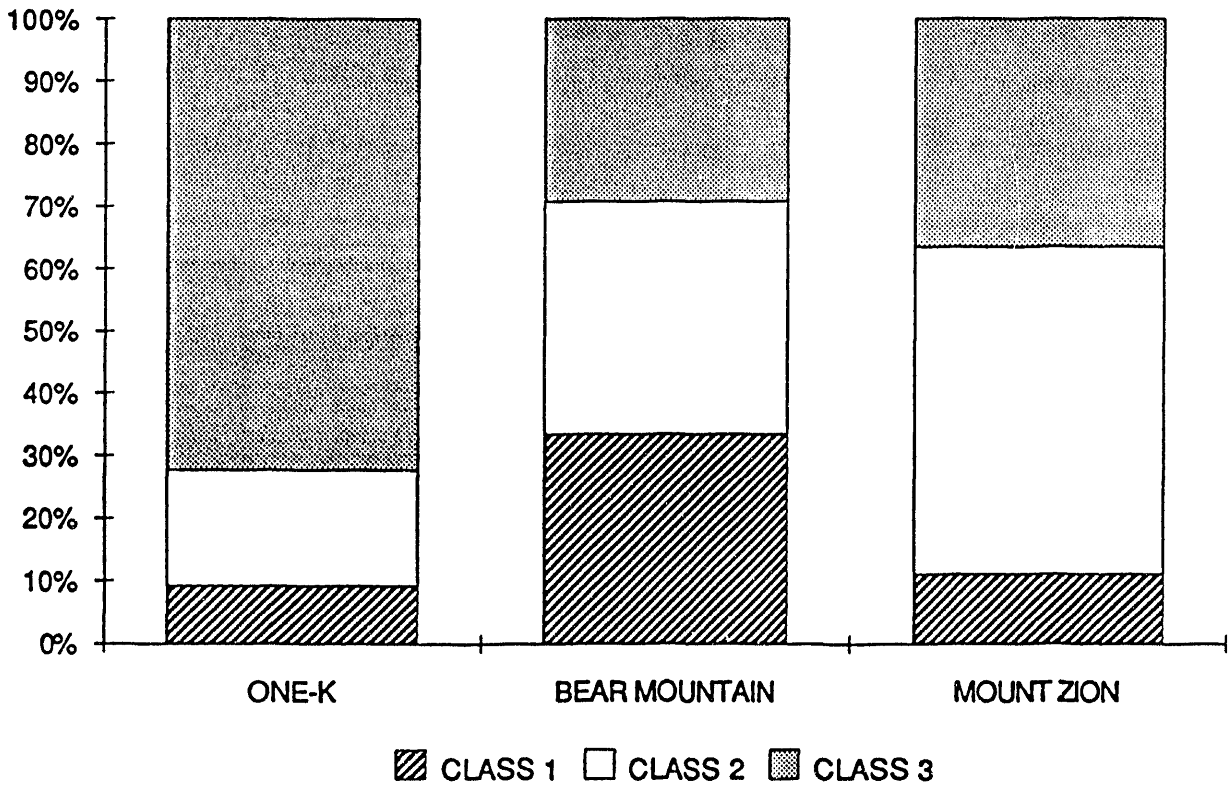


Figure 4. Stand Class Composition of Each Transect for the UWB Clutter Experiment Forested Site

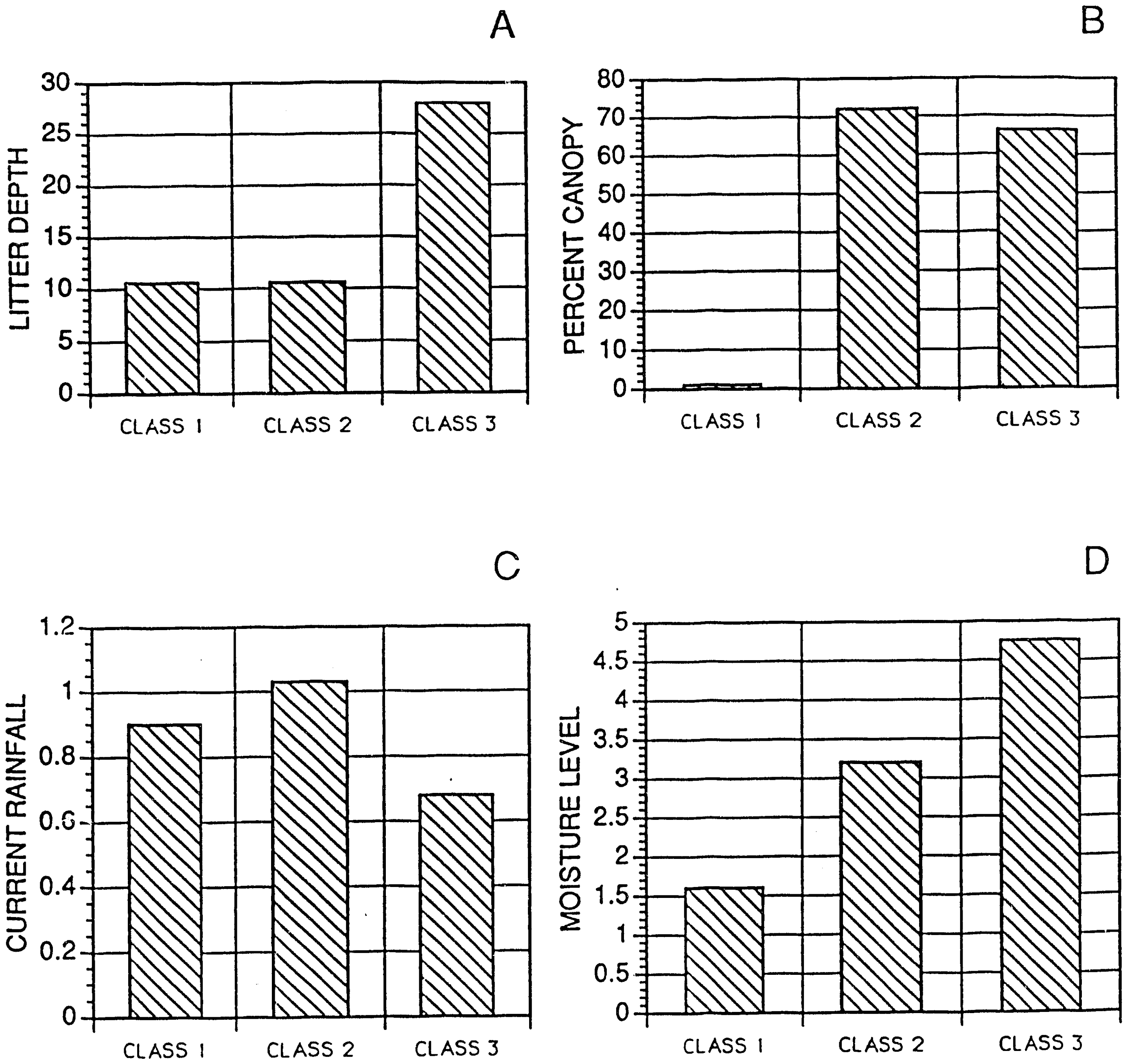


Figure 5. Average Stand Characteristics by Overstory Classification Including (A) Litter Depth (inches), (B) Percent Canopy Closure, (C) Current Rainfall (inches), and (D) Average Moisture Level Based on Circular Plots with a 16.7 ft Radius

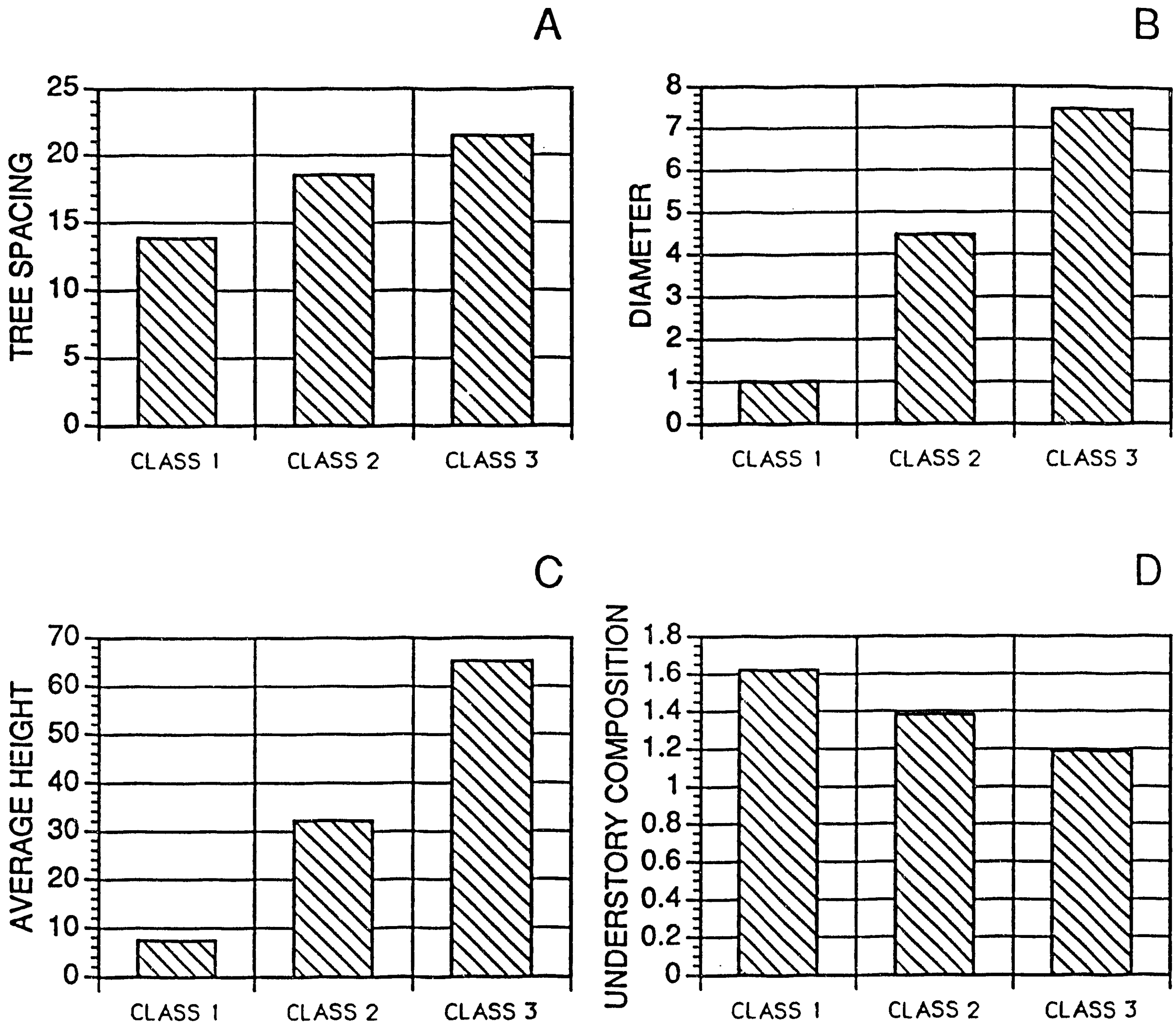
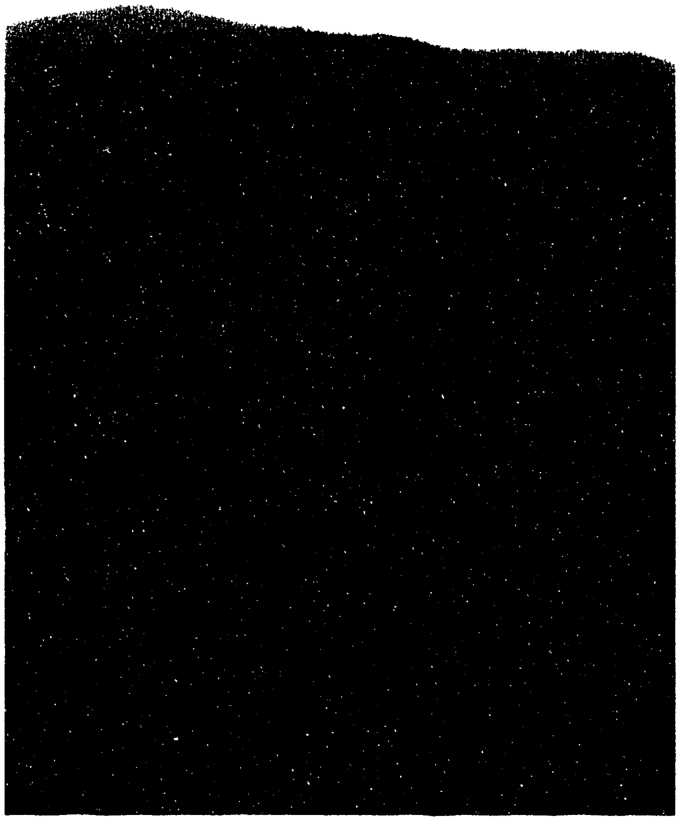


Figure 6. Average Stand Characteristics by Overstory Classification Including (A) Tree Spacing (ft), (B) Average Tree Diameter at Breast Height (inches), (C) Average Tree Height (ft), and (D) Average Understory Composition Based on Circular Plots with a 16.7 ft Radius

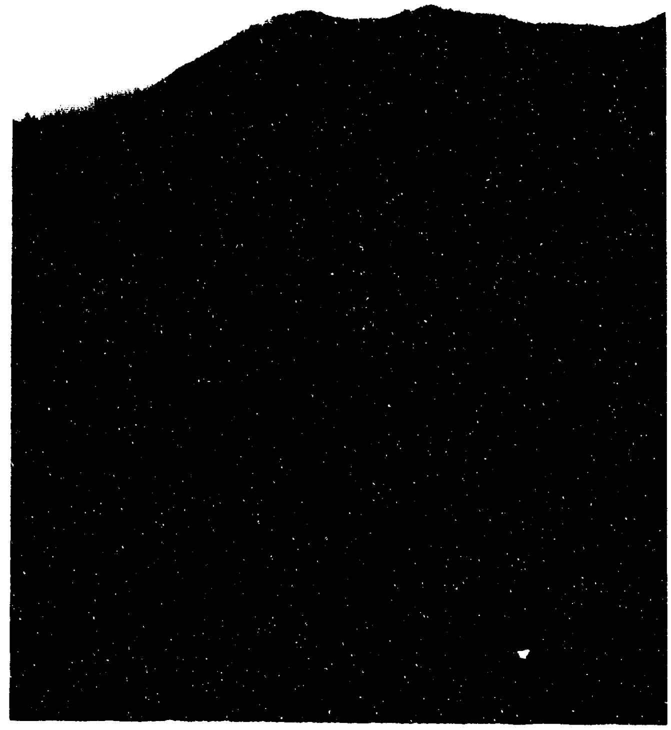
APPENDIX A

Appendix A contains photographs of the three transects; One-K, Mount Zion, and Bear Mountain as viewed from the radar site.

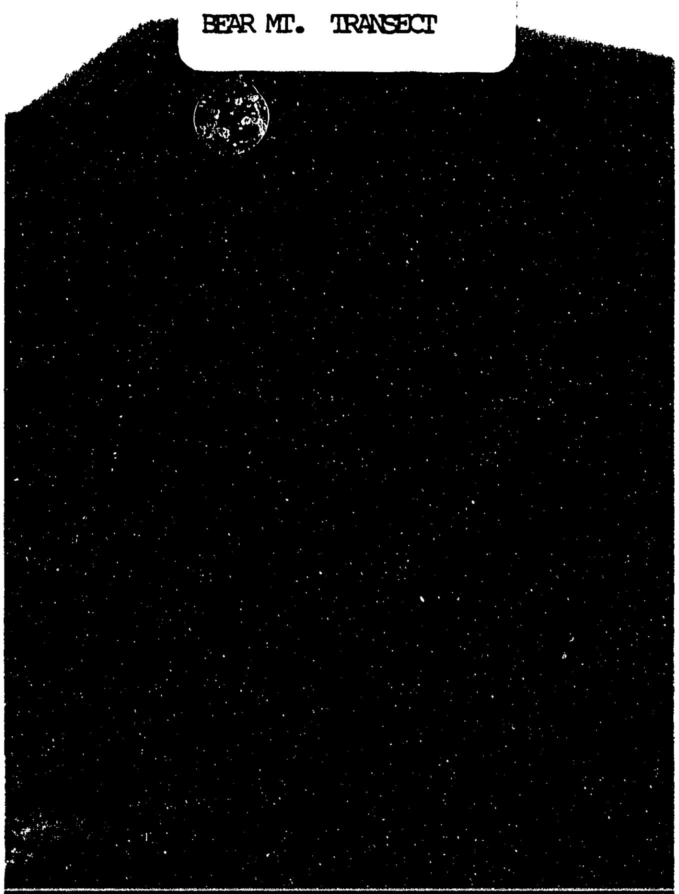
ONE-K TRANSECT



MT. ZION TRANSECT

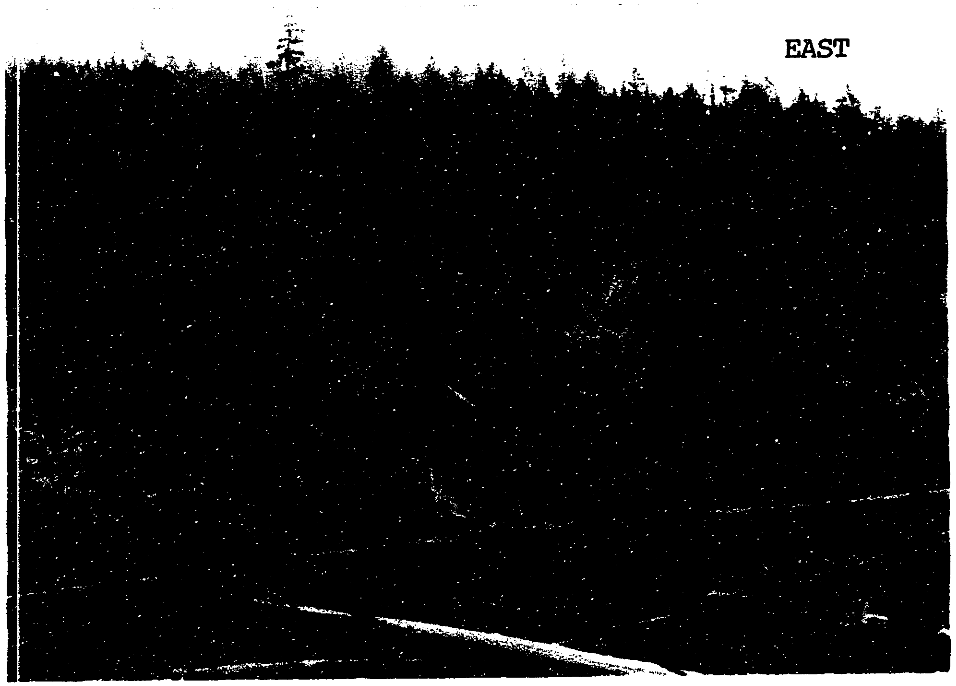


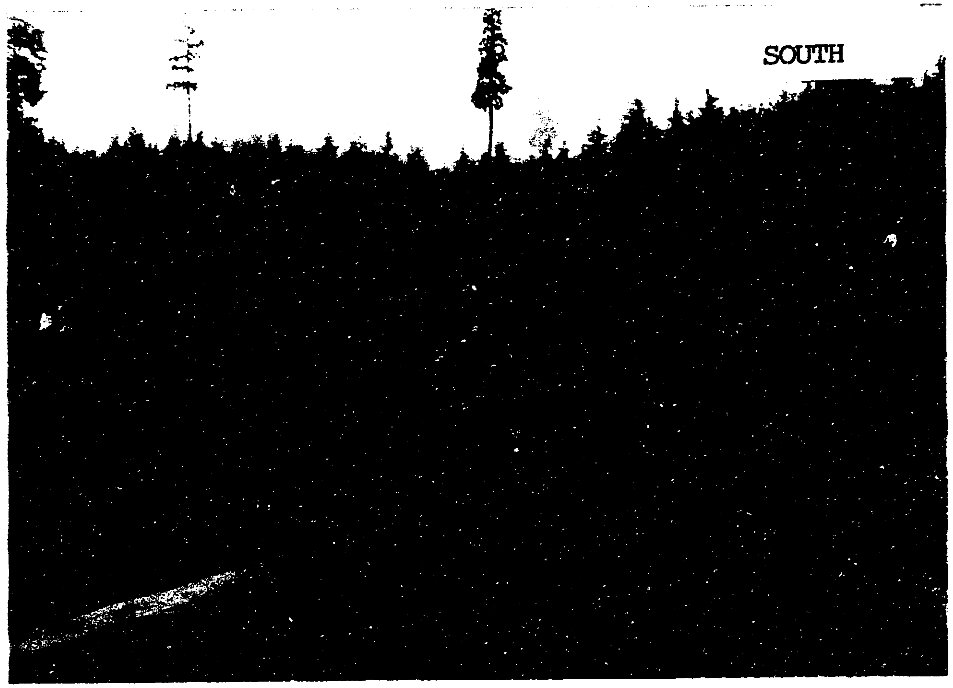
BEAR MT. TRANSECT



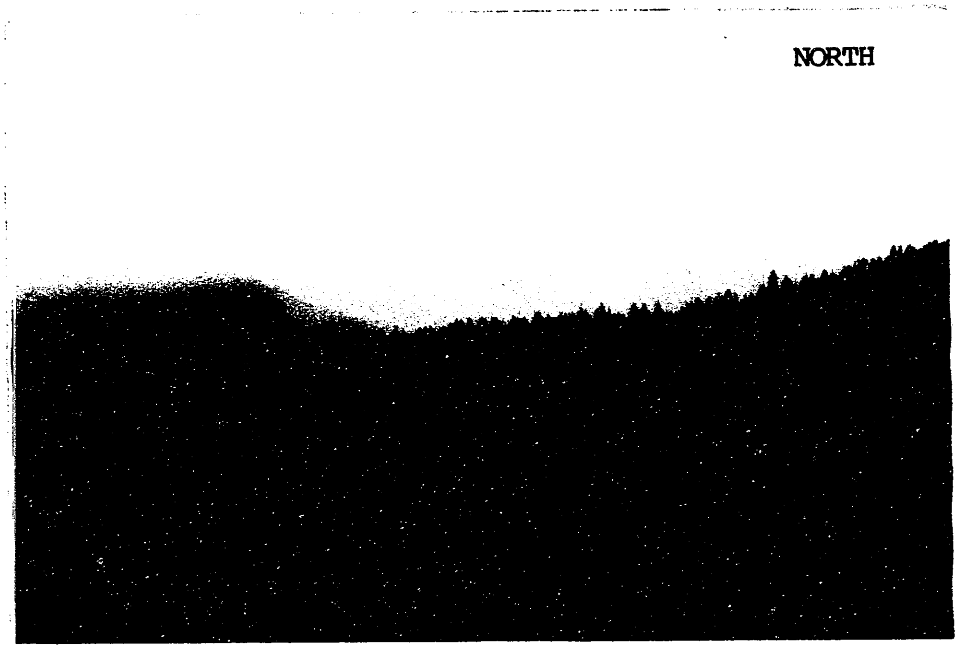
APPENDIX B

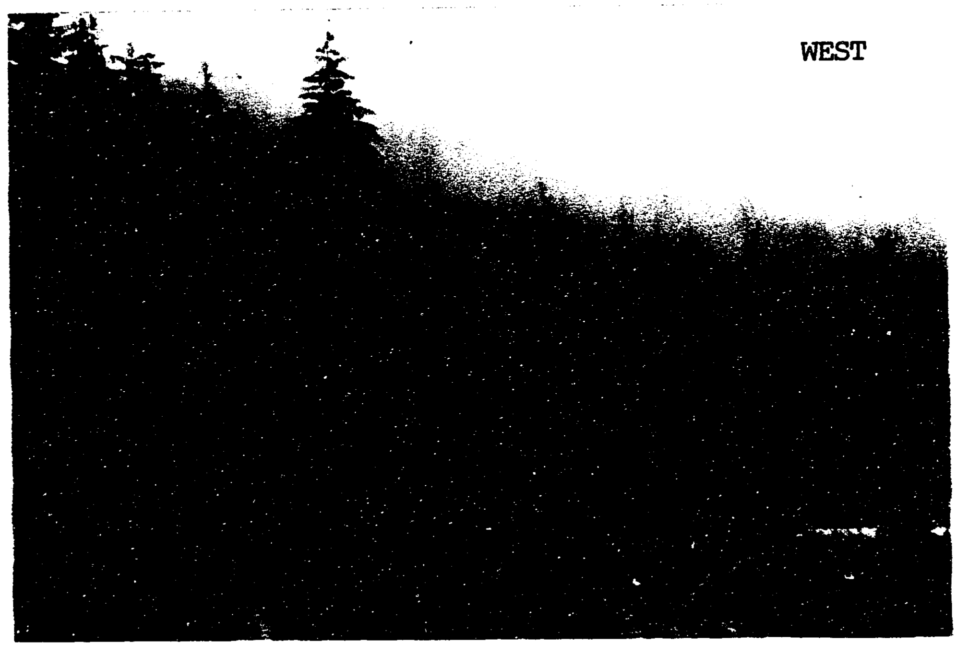
Appendix B contains photographs and field data sheets for the individual sample plots. The sites are numbered with the lowest numbered plot closest to the radar site for each transect. Photographs of the canopy are on the reverse side of the photograph holder for each site.





BEAR MT.- SAMPLE PLOT #1





UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/24/91 15:00
Date

BEAR MTN.
Transect

#1 - 261° BEARING
Sampling Station

Site Description: APPROX. 50 YDS FROM 1ST BALLOON THIS TRANSECT (79° BEARING) - S. EDGE OF CLEARCUT

Slope: OVERALL 5-10% SITE 5% - SIDESLOPE MORE THAN T FROM RADAR SITE

Overall Canopy Cover: 0% OPEN

General Over/Under Story Description: NO OVERSTORY - CLEARCUT AREA PREVIOUSLY LOGGED &

(Major Species/Woody Fuels/Litter) BURNED - NO SLASH PILED - SIZE OF CLEARCUT 20-40 A (EST)
REGENERATION PREDOMINANTLY D.F. - WH NEAR EDGES - LOGGED STUMP SPACING 8-10 FT
SIZE 5"-24" DIA. - QUITE A BIT OF DOWN POLE STOCK 4-12" DIA. - 8-20 FT LONG -
OVERALL LITTER DEPTH TO 24" - MOST GROUND VEGETATION ANNUAL SPP. WHICH HAVE
TURNED BROWN - SOME SALAL, RUBUS, OTHER - MORE RUBBISH THAN ZION CLEARCUT - SLASH NOT
PILED HERE - SCATTERED

Photo Log: Roll/Photo
N 1/35
E 1/36
S 2/1
W 2/2
C 2/3

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: HARD TO ASSESS LOCAL VARIATION BETWEEN MT. ZION CLEARCUT
- SEEMS DRIER - NO OVERSTORY TO REDUCE EVAPORATION - WOODY MATERIAL
LESS ROTTED THAN OTHER SITES - NO MOSS - DRIZZLING NOW - SET RAIN GAUGE 13:10

Stand Data:

Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	70	## 25	4	<1	0	0	0	0
% Overstory	70	25	4	<1	0	0	0	0
Number/Class	·	·	·	1*	0	0	0	0
Average Height	·	·	·	5'	-	-	-	-
Major Species	·	·	·	DF	-	-	-	-
Minor Species	·	·	·	-	-	-	-	-

* SEEDLINGS < 4.5 FT (@ DBH) NOT TALLIED AS TREES - COUNT AS SHRUBS
\## MOSTLY BROWN ANNUALS

Reviewed By: V1 Cullinan

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

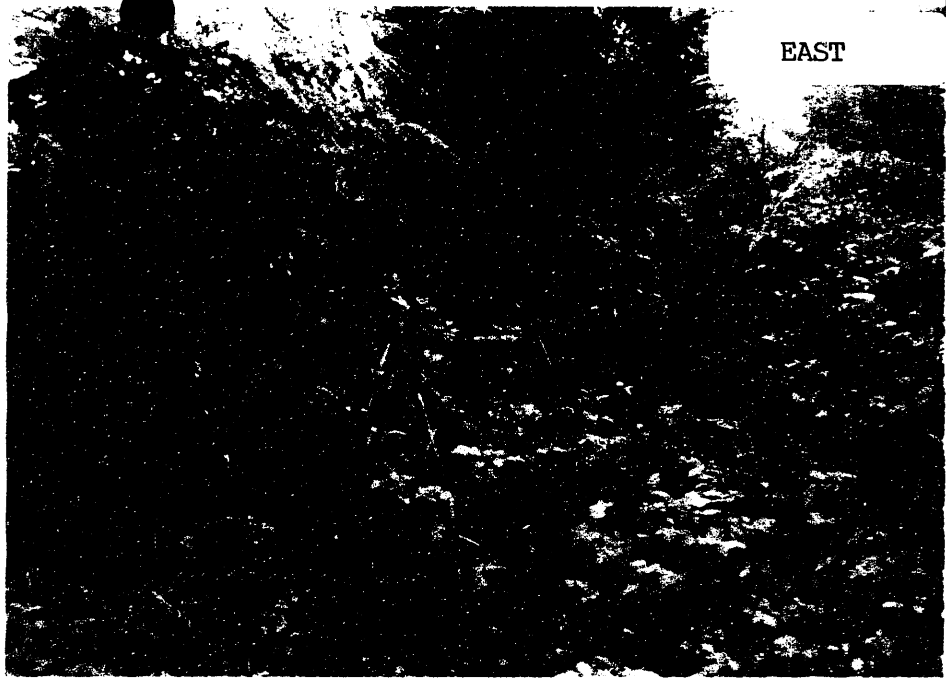
WH - Western Hemlock

WRC - Western Red Cedar

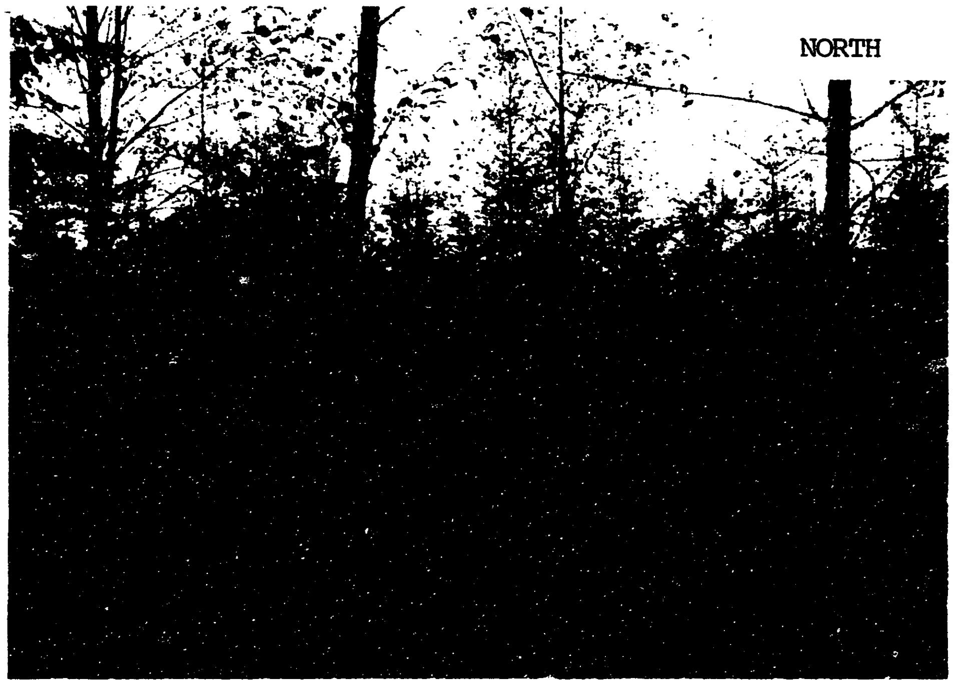
PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species

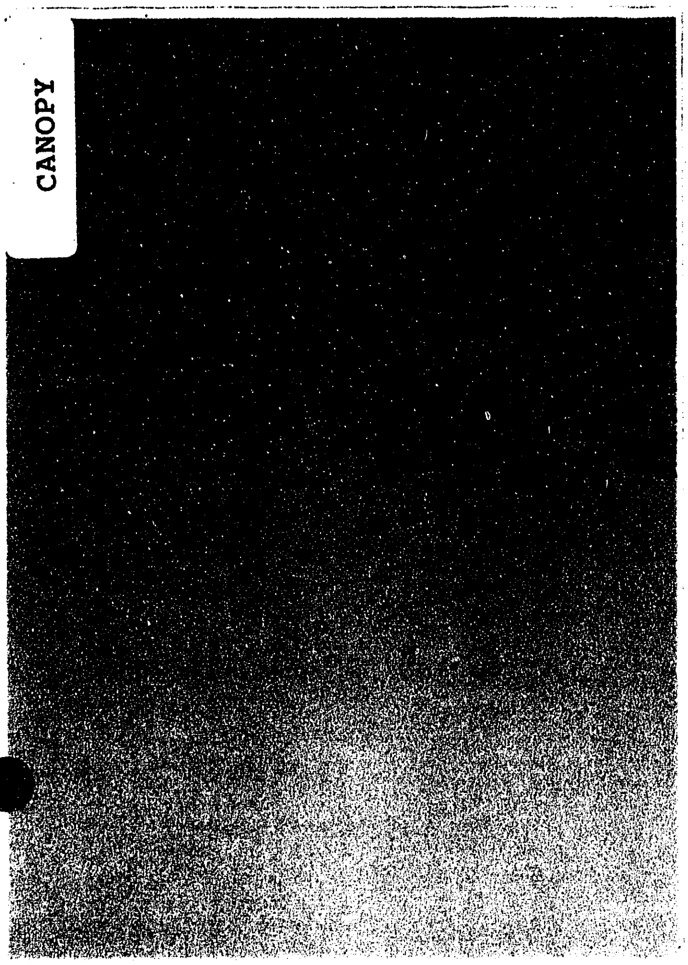


BEAR MT.- SAMPLE PLOT #2



BEAR #2
WEST

BEAR #2
SOUTH



CANOPY

BEAR #2
EAST

UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/24/91 15:30
Date

BEAR MTN
Transect

#2 - 261° BEARING
Sampling Station

Site Description: APPROX. 75-100 YDS S.W OF. 1ST BALLOON - 261° BEARING - MIXED DEC/CONIFER STAND

Slope: OVERALL -5 TO +15% * SITE 0-5%
Overall Canopy Cover: 15%

* % RELATIVE TO RADAR SITE

General Over/Under Story Description: (Major Species/Woody Fuels/Litter) OVERSTORY - MIXED ALDER, WILLOW & OTHER DEC. SPP. - ALSO WH DF - AVE. CONIFER HT. 20-30 FT DECIDUOUS SPP. HTS 20-30 FT UNDERSTORY: SOME OPEN GRASSY AREAS OTHER POCKETS THICK W/ RUBUS SPP. BRAMBLES, SALAL MINOR RHODODENDRON - FORBS, FERNS & GRASSES VERY COMMON IN OPEN AREAS - LITTER - MINOR STEMS & TWIGS MOSTLY < 2" - OCCASIONAL OLD STUMPS - MOSTLY ROTTED - AVE. LITTER DEPTH < 3" INCLUDING THIS YEARS FALLEN LEAVES, ANNUALS

Photo Log:

N 2/4
E 2/5
S 2/6
W 2/7
C 2/8

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: AREA APPEARS MODERATELY DRY - NO BOGS OR STANDING WATER, MOSTLY GRASSES - NO MOSS - THIN OVERSTORY SHOULD ALLOW RAPID DRYING, WITH THIN LITTER ACCUMULATION ESPECIALLY - NO RAIN GAUGE SET -

Stand Data:

Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	28	50	20	1	<1	0	0	0
% Overstory	OPEN ← 90 →		5	1	2	2	0	0
Number/Class	-	-	-	9	1	0	0	0
Average Height	-	-	-	10'	25'	0	-	-
Major Species	-	-	-	DEC-ALDER	WH	-	-	-
Minor Species	-	-	-	WH	-	-	-	-

Reviewed By: [illegible signature]

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

WH - Western Hemlock

WRC - Western Red Cedar

PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species

BEAR MT.- SAMPLE PLOT #3

BEAR #3
SOUTH

BEAR #3
EAST

BEAR #3
WEST

CANOPY

UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/24/91 16:45
Date

BEAR MTN
Transact

#3 - 261° BEARING
Sampling Station

Site Description: DOWN HILLSIDE FROM CLEARCUT NEAR 2ND BALLOON APPROX 100 YDS - BEARING 81°

Slope: OVERALL 60-80% SITE 70%

Overall Canopy Cover: 60%

General Over/Under Story Description: OVERSTORY - SAWTIMBER/LRG. POLE STAND - PREDOMINANTLY WH
(Major Species/Woody Fuels/Litter) SOME DF - FAIRLY GOOD HT. LAYERING THROUGHOUT - MOSTLY > 50' FT LARGER TREES > 120-140' FT. - UNDERSTORY - SALAL, BRACKEN FERN, OREGON GRAPE, SMALLER WRC - LITTER - FAIRLY HEAVY DOWNED DECOMPOSING LOGS - OLD & MOSS COVERED - MOSTLY SOFT & ROTTING; SOME BLOWDOWN NR. CLEARCUT BOUNDARIES AVE LITTER DEPTH - 24-36" NR EDGES; 12-24" INTERIOR OF STAND - CROWNS VARIABLE 30-70% OF TREE HEIGHTS - THIS AREA WILL PROBABLY CREATE MORE SCATTER THAN OTHER SITES DUE TO MIXED LEVELS & HTS.

Photo Log: ROLL/PHOTO

N 2/12
E 2/13
S 2/14
W 2/15
C 2/16

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: SITE APPEARS RELATIVELY WET - CANOPY COVER & DEEP LITTER KEEP GROUND MOIST - NO BOGS - QUITE A BIT OF MOSS
NO RAIN GAUGE SET HERE

Stand Data:

Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	75	** 0	* 10	1	1	1	2	10
% Overstory	OPEN ← 47 →		5	1	2	5	15	25
Number/Class	-	-	-	3	2	1	1 (15.2")	2 (25.1") (26.0")
Average Height	-	-	-	10'	15'	25'	90-100' EST.	120-130' EST.
Major Species	-	-	-	WH	WH	DF.	DF	DF.
Minor Species	-	-	-	-	-	WH	WH	WH

* FERNS PREDOMINANTLY + UNKNOWN - SIMILAR TO SALAL - MAY BE VARIETY
** SOME MOSS ON DECAYING LOGS

Reviewed By: VI Cullinan

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

WH - Western Hemlock

WRC - Western Red Cedar

PSF - Pacific Silver Fir

M - Madrone

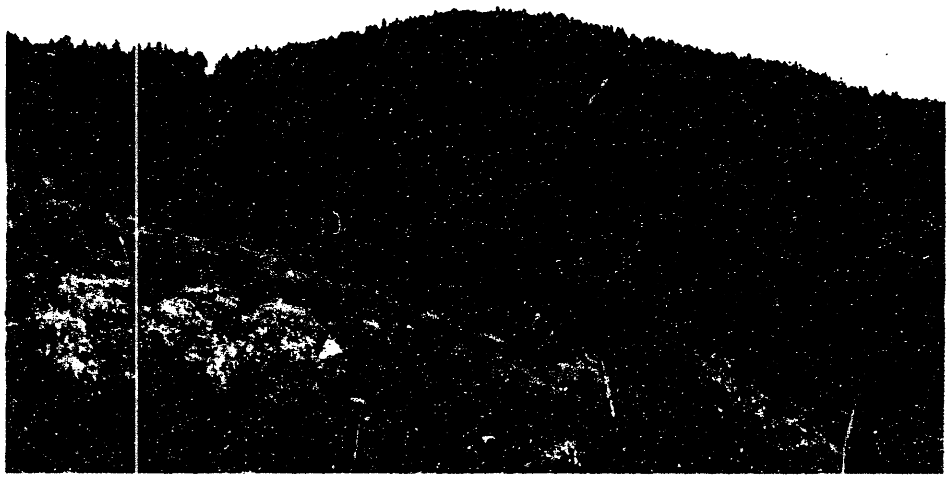
DEC - Deciduous Species

EAST

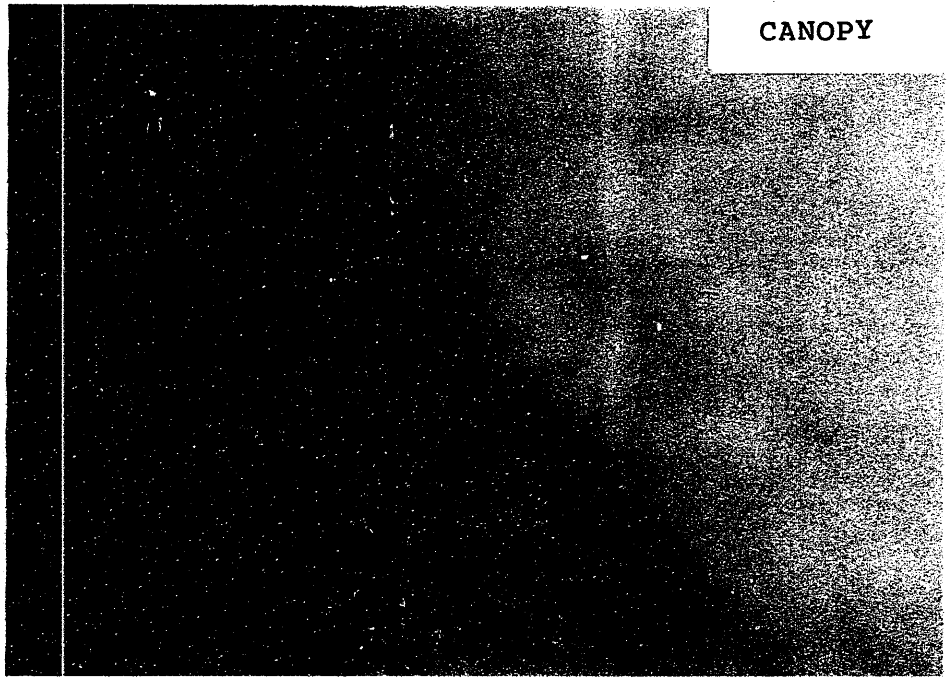
SOUTH

BEAR MT.- SAMPLE PLOT #4

NORTH



WEST



REAR #4
WEST

EAST

SOUTH

UWB CLUTTER EXPERIMENT

TELINICK
Observer

10/25/91 0900
Date

BEAR MTN.
Transect

#4 - 261° BEARING
Sampling Station

Site Description: APPROX 50 YDS DOWN HILLSIDE FROM BEAR MTN. TARGET ZONE (SPUR RD) NEAR W/ END OF CLEARCUT - 79° BEARING

Slope: OVERALL 70-100% SITE 80%

Overall Canopy Cover: 0% CLEARCUT

General Over/Under Story Description: OVERSTORY - OPEN CLEARCUT - 20-40 A ESTIMATED SIZE -

(Major Species/Woody Fuels/Litter) UNDERSTORY - PREDOMINANTLY DISTURBANCE WEED SPECIES - ANNUALS - THISTLE, VARIOUS COMPOSITES - OCCASIONAL WRC OR ALDER SEEDLINGS - VERY SPARSE - MINOR GRASSES - LITTER - LOGGING DEBRIS SCATTERED MOSTLY 1-8" DIA - LENGTH 1-20' FAIRLY EVENLY DISPERSED - STUMP SPACING 6-10' AVE. AVE SIZE 12" - SOME DEEP LITTER AREAS MOSTLY DECOMPOSED MATERIAL - AVE 12-24" DEPTH - AREAS OF BARE MINERAL SOIL IN YARDING TRAILS FEW POLES USED FOR CABLE LOG 50-100 FT. - SPACING - AVE DIA. 8"

Photo Log: ROLL / PHOTO

- N 2/17
- E 2/18
- S 2/19
- W 2/20
- C 2/21

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: SITE APPEARS RELATIVELY DRY - NO CANOPY COVER TO SHIELD SUNLIGHT - LITTER IS FAIRLY DEEP HOWEVER S.E. ASPECT OF SLOPE DRIES MORE THAN OTHER CLEARCUTS - SET RAIN GAUGE 0910

Stand Data:

Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	* 63	35	THIMBLEBERRY 2	0	0	0	0	0
% Overstory	63	35	2	0	0	0	0	0
Number/Class	-	-	-	0	0	0	0	0
Average Height	-	-	-	-	-	-	-	-
Major Species	-	-	-	-	-	-	-	-
Minor Species	-	-	-	-	-	-	-	-

* ALL LITTER - NO MINERAL SOIL

Reviewed By: VI Cullinan

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

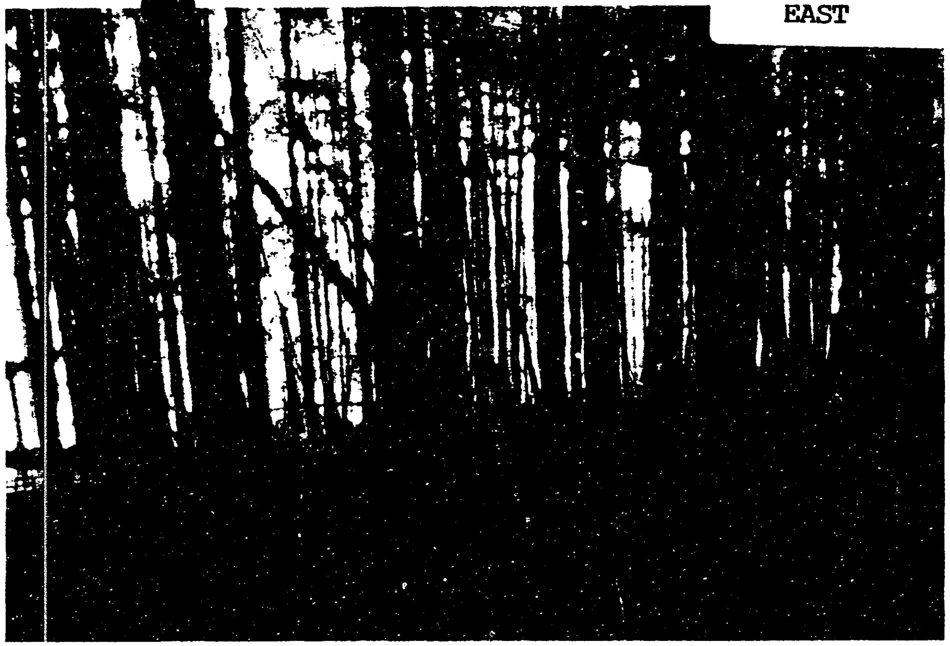
WH - Western Hemlock

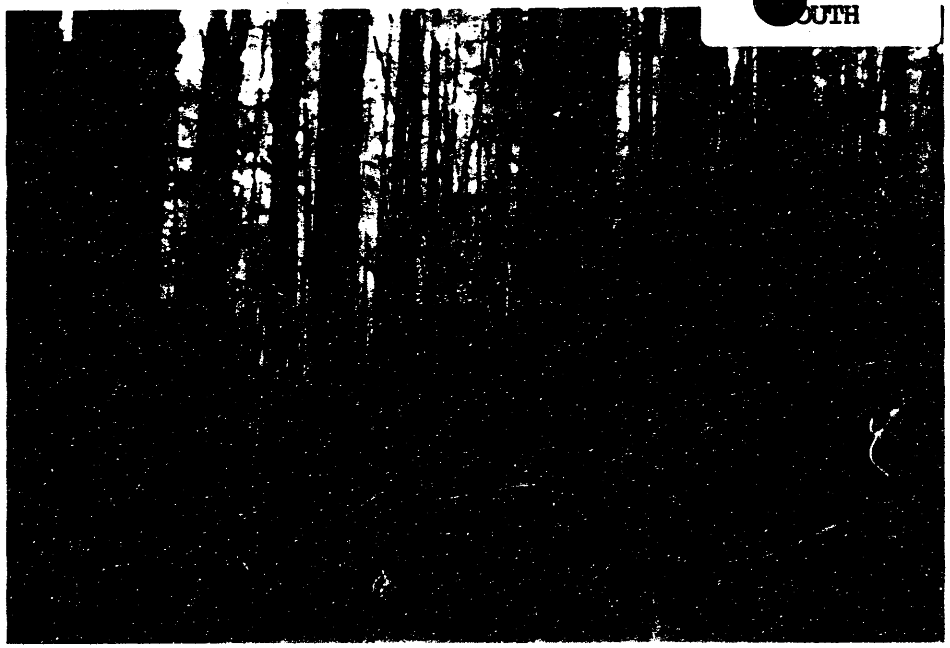
WRC - Western Red Cedar

PSF - Pacific Silver Fir

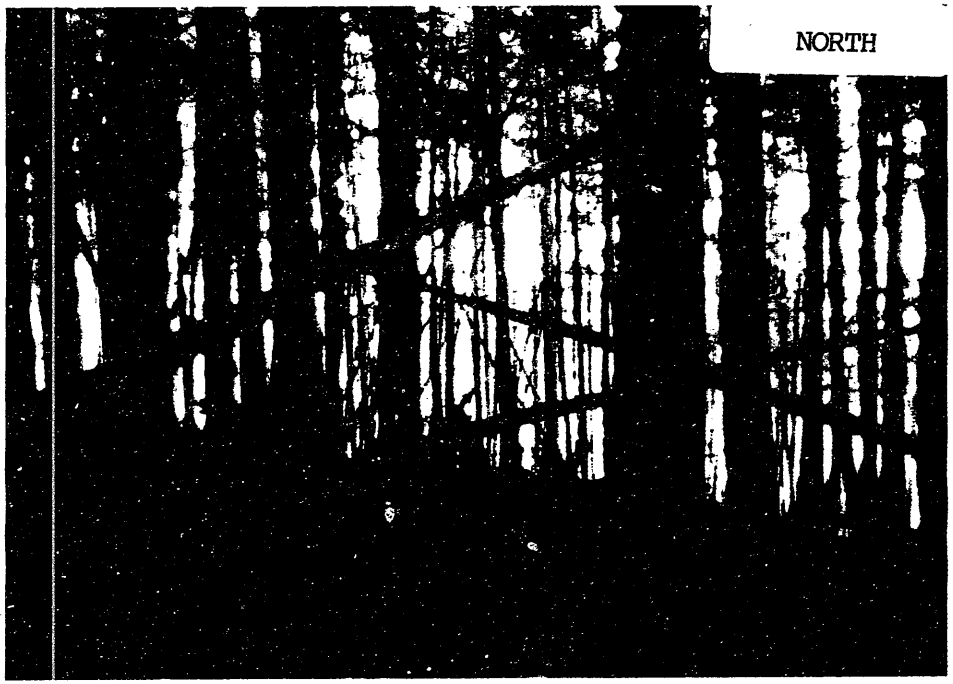
M - Madrone

DEC - Deciduous Species





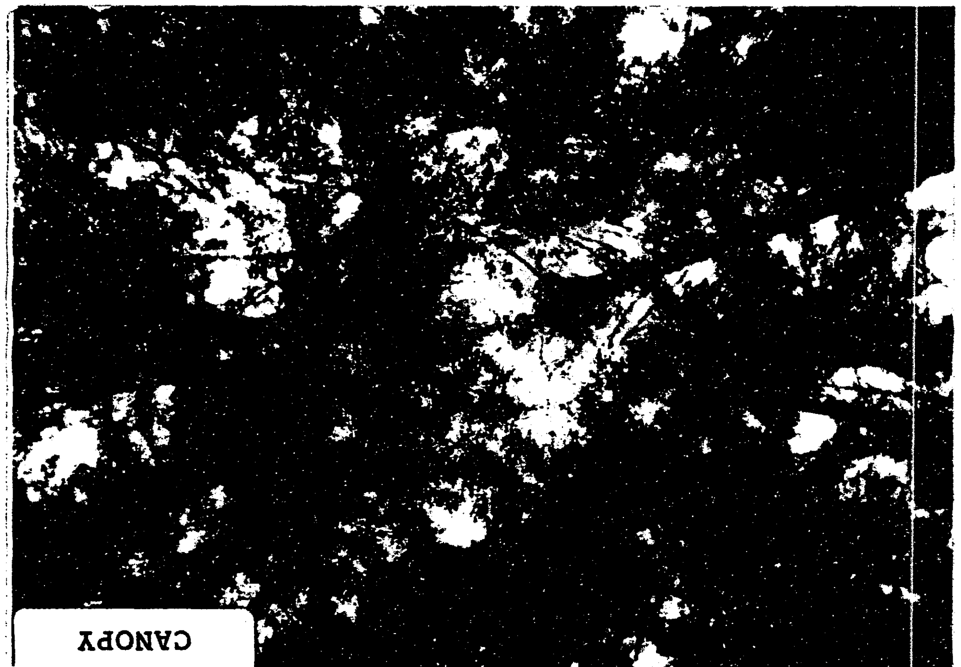
BEAR MT.- SAMPLE PLOT #5



BEAR #5
SOUTH

BEAR #5
EAST

BEAR #5
WEST



UWB CLUTTER EXPERIMENT

TELINICK
Observer

10/25/91 09:35
Date

BEAR MTN
Transect

#5 261° BEARING
Sampling Station

Site Description: APPROX 40 YDS UPSLOPE FROM BEAR MTN. TARGET ZONE (SPUR RD) W POLE STAND 261° BEARING

Slope: OVERALL 40-50% SITE 40%

Overall Canopy Cover: 90-95%

General Over/Under Story Description: (Major Species/Woody Fuels/Litter) OVERSTORY - PREDOMINANTLY WH, D.F W/ OCCASIONAL WRC - HTS AVE 70+ FT. - SOME TO 100+ FT. STEM DIA. @ DBH AVE 8" RANGE 2-12" - SIMILAR TO ZION #4 W/ LESS LITTER - LESS DOGHAIR - UNDERSTORY - MOSTLY ABSENT - OCCASIONAL RHODODENDRONS - VERY SPARSE - QUITE A FEW 0-2" SAPLINGS 10-20' FT W/ SPARSE FOLIAGE - LITTER - MOD. AMT. OF DOWNED POLES 2-6" DIA. TO 20+ FT LENGTH PLUS OLDER ROTTING LOGS TO 16+" - NO LOGS STUMPS NOTED - AVE LITTER DEPTH TO 12" THICK

Photo Log: ROLL / PHOTO

N 2/22
E 2/23
S 2/24
W 2/25
C 2/26

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: AREA APPEARS RELATIVELY WET - THICK CANOPY PREVENTS DRYING OUT + MODERATE LITTER TO RETAIN MOISTURE - SOME MOSS ON DECAYING LOGS AND TREE BRANCHES - SET RAIN GAUGE - 0955

Stand Data: Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	** 87	0	RHODODEND. 1	2	5	5	0	0
% Overstory	OPEN ← 5 →		1	4	30	*** 60	0	0
Number/Class	-	-	-	12	21	10*	0	0
Average Height	-	-	-	15'	30-40'	80'	-	-
Major Species	-	-	-	WRC	WH	WH	-	-
Minor Species	-	-	-	WH	WRC	DF	-	-

* ONE TREE SPLIT TRUNK BELOW DBH - COUNTED AS 2
** MOSTLY LITTER W/ SOME TWIGS + ROTTING LOGS
*** OVERSTORY LAYERS TIERED - 6-12" CLASS AS DOMINANT OVERSTORY

Reviewed By: V. Cullinan

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

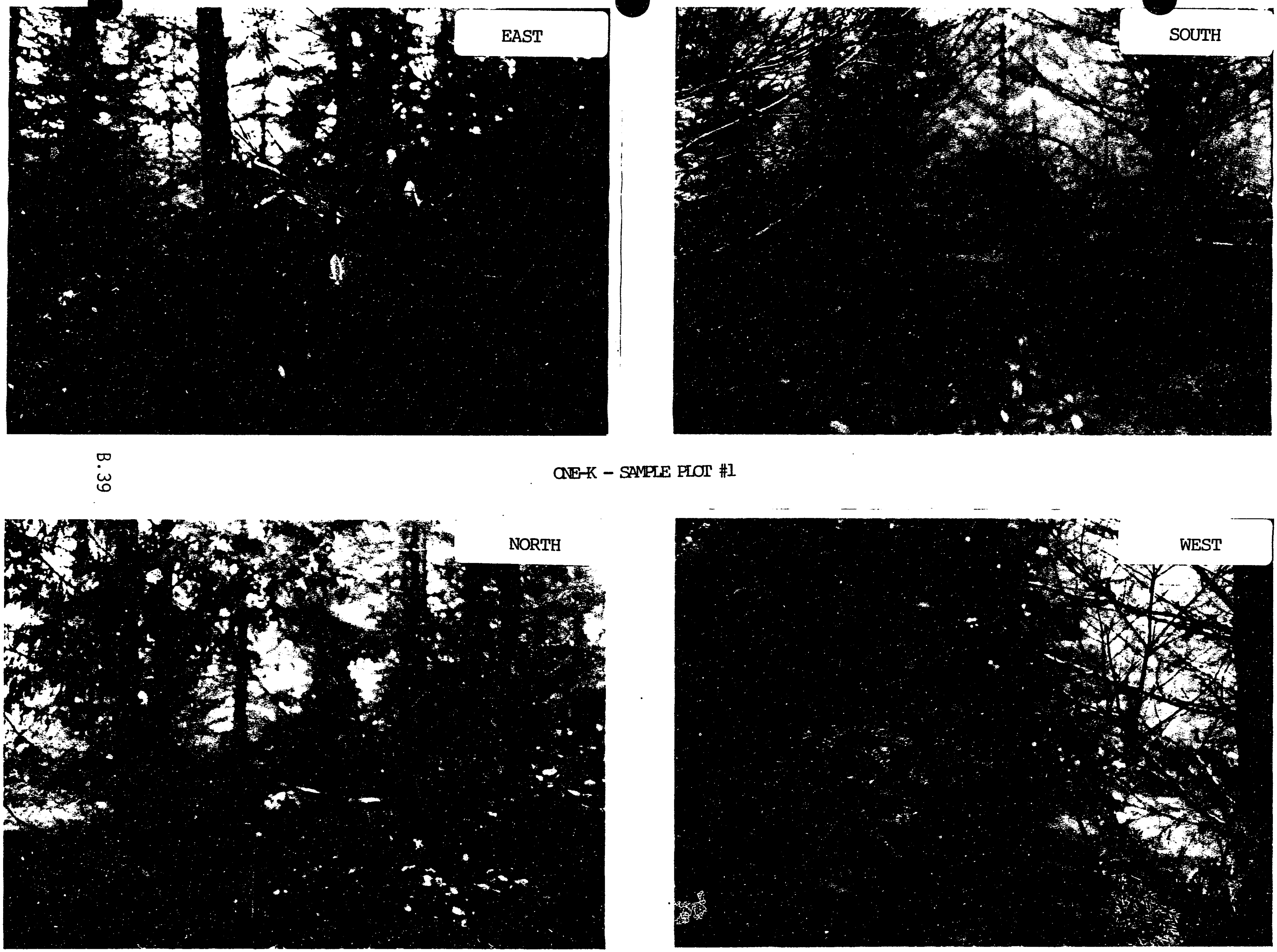
WH - Western Hemlock

WRC - Western Red Cedar

PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species



ONE-K - SAMPLE PLOT #1

ONE K #1
SOUTH

ONE K #1
EAST

ONE K #1
WEST

UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/25/91 1430
Date

ONE-K
Transect

#1 -216° BEARING
Sampling Station

Site Description: APPROX. 50 YDS FROM BALLOON #1 - BEARING 216°

Slope: OVERALL -5 TO +10% RELATIVE TO RADAR SITE; SITE 0%

Overall Canopy Cover: 80% OVERALL; 90-95% SITE

General Over/Under Story Description: (Major Species/Woody Fuels/Litter) OVERSTORY - PREDOMINANTLY POLE SIZED TIMBER - DF/WH/WRC AVE HT. 40-60FT - DIA. 6-12" - TREES ARE FULL CROWNED - 50-75% OF BOLE IS NEEDLED/BRANCHED - LOWER DEAD BRANCHES STILL ON TREES - MOSTLY EVEN-AGED TIMBER (SIMILAR TO ZION #2); UNDERSTORY PREDOMINANTLY RHODODENDRON, SALAL, HUCKLEBERRY, DECIDUOUS SHRUBS/LOSING LEAVES; NOT HEAVY UNDERSTORY: LITTER FAIRLY HEAVY - OLD DECOMPOSING LOGS PLUS LARGE STUMPS 7 24" - MOSS COVERED - FAIRLY HEAVY - FEW FORBS - LITTER DEPTH TO 24" .. NO MINERAL SOIL EXPOSED

Photo Log: ROLL/PHOTO

- N 3/11
- E 3/12
- S 3/13
- W 3/14
- C 3/15

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: SITE APPEARS RELATIVELY WET - SIMILAR TO 1-K #3 TREES ARE SMALLER BUT FULLY CANOPIED TO PREVENT SOILS FROM DRYING - HEAVY LITTER + MOSS HOLD MOISTURE IN - NEAR DRAINAGE ON AIR PHOTOS . RAIN GAUGE SET - UNDER CANOPY 14:45

Stand Data:

Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	88	1	5	0	1	5	0	0
% Overstory	← OPEN 10 →		5	2	13	70	0	0
Number/Class	-	-	-	4	2	7	0	0
Average Height	-	-	-	<10'	40'	60-70' EST	0	-
Major Species	-	-	-	WH	WH	DF		
Minor Species	-	-	-	WRC	-	WH		

Reviewed By: [signature]

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

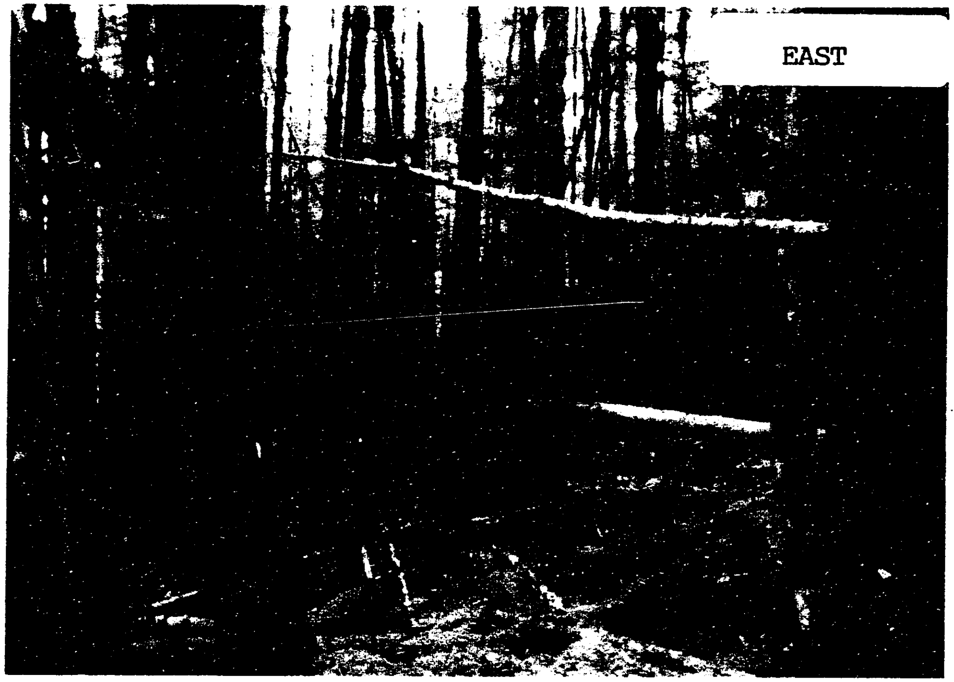
WH - Western Hemlock

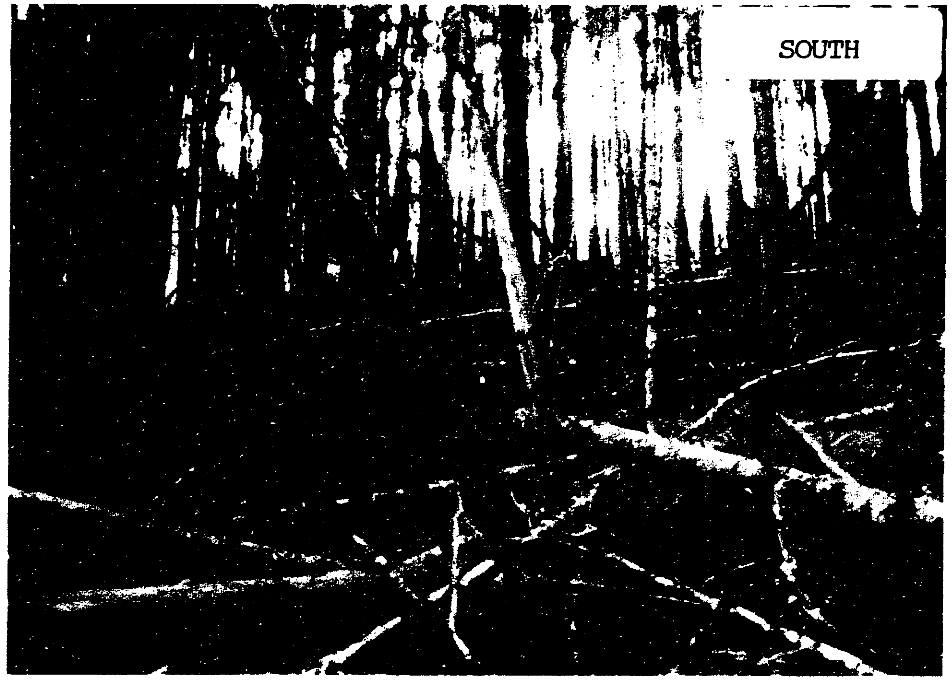
WRC - Western Red Cedar

PSF - Pacific Silver Fir

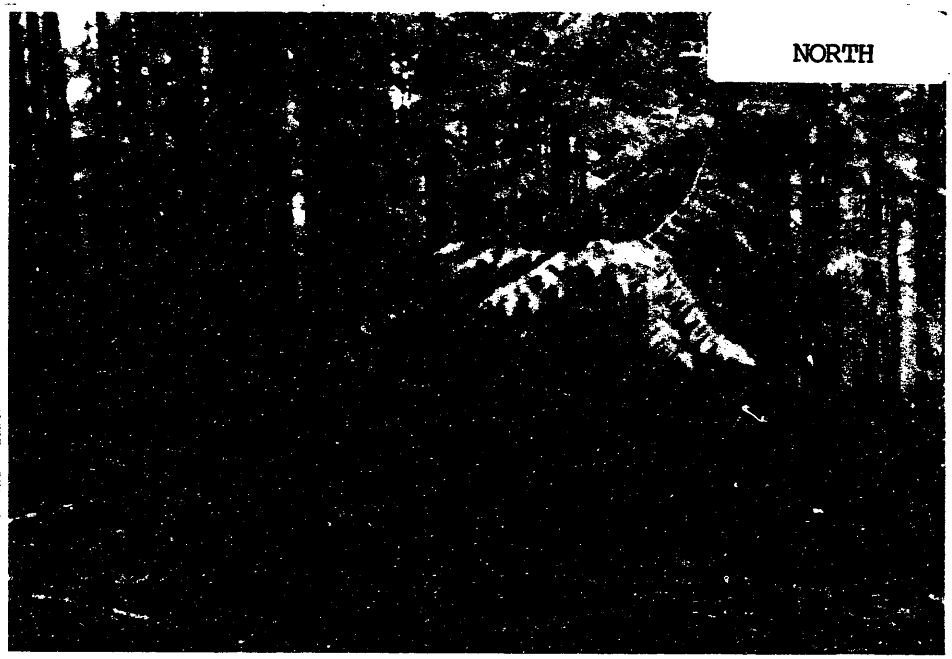
M - Madrone

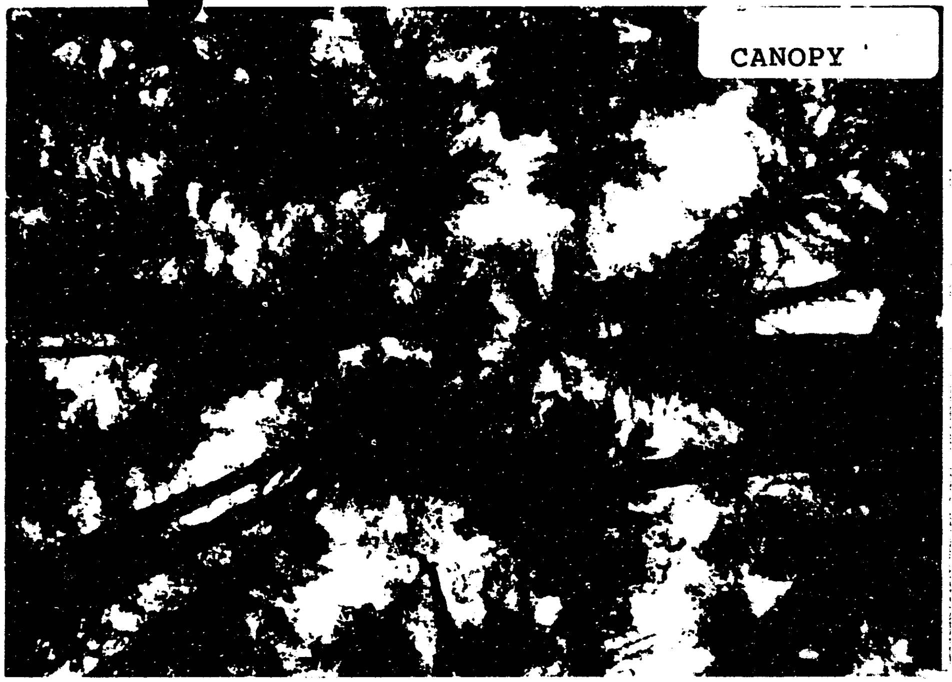
DEC - Deciduous Species





ONE-K – SAMPLE PLOT #2





ONEK #2
WEST

ONEK #2
SOUTH

ONEK #2
EAST

UWB CLUTTER EXPERIMENT

TELEMICK
Observer

10/25/91 13:20
Date

ONE-K
Transect

#2 - 216° BEARING
Sampling Station

Site Description: APPROX. 100 YDS FROM 2ND BALLOON THIS TRANSECT - 36° BEARING FROM 1-K TARGET SITE

Slope: OVERALL 40-80% SITE 70% Overall Canopy Cover: 85-90%

General Over/Under Story Description: (Major Species/Woody Fuels/Litter) OVERSTORY - FAIRLY DENSE - SIMILAR TO BEAR MTN #5 OR MT ZION #4 - DOMINANT SPECIES DF - HTS 130-150 FT; DIA AVE 16-24". MOSTLY 6-12 & 12-16" CLASS - DF, WH w/ OCCASIONAL TALL ALDERS - THIS CLASS (CO-DOMINANTS) ARE 80-120 FT - CROWN PROFILES VARY - OVERALL < 33% OF TREE HT. - FEW LOWER BRANCHES - UNDERSTORY - FEW SHRUBS - MOSTLY WRC & WH TO 40' FT - LITTER - QUITE A FEW DOWNED POLES 2-6" CLASS TO 30' FT LENGTH PLUS LARGER MOSTLY DECOMPOSED LOGS 12-24" OVERALL LITTER TO 24" THICK

Photo Log: ROLL/PHOTO

N	3/6
E	3/7
S	3/8
W	3/9
C	3/10

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: SITE IS RELATIVELY WET BUT LESS THAN 1-K #4 - CANOPY COVER PREVENTS MOST SUNLIGHT PENETRATION - THICK LITTER LAYER - 24"+ THICK MOSS COVERED - LOTS OF DECOMPOSITION - HOLDS MOISTURE - NO GAUGE SET - NORTH ASPECT

Stand Data: Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	INC MOSS 85	0	OR. GRAPE/WRC 3	0	2	5	5	0
% Overstory	← 15	OPEN →	0	1	4	30	30	*** 20
Number/Class	-	-	-	* 0	6	9	3 (13.4) (15.0) (14.5)	0
Average Height	-	-	-	-	30	100' EST	120' EST	-
Major Species	-	-	-	SHIFT - 1 COLUMN → WH	** DEC. ALDER	DF →		-
Minor Species	-	-	-	WRC	WH	WH →		-

* 1 SMALL WRC - NO STEM @ 4.5 DBH - COUNT AS SHRUB
** NOT TYPICAL OF OVERALL STAND - MOSTLY D.F. WH OTHER AREAS
*** LARGE DF OUTSIDE PLOT BOUNDARY - CANOPY EXTENDS INTO PLOT

Reviewed By: [signature]

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

WH - Western Hemlock

WRC - Western Red Cedar

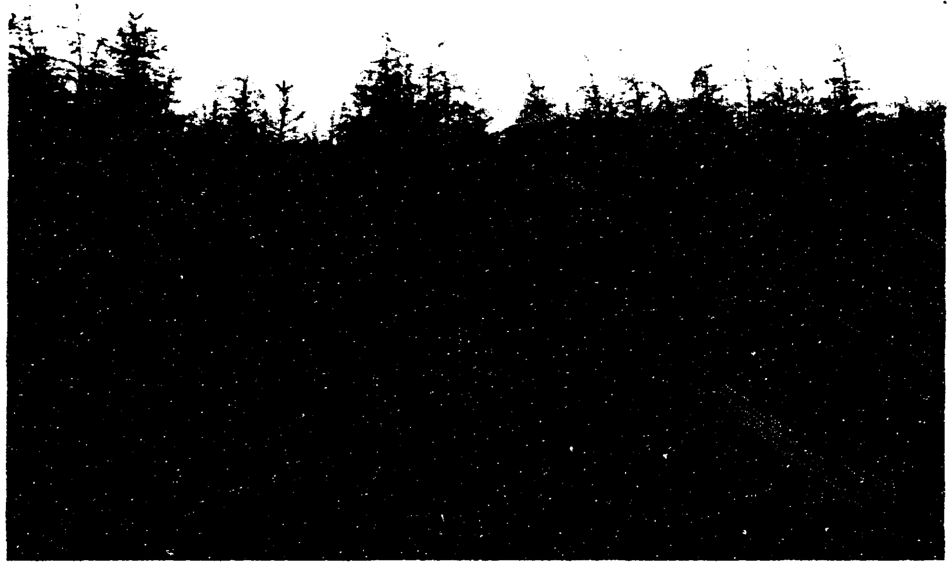
PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species

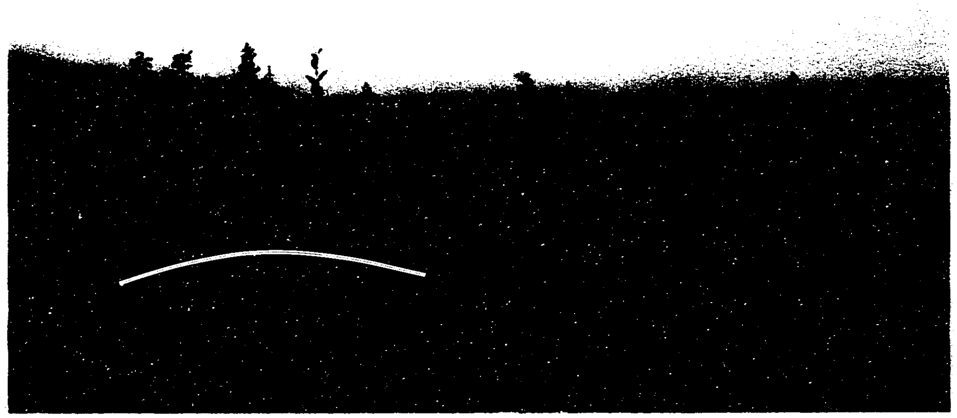
EAST

SOUTH



ONE-K - SAMPLE PLOT #3

NORTH

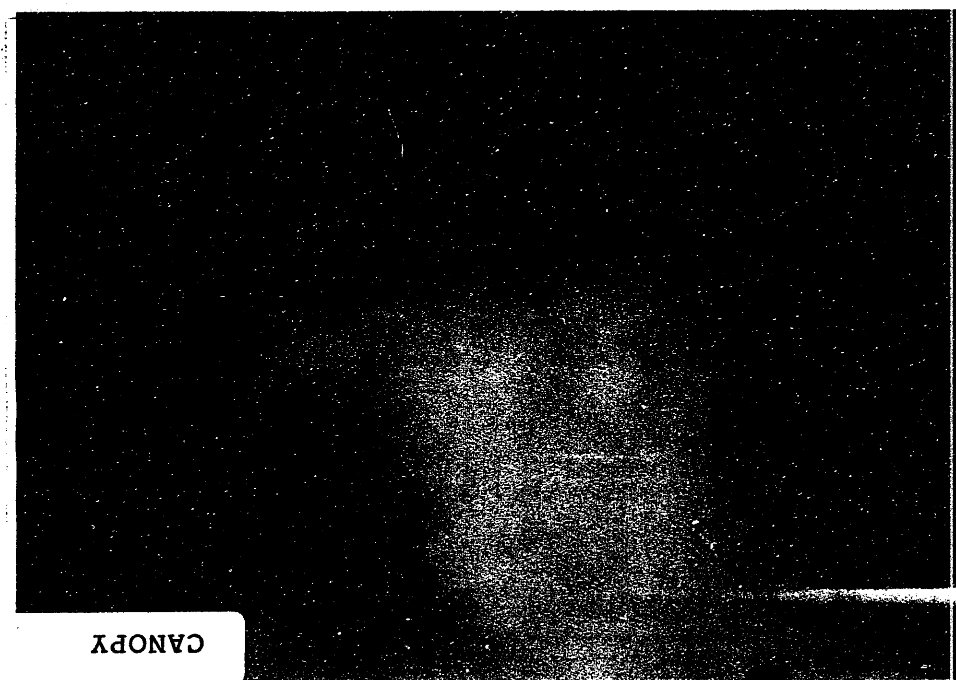


WEST

ONE-K #3
SOUTH

ONE K #3
EAST

ONE K #3
WEST



UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/25/91 12:35
Date

ONE-K
Transect

#3-216° BEARING
Sampling Station

Site Description: APPROX. 25 YDS N.E. OF 1-K TARGET SITE - BEARING 36° FROM TARGET
OVERALL CLEARCUT 15-100% TOP TO BOTTOM OF HILL

Slope: SITE 85% - SMALL - SLOPE ON SITE - HOLE   Overall Canopy Cover: 0%

General Over/Under Story Description: OVERSTORY - OPEN - CLEARCUT UNDERSTORY: HEAVY REPRODUCTION

(Major Species/Woody Fuels/Litter) PROBABLY PLANTED DF SEEDLINGS SPACED 10'x10' AVE - HT AVE 10 FT - MOSTLY WH SEEDLINGS W/ SPACING < 3x3 FT - HT < 4 FT - SOME PSF GRAND FIR ALSO PRESENT - SOME ALDER LOSING LEAVES 10-20 FT - MOSTLY IN CLUSTERS - OTHER VEGETATION PRESENT MOSTLY ANNUALS, GRASSES - SOME SALAL, BERRY - ANNUALS, GRASSES DYING BACK; - LITTER - SCATTERED BURNED LOGS + PILES < 10" AVE DIA. MOSTLY - STUMPS SOLID < 10-24" D.A. - 12-24" HT. LITTER ACCUMULATIONS LIGHT AREA BURNED PRIOR TO PLANTING - AVE 4" DEPTH - INFREQUENT PATCHES OF MINERAL SOIL

Photo Log:

N 3/1
E 3/2
S 3/3
W 3/4
C 3/5

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: SITE TYPICAL OF OTHER CLEARED AREAS - PERHAPS SL. DRYER DUE TO LIGHTER LITTER LOADS - SOME SHADING FROM SEEDLINGS / SAPLINGS - SET RAIN GAUGE HERE 12:45

Stand Data:

Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	15	40	45	0	0	0	0	0
% Overstory	15	OPEN 40	45	0	0	0	0	0
Number/Class	-	-	-	3*	0	0	0	0
Average Height	-	-	-	10'	-	-	-	-
Major Species	-	-	-	DF	-	-	-	-
Minor Species	-	-	-	** WH	-	-	-	-

* ONLY TALLIED TREES W/ A VISIBLE STEM @ 4.5 DBH - DID NOT COUNT GROWTH LEADERS AS STEMS
** MAJORITY OF SEEDLINGS WH NOT LARGE ENOUGH TO TALLY
*** SEEDLINGS TALLIED AS SHRUBS - THIS PLOT

Reviewed By: V. Callin

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

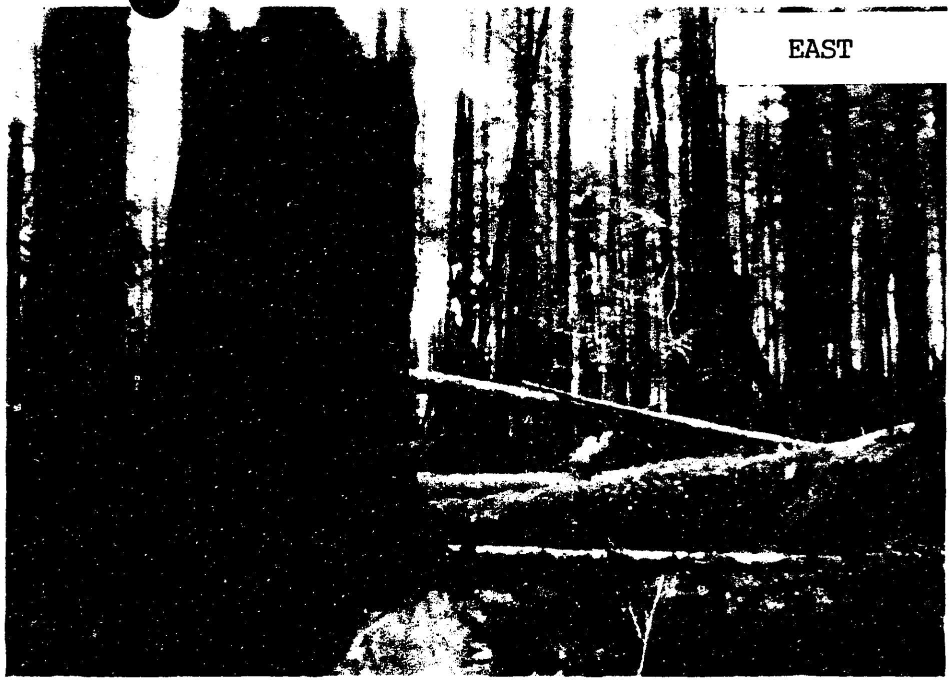
WH - Western Hemlock

WRC - Western Red Cedar

PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species

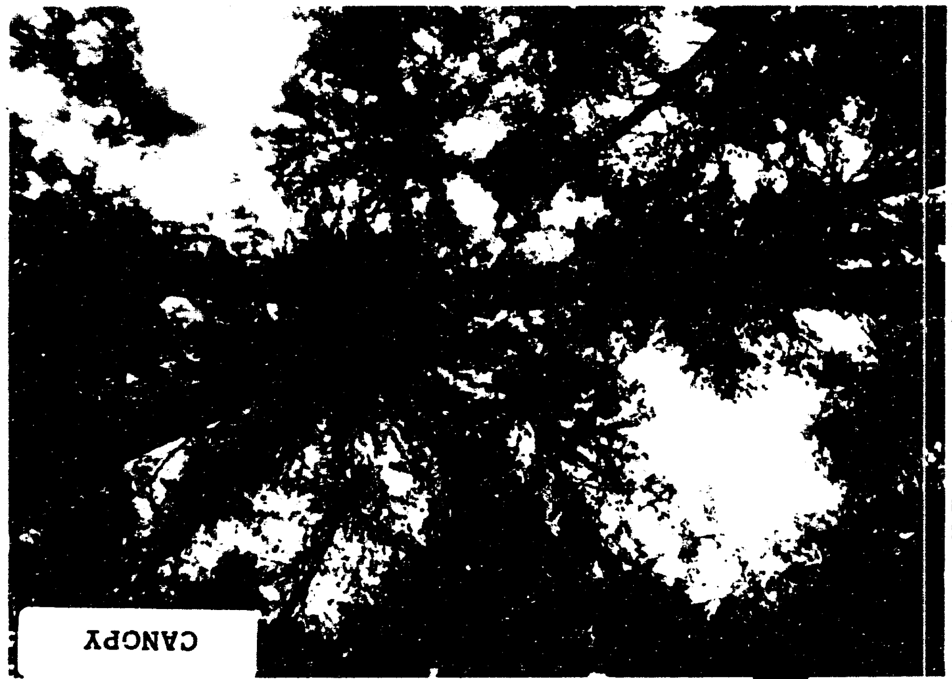


ONE-K - SAMPLE PLOT #4

ONE K - #4
SOUTH

ONE-K #4
EAST

ONE K - #4
WEST



UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/25/91 11:30
Date

ONE-K
Transect

#4 - 216° BEARING
Sampling Station

Site Description: APPROX. 200 YDS S.W OF LOGGING SPUR RD. BEYOND 1-K TARGET SITE - BEGINNING OF POS. SLOPE - 216° BEARING
OVERALL 10-30% - INCREASING TOWARD HILLTOP

Slope: SITE 20% Overall Canopy Cover: 85%

General Over/Under Story Description: OVERSTORY - OLD GROWTH TYPE STAND - SOME VERY LARGE 724"
(Major Species/Woody Fuels/Litter) DF, WH, WRC, PSF - HTS. EXCEED 150 FT. - SECOND & THIRD LAYERS IN CANOPY - CO DOMINANTS - 6-12"+ DBH - HEIGHTS TO 120 FT - CROWNS LIMITED TO UPPER 33% OF BOLES - SMALLER SUPPRESSED TREES MORE SPORADIC - MOSTLY DEAD OR MINIMAL FOLIAGE - MATURE STAND - UNDERSTORY - SPORADIC PATCHES OF WRC - SHRUBBY - SOME RHODODENDRON SCARCE - LITTER MAJOR ACCUMULATIONS OF DOWN ROTTING LOGS; LARGE STUMPS - 24-36" DIAM MANY BROKEN TREES - TO 40FT - NURSE LOGS PROMINANT - HEAVY MOSS ON GROUND - VERY SOFT SPONGY - LITTER TO 36"

Photo Log:
N 2/30 Roll #2
E 2/31
S 2/32
W 2/33
C 2/34

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: APPEARS WETTER THAN ALL SITES SO FAR - HEAVY CANOPY + DEEP LITTER KEEP GROUND VERY DAMP - MOSS ALSO RETAINS MOISTURE - SET RAIN GAUGE UNDER CANOPY - 11:45 - NOTED SMALL STREAM NR. TRANSECT SAMPLE PT.

Stand Data: Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	* 90	1	HUCKLEBERRY 1	0	1	2	0	5
% Overstory	← OPEN 5 →		0	0	0	5	** 30	60
Number/Class	-	-	-	0	1	3 +1 DEAD	0	3 (31.0") (26.4") (37.0")
Average Height	-	-	-	-	30' DYING	80-100' EST	-	7150' EST
Major Species	-	-	-	-	PSF	PSF	-	DF
Minor Species	-	-	-	-	-	WH	-	WH

* MOSTLY MOSS COVERED LOGS 724" STUMP 7 36"
** MAJORITY OF OVERSTORY CANOPY BY DOMINANT 16+" TREES

Reviewed By: [signature]

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

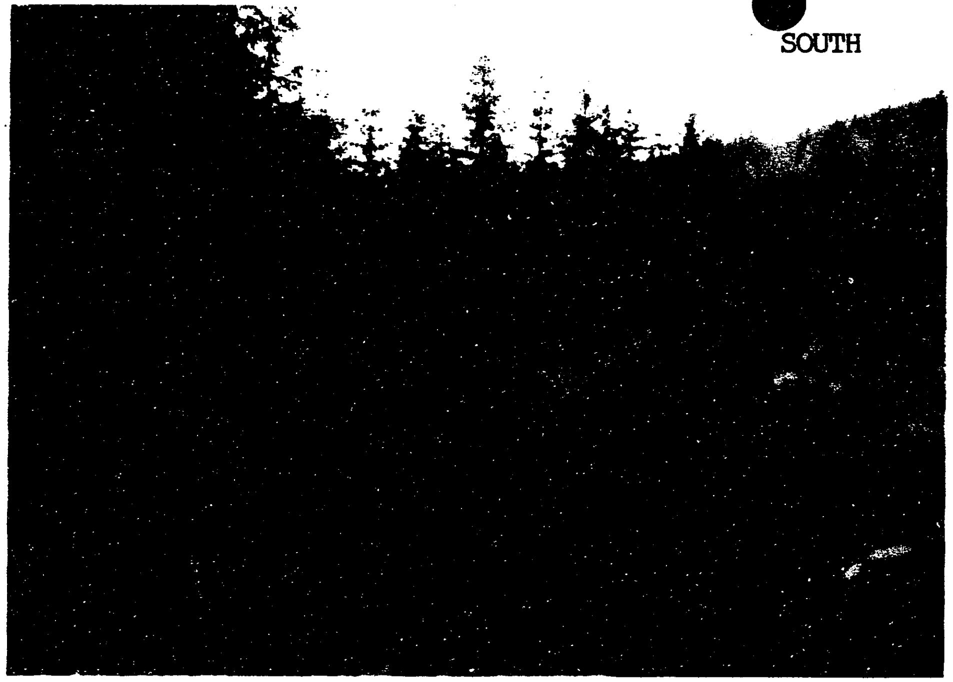
WH - Western Hemlock

WRC - Western Red Cedar

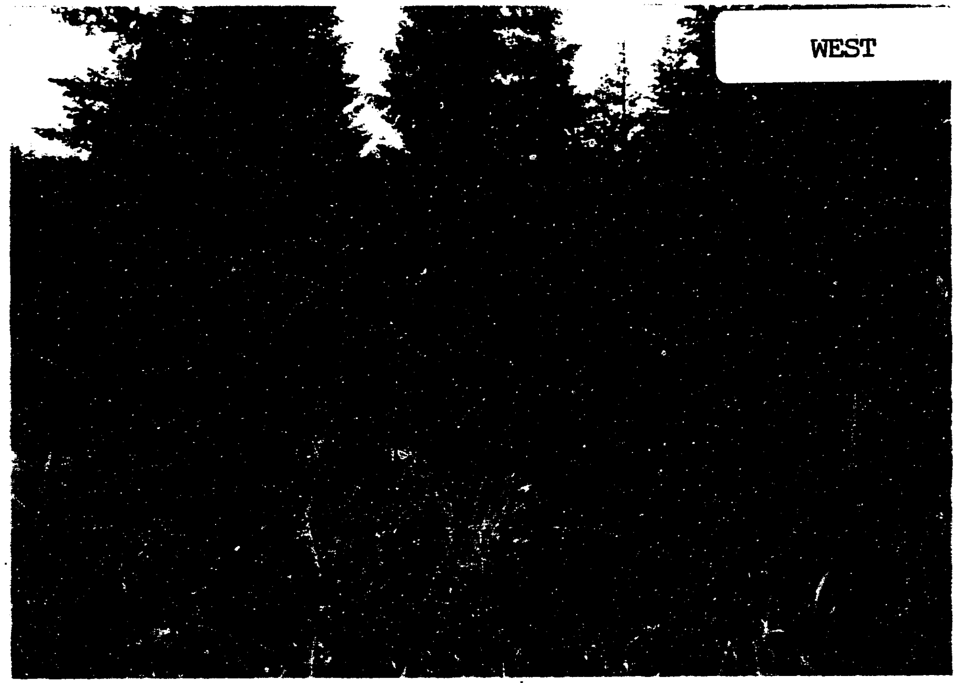
PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species

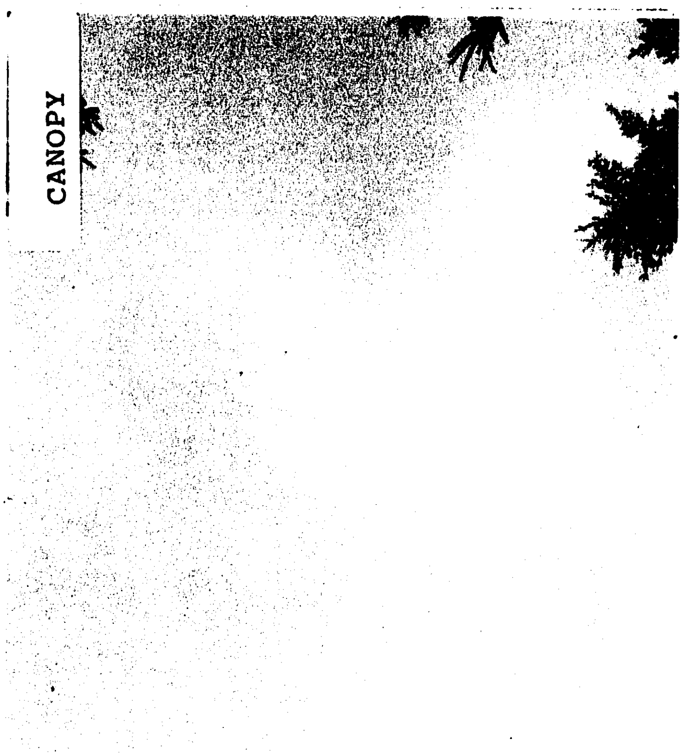


MT. ZION - SAMPLE PLOT #1



ZION #1
WEST

ZION #1
SOUTH



ZION #1
EAST

UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/24/91 10:55
Date

MT ZION
Transect

#1 167° BEARING
Sampling Station

Site Description: APPROX 1/4 MILE FROM RD. - BALLOON #1 - BEARING 347° - NEAR BEND OF ROAD

Slope: 0% Overall Canopy Cover: < 5%

General Over/Under Story Description: LONG NARROW OPEN MEADOW - RUNS SW TO NE - OLD CLEARCUT
(Major Species/Woody Fuels/Litter) AT BEGINNING OF POS. SLOPE FROM RADAR SITE - APPROX. 200 YDS LONG x 75 YDS WIDE OVERSTORY ABSENT EXCEPT ALONG EDGES - A FEW SMALL REPROD. IN CLEARING < 3 FT TALL - PREDOMINANT SURROUNDING SPECIES D.F. : UNDERSTORY PREDOMINANTLY TALL GRASSES TO 3' FT. - SOME FORBS - YARROW THISTLE (MOST VEG. DYING BACK - BROWN) BORDERS HEAVY W/ SALAL, RHODODENDRON; LITTER - LARGE STUMPS LOGS TO 24" VARIOUS STAGES OF DECOMP. - MOST LITTER IS DYING LEAVES - FEW FIR NEEDLES < 1" OVERALL

Photo Log:

	Roll/Photo
N	1/15
E	1/16
S	1/17
W	1/18
C	1/19

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: SIMILAR TO PREVIOUS SITE - HOWEVER DUE TO LACK OF CANOPY THIS AREA DRIES CONSIDERABLY FASTER - NO BOGS, NOT AS MUCH MOSS
DID NOT SET RAIN GAUGE

Stand Data: Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	15	80	2	1	2	0	0	0
% Overstory	OPEN ← 88 →		1	1	5	5*	0	0
Number/Class	-	-	-	1	2	0	0	0
Average Height	-	-	-	6'	30'	-	-	-
Major Species	-	-	-	WH	DF	-	-	-
Minor Species	-	-	-	-	-	-	-	-

*TREE OUT BUT OVERHANGS PLOT RADIUS

Reviewed By: [signature]

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

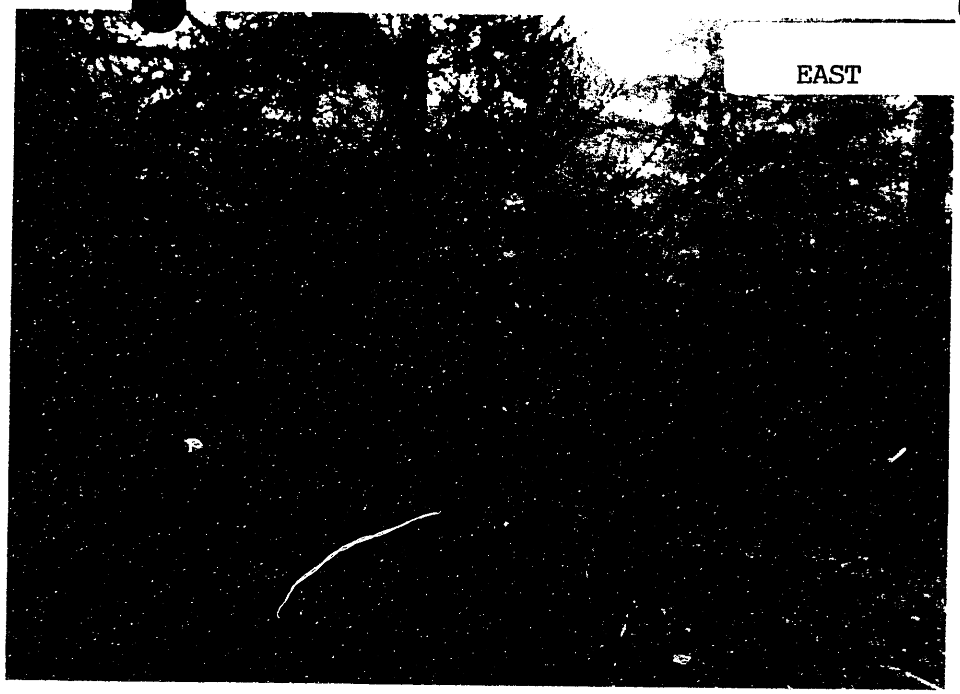
WH - Western Hemlock

WRC - Western Red Cedar

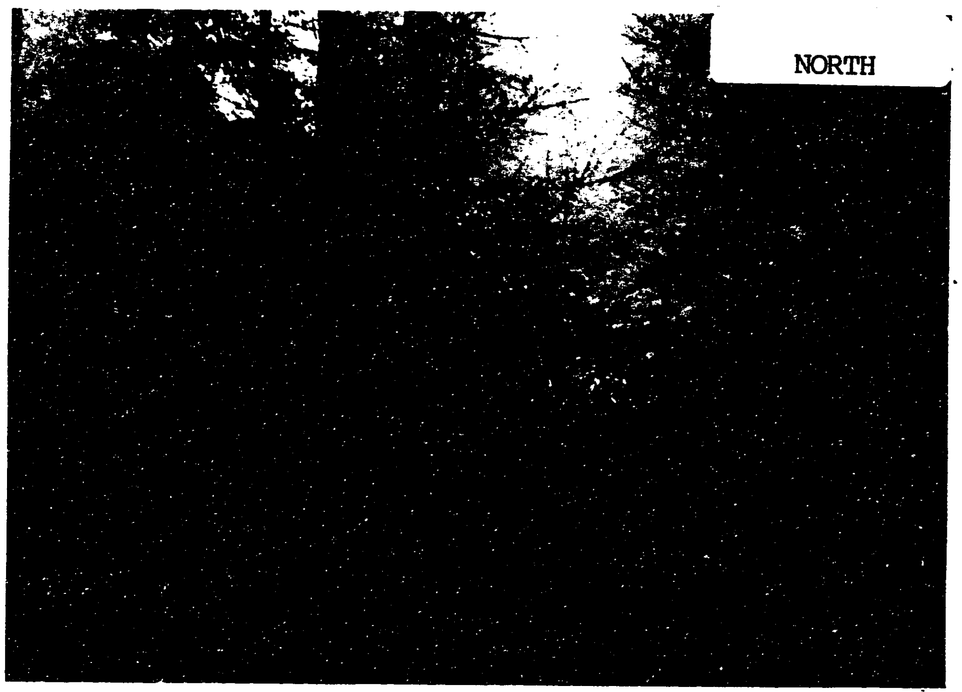
PSF - Pacific Silver Fir

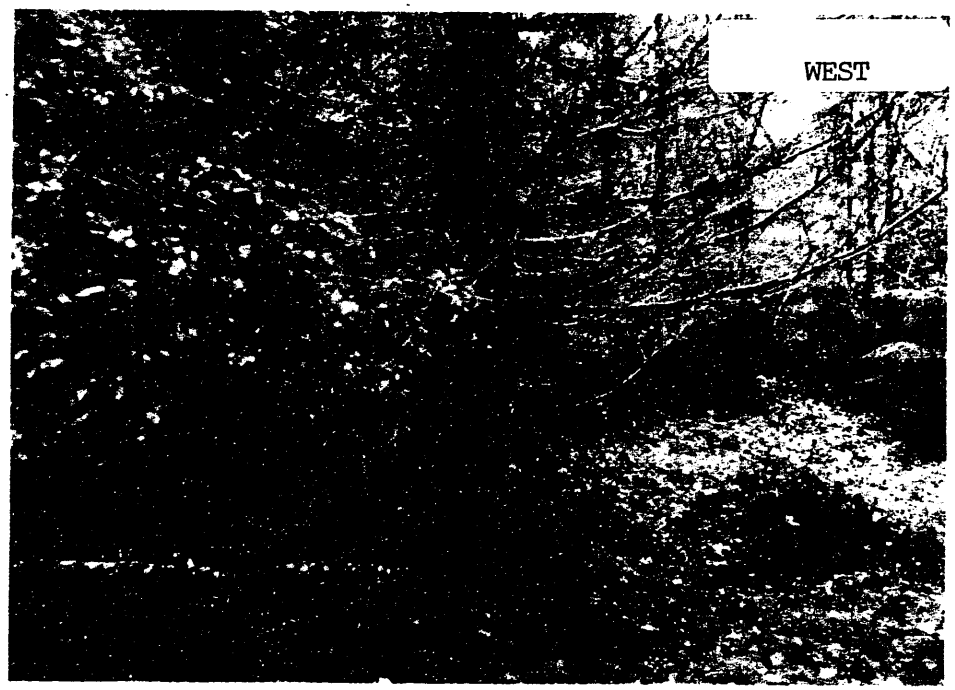
M - Madrone

DEC - Deciduous Species



MT. ZION - SAMPLE PLOT #2





ZION #2
SOUTH

ZION #2
EAST

ZION #2
WEST

UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/24/91 09:30
Date

MT ZION
Transect

#2 - BEARING 167°
Sampling Station

Site Description: APPROX. 125 FT FROM ROAD - BALLOON #1 - BEARING 347° - NEAR BEND OF ROAD

Slope: OVERALL 0-5% SITE 0-5%

Overall Canopy Cover: 80%

General Over/Under Story Description: (Major Species/Woody Fuels/Litter) OVERSTORY - PREDOMINANTLY EVEN AGED DF - SOME WH; CROWNS AVERAGE ≥50% OF OVERALL TREE HT. SMALL BRANCHES ON TREE BOLES FROM GROUND UP (MANY DEAD) - SMALLER WH/DF IN BETWEEN LARGER POLES: UNDERSTORY - MOD TO HEAVY (IN CANOPY BREAKS) - MOSTLY SALAL, BARBERRY TWISTED STALK + LEAFY SPP. < 6" TALL NO GRASSES / NO MOSS: PREVIOUSLY LOGGED - STUMPS 8-24" - ROTTING, MOSS COVERED - SOME DOWNED DEBRIS - MOSS COVERED - 2-6" DIA. 1-16 FT LONG - STUMP SPACING AVE 20 × 20 FT. - LITTER DEPTH AVE < 2" OVERALL

Photo Log: ROLL/PHOTO

N	1/10
E	1/11
S	1/12
W	1/13
C	1/14

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: AVERAGE MOISTURE - SOME MOSS ON STUMPS + LOWER TREE BRANCHES - NO BOGS OR STANDING WATER: RAIN DOES PENETRATE CANOPY SET RAIN GAUGE AT 0953 THIS SITE - NR. ~~EDGE~~ BREAK OF CANOPY - CURRENTLY DRIZZLING

Stand Data: Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	50	40	5	1 (BOTH 0-2 + 2-6")		2	2	0
% Overstory	OPEN ← 33 →		5	5	2	15	40	0
Number/Class	-	-	-	5	1	1	2 (12-13')	0
Average Height	-	-	-	<10'	20'	60'	70'-90'	-
Major Species	-	-	-	WH	WH	DF	DF	-
Minor Species	-	-	-	-	-	-	-	-

Reviewed By: [signature]

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

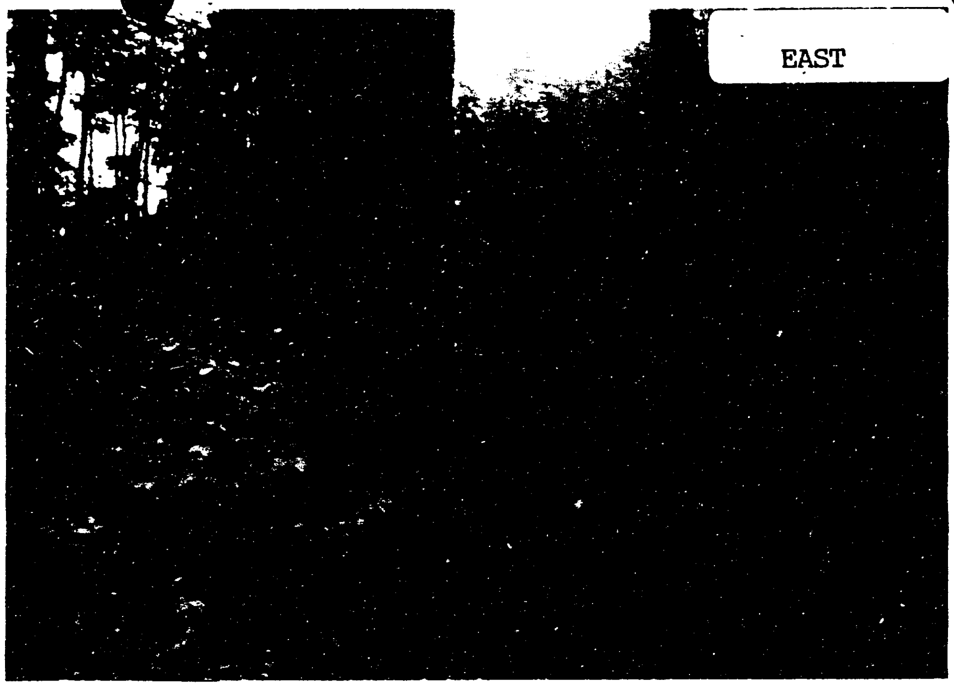
WH - Western Hemlock

WRC - Western Red Cedar

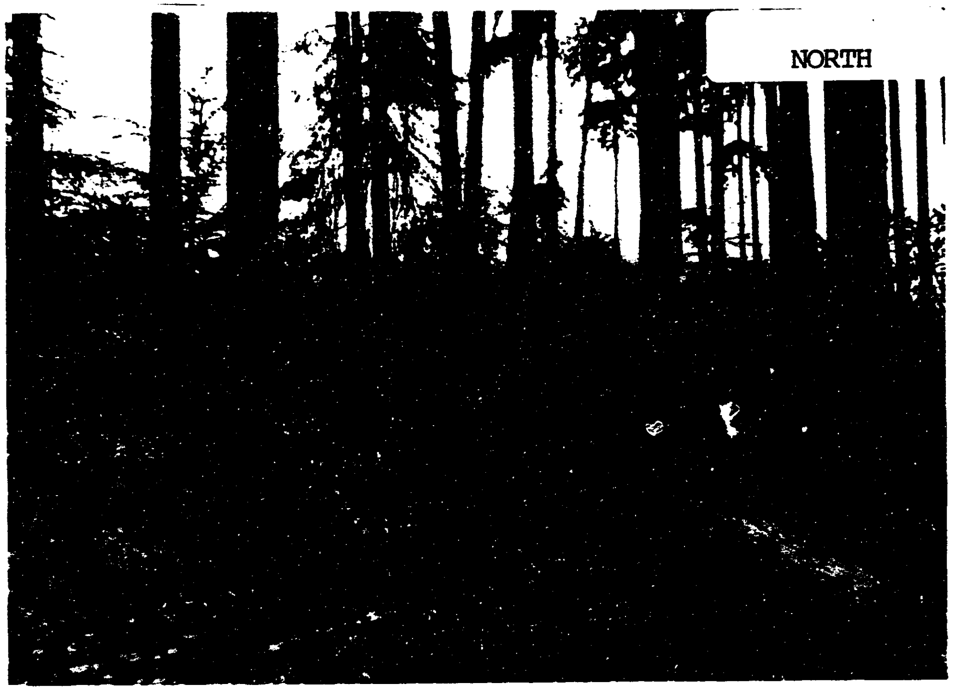
PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species



MT. ZION - SAMPLE PLOT #3



ZION #3
SOUTH

ZION #3
EAST

ZION #3
WEST

UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/24/91 11:45
Date

MT ZION
Transect

#3 - 167° BEARING
Sampling Station

Site Description: APPROX. 250 YDS FROM BALLOON #1 - BEARING 167° - NEAR BEND OF ROAD

Slope: PLOT SITE 5-10% OVERALL - VARIABLE - STAND BISECTED BY 2 RAVINES - SLOPES -100% TO +100% - AVERAGE AT SITE 10-15%

Overall Canopy Cover: 30%

General Over/Under Story Description: (Major Species/Woody Fuels/Litter) OVERSTORY - STAND OF EXTREMELY TALL WH/DF - EXCEED 150' CROWNS LIMITED TO UPPER 30-50% OF TOTAL HT - STEM DIA. AVE 12-24" PLUS - SOME WRC + DEC. ALDER IN OPEN SPACES FORM 2ND CANOPY LAYER - UP TO 60' 3RD LAYER PREDOMINANTLY WRC + WH REGENERATION TO 20 FT. UNDERSTORY PRIMARILY RHODODENDRON, HUCKLEBERRY + MISC. DEC. SHRUBS (<10'). LITTER - FLOOR - HEAVY WINDFALL W/ LARGE DOWNED TIMBER 1-2 FT. TO 50+ FT LONG - OVERALL DEPTH TO 36" W/ FALLEN DEBRIS - VARIOUS STAGES OF DECOMPOSITION HEAVY MOSS GROWTH - SOME FORBS PRESENT - TWINFLOWER, BARBERRY, WILD GINGER ETC.

Photo Log: ROLL/PHOTO

N 1/20
E 1/21
S 1/22
W 1/23
C 1/24

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: APPEARS TO BE FAIRLY MOIST: RUNNING WATER IN DRAINAGES W/IN STAND. OPEN CROWN AT SUCH HEIGHTS ALLOW FAIR SUNLIGHT PENETRATION; HEAVY LITTER + MOSS SHOULD RETAIN MOISTURE - SET RAIN GAUGE @ SITE IN OPENING - 12:00

Stand Data:

Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	LOGS MOSTLY 70	* 9	15	1	1	1	1	2
% Overstory	OPEN 20' ↔	**	10	5	5	10	25	25
Number/Class	-	-	-	16	3	1 (11.3")	1 (12.4")	1 (24.5")
Average Height	-	-	-	10'	20'	40'	90' EST.	130+' EST.
Major Species	-	-	-	WH (14)	WH	WRC	WH	WH
Minor Species	-	-	-	WRC (2)	-	-	-	-

*MOST MOSS GROWING ON DOWNED TIMBER
**DIFFICULT TO ASSESS DUE TO OVERSTORY CANOPY HT.

Reviewed By: [signature]

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

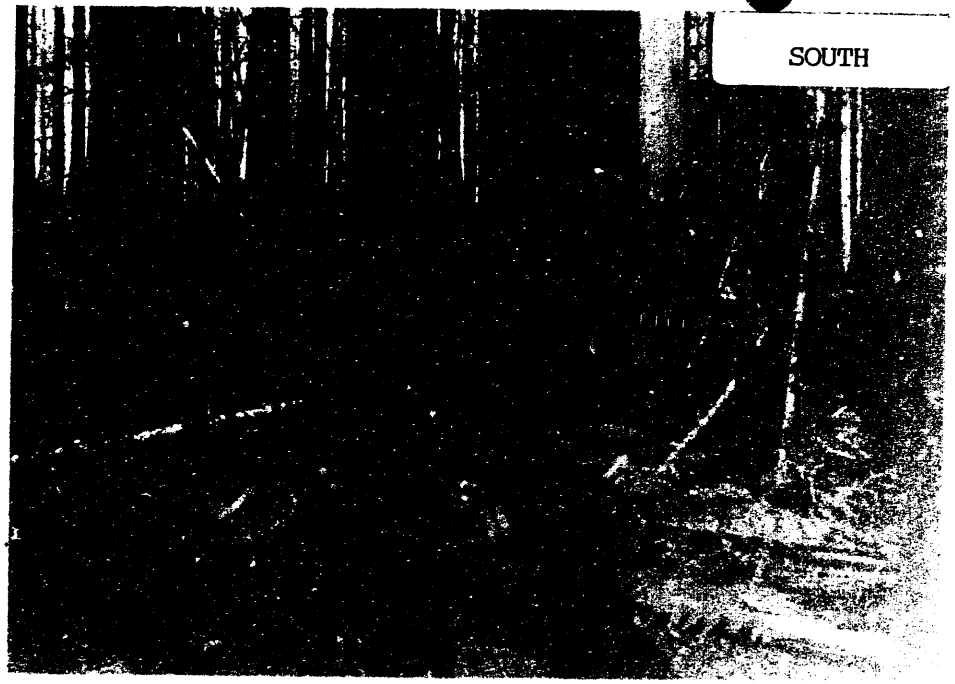
WH - Western Hemlock

WRC - Western Red Cedar

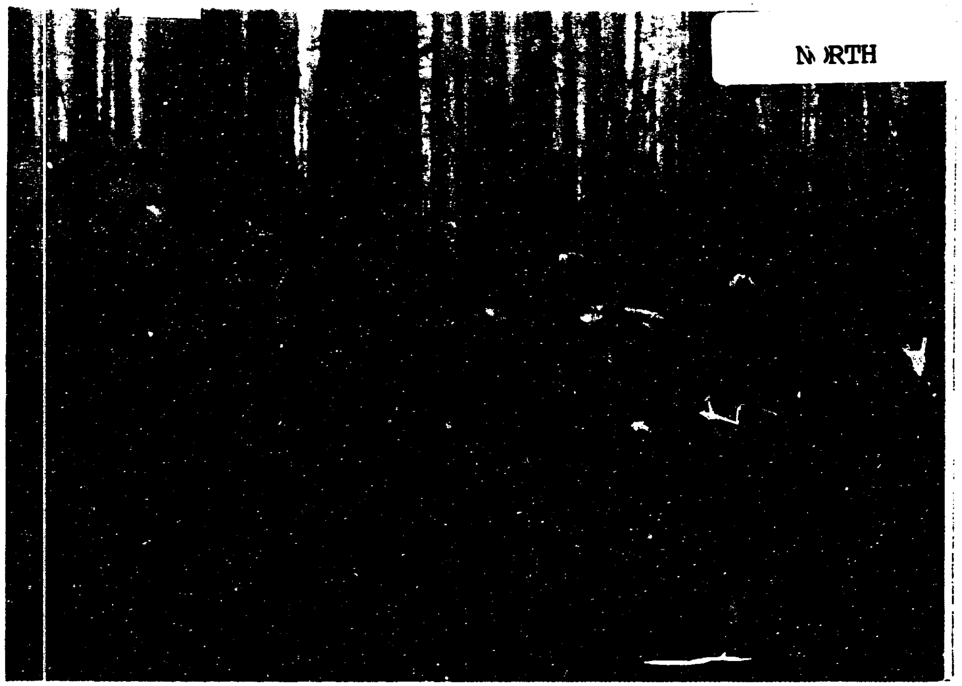
PSF - Pacific Silver Fir

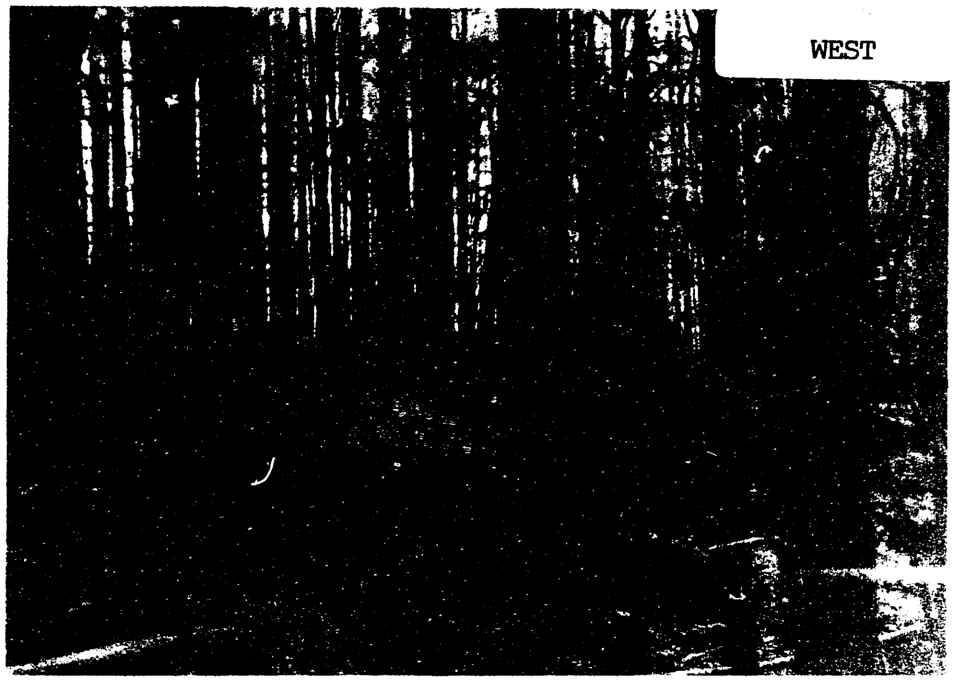
M - Madrone

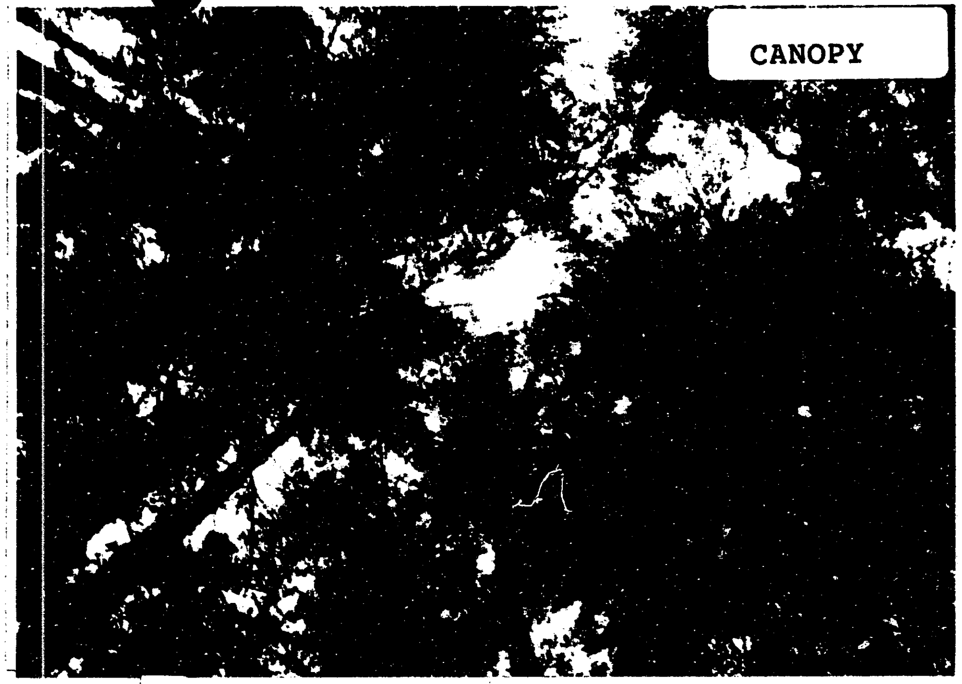
DEC - Deciduous Species



MT. ZION - SAMPLE PLOT #4







ZION #4
WEST

ZION #4
EAST

ZION #4
SOUTH

UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/24/91 13:20
Date

MT ZION
Transect

#4 - 167° BEARING
Sampling Station

Site Description: APPROX. 75-100 YDS FROM BALLOON #2 - BEARING 347° - IN DOGHAIR STAND

Slope: OVERALL 15-20% SITE 10%

Overall Canopy Cover: 95%

General Over/Under Story Description: OVERSTORY - GENERALLY SMALL POLE/DOGHAIR - EVEN AGED STAND

(Major Species/Woody Fuels/Litter) PREDOMINANTLY WH, W/ D.F., WRC*- HEIGHTS AVE 60-80 FT DIA. <2" TO 12" (AVE 4-8"); UNDERSTORY MOSTLY ABSENT - SCATTERED RHODODENDRON, WRC SEEDLINGS - SMALL STEMS W/ NO LEAVES (DEAD) FAIRLY COMMON; LITTER: HEAVY LITTER ACCUMULATIONS - MOSTLY OLD DECOMPOSED LOGS + STUMPS - COVERED W/ MOSS PLUS LIGHT NEEDLE CAST ON SURFACE - LITTER DEPTH 1-2 FT AVERAGE

* PSF ALSO NOTED

Photo Log: ROLL/PHOTO

- N 1/25
- E 1/26
- S 1/27
- W 1/28
- C 1/29

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: SITE TYPICAL OF HEAVY CANOPY COVER - SOME RAIN PENETRATING - GROUND SOFT - LITTER HOLDS MOISTURE FOR CONSIDERABLE TIME W/ MINIMAL SUNLIGHT PENETRATION - CONSIDERABLE MOSS

RAIN GAUGE SET - UNDER CANOPY - 13:30

Stand Data: Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	61	25	2	1	5	5	1	0
% Overstory	OPEN 5		1	5	24	50	15	0
Number/Class	-	-	-	6	+ 6	10	(14.1") 1	0
Average Height	-	-	-	10'	30'	40-50'	60-70' (est)	0
Major Species	-	-	-	WH	WH	DF	WH	-
Minor Species	-	-	-	WRC	WRC/PSF	WH	-	-

+ ALMOST 1/2 OF STANDING POLES DEAD W/ NO CROWNS - THESE WERE NOT TALLIED

Reviewed By: V1 C[illegible]

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

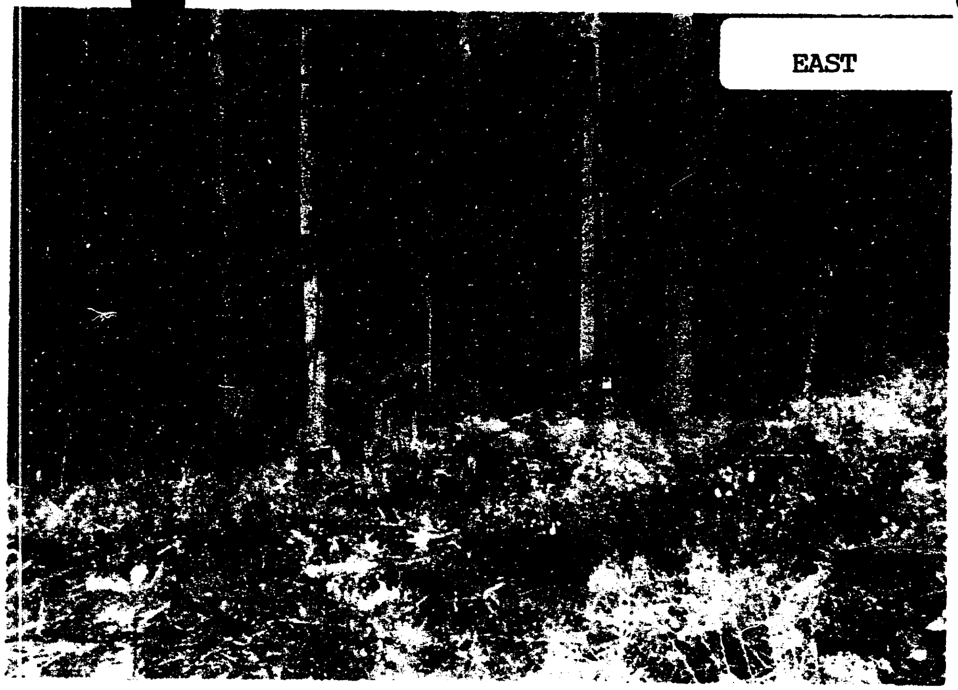
WH - Western Hemlock

WRC - Western Red Cedar

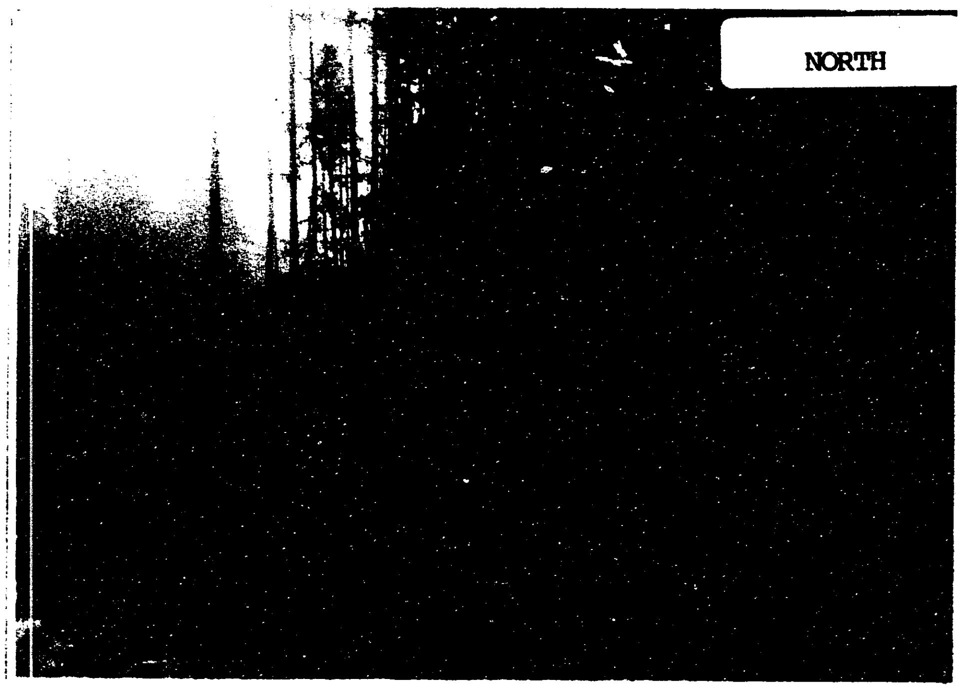
PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species



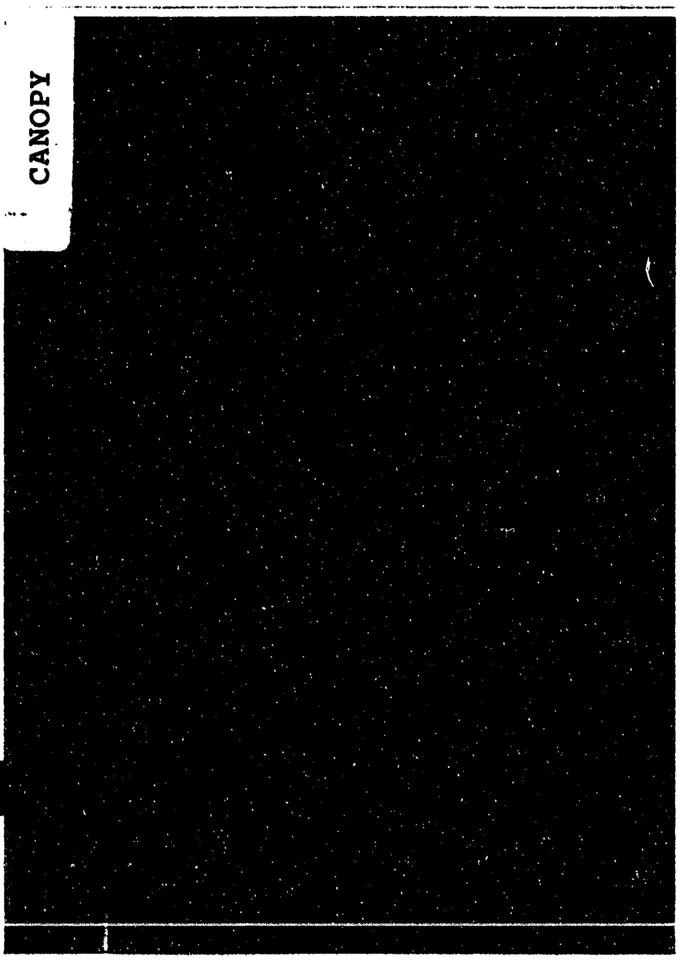
MT. ZION - SAMPLE PLOT #5



ZION #5
WEST

ZION #5
SOUTH

CANOPY



ZION #5
EAST

UWB CLUTTER EXPERIMENT

TELENICK
Observer

10/24/91 14:15
Date

MT ZION
Transect

#5 - 167° BEARING
Sampling Station

Site Description: CLEARCUT AREA - S. OF BALLOON #2 (167° BEARING) - N.E. EDGE OF CLEARCUT ± 100YDS FROM BALLOON

Slope: OVERALL 15-20% SITE - 15%

Overall Canopy Cover: 0% - OPEN

General Over/Under Story Description: (Major Species/Woody Fuels/Litter) RECENT CLEARCUT - DEBRIS STILL SCATTERED - SOME BARE MINERAL SOIL EXPOSED - MOST UNDERSTORY VEGETATION - BRACKEN FERN, THIMBLEBERRY, LACTUCA, VARIOUS COMPOSITES; MINOR VEGETATION - SEEDLINGS < 1' TALL - OCCASIONAL ALDER 6-8' - STUMPS SPACED 10-20' AVE 12-24" DIA. - MOST LOGGING DEBRIS 4-8" DIA. OCCASIONAL ROTTED LOGS TO 16" DIA. - 10-20' LONG; OVERALL CLEARCUT SIZE HARD TO DETERMINE AT LEAST 10 A - LITTER DEPTH AVE 1 FT. OVERALL

Photo Log: ROLL/PHOTO

N 1/30
E 1/31
S 1/32
W 1/33
C 1/34

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: TYPICAL OF AREA - NO MOSS - PROBABLY DRIER OVERALL DUE TO EXPOSURE - DRIZZLING NOW - IN CLOUDS - NO RAIN GAUGE SET

Stand Data: Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover	80	19	1	0*	0	0	0	0
% Overstory	80	OPEN 19	1	0	0	0	0	0
Number/Class	-	-	-	0	0	0	0	0
Average Height	-	-	-	–	–	–	–	–
Major Species	-	-	-	–	–	–	–	–
Minor Species	-	-	-	–	–	–	–	–

* SEEDLINGS < 4.5 FT TALL NOT TALLIED

Reviewed By: V. C. Cline

See Back of Form for Notes

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

WH - Western Hemlock

WRC - Western Red Cedar

PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species

Supplement 1. UWB Clutter Experiment Geographic Information for Ground Truth Data Collection Site

Identification Key for the Geological Information System (GIS) Data Summaries*
U.S.G.S. Mount Zion Quadrangle

Item: Polygon Identification Code (Overlay)
Subject: Database Identification Code (Not Applicable)
Class: Primary Stand Classification Code
- C: Crop
- M: Mature
- I: Immature
- E: Excessive

Species: Predominant Tree Species
- A: Pacific Silver Fir
- AF: Subalpine Fir
- C: Western Redcedar
- DF: Douglas Fir
- H: Western Hemlock
- RA: Red Alder

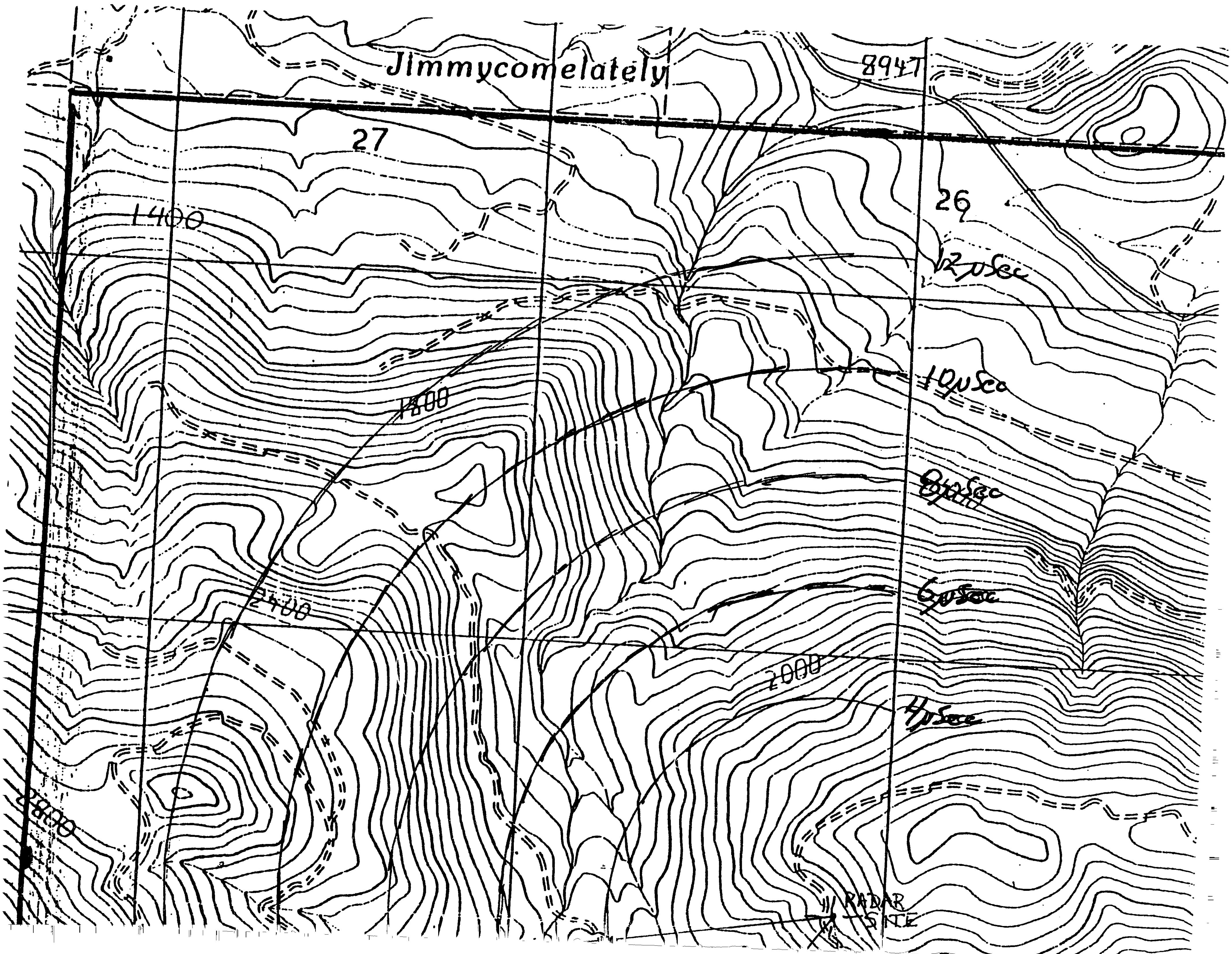
Size: Size Classification Code
- ND: Seedlings with no diameter (0.0-0.4" Diameter breast height (DBH))
- SS: Seedlings and saplings (0.5-4.9" DBH)
- PL: Poles (5.0-8.9" DBH)
- MS: Small sawtimber (9.0-20.9" DBH)
- LS: Large sawtimber (21.0" and larger DBH)

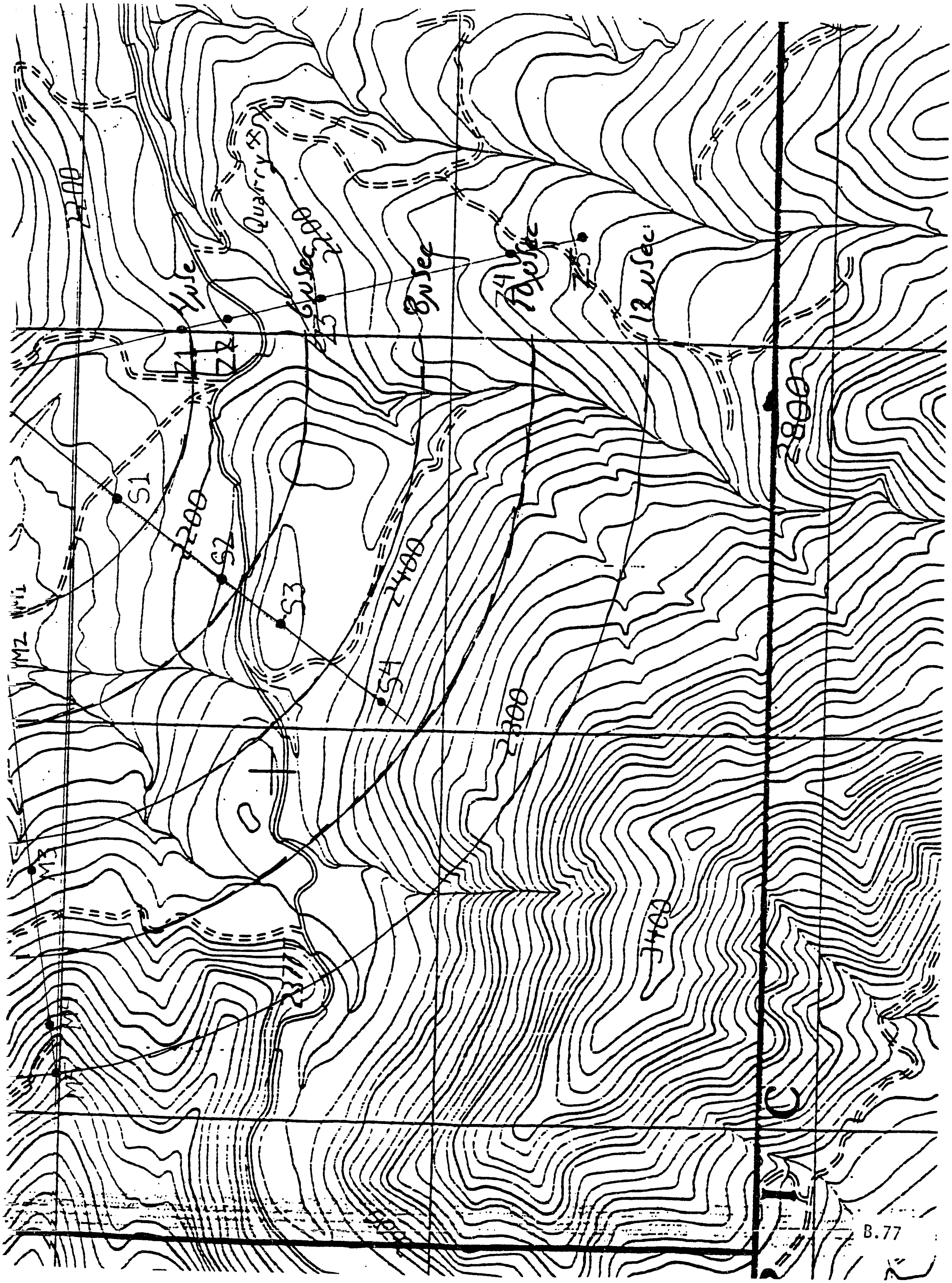
YRO: Year of Origin
BA: Total Basal Area per Acre
MBF: Thousand Board Feet per Acre
Area: Acres per Stand

Data has been compiled with a master key and three subdirectories, one for each primary stand classification listed above. For example, polygon number 396 on the overlay can be found under Item number 396 in the master key. This polygon is designated as Class C and is predominantly Douglas Fir with a size class of small sawtimber. The year of origin was 1880 and the average basal area per acre is 174 ft for all tree species. The site has 14,000 board feet per acre of commercial timber in a area of 145.526 acres. The Class C designation for this site can be cross referenced in the Class C subdirectory. Using this subdirectory under Item number 396 gives further details of the polygon vegetative characteristics. For example, the major species is again listed as Douglas Fir. The average DBH of the Douglas Fir is 10" with 216 trees/acre. The average basal area considering only the Douglas Fir is 109 ft for a total of 13,000 board feet.

* GIS data has been provided by the U.S. Forest Service, Quilcene Ranger District.

Supplement 2: UWB Clutter Experiment
Ground Truth Transect Location


Jimmycomelately
894T
27
26
1400
1800
2400
2000
2800
12μSec
10μSec
8μSec
6μSec
4μSec
RADAR SITE


Quarry
2200
2400
2300
S1
S2
S3
S4

APPENDIX C:

Ground Truth for Maynard Site 1992 Sequim Measurements

1992 UWB CLUTTER EXPERIMENT GROUND TRUTH STUDY

R.W. Bienert
E. Telenick
V.I. Cullinan

November 1992

Letter Report Prepared for Pacific Northwest Laboratories

INTRODUCTION

In October 1991, Battelle/Marine Sciences Laboratory (MSL) was requested to participate in the collection of ground truth data in support of the UWB Clutter Radar Experiment conducted for the Defense Advanced Research Project Agency (DARPA). Data collection emphasized a general characterization of the landscape and vegetation along three transect lines from a forested site within the Quilcene Ranger District, Olympic National Forest, Washington. Details of the purpose, sampling methodologies, and results of this study have been described in Cullinan and Telenick (Letter Report, November 1991).

In September 1992, Battelle/Marine Sciences Laboratory was requested to perform an additional field survey at a location approximately 5 km southwest of the site examined in 1991. This letter report presents the methods and results for the 1992 field study.

METHODS

Field surveys were conducted during September 13 to October 11, 1992 at a pre-selected forested site within the Quilcene Ranger District of the Olympic National Forest. The objective of the field surveys was to perform a baseline characterization of the landscape and vegetation at the new location chosen for the 1992 UWB Clutter Experiment. The parameters of interest for this study were: 1) stand type including dominant species, and size and distribution of trees; 2) canopy profile and coverage; 3) cover and type of understory vegetation; 4) ground litter type and estimate of accumulation; and 5) relative moisture level.

Transect Locations

The proposed site for the 1992 UWB Radar Clutter Experiment was located approximately 1 km west of the junction of Forest Service roads 28 and 240 along a ridge line overlooking the Eddy Creek drainage basin (Figure 1). Three transect lines extending 2 km from the radar site at angles of 30°, 0° and 330° (magnetic declination 20° E), bounded the "target area" selected for the ground truthing study. Areas of negative slope were excluded from examination. This included the majority

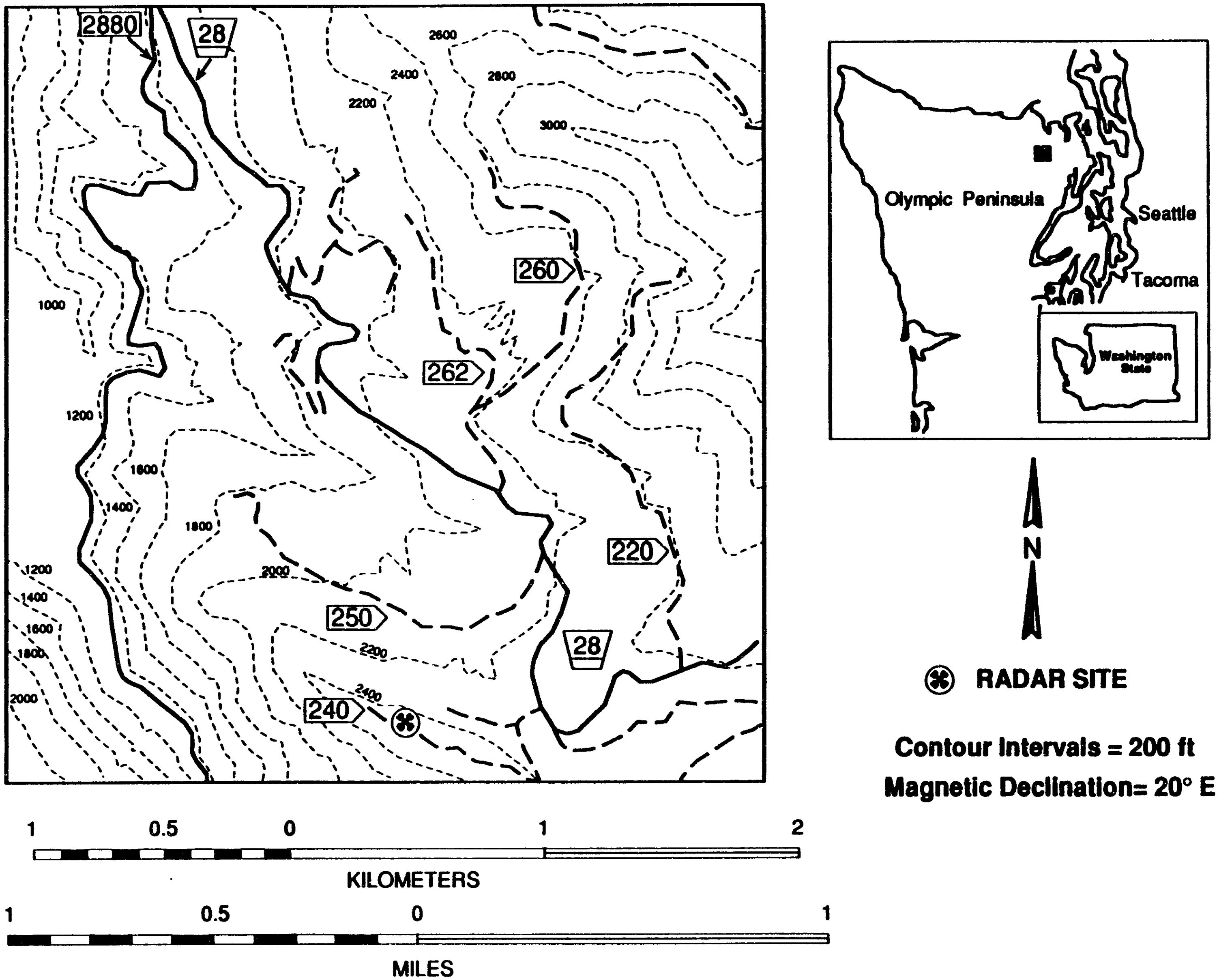


FIGURE 1. Location of the Radar Site and Study Area

of the area descending toward Eddy Creek, as well as other small drainages and side slopes within the selected target area.

Location of the transects was accomplished using a hand held compass, color aerial photographs, a 7.5 minute USGS topographic map (Mount Zion quadrangle), helium balloons, and an observer located at the radar site. Using two-way radios, the observer guided a second technician equipped with the helium balloons to points along the transects which intersected accessible roads. Three balloons were used to mark the center line of each transect. The most distant balloon along each transect was located at least 2 km from the radar site.

Once the transects were located, color aerial photographs were used to delineate potential timber stands and clearcuts for sampling. An initial field survey was conducted to verify stand types, and potential sampling locations were identified based on gross differences in species composition between stands. A total of 13 sample plots were selected along the three transects: five each for the 30° and 0° transects, and four for the 330° transect (Figure 2).

Field Methods

Each plot location was carefully selected to ensure that all plots were representative of the particular stands being characterized. In some cases, this involved locating plot centers away from the edges of clearcuts or logging roads to minimize the effects of blowdown or logging construction. A plot radius of 16.7 ft, which represents 1/50th of an acre on level ground, was selected because it was large enough to accommodate minor site variability yet small enough to allow a singe surveyor to efficiently inventory the site. The center of each plot was marked with a surveyor's stake and flagging tape. The perimeter of each plot was marked with a lead-free, fluorescent paint developed for construction and forestry applications. Photographic records were obtained for each of the sample plots. A total of five color photographs were taken at each site: one each facing north, south, east and west from the approximate center of the plot, and one facing straight up to record the canopy cover.

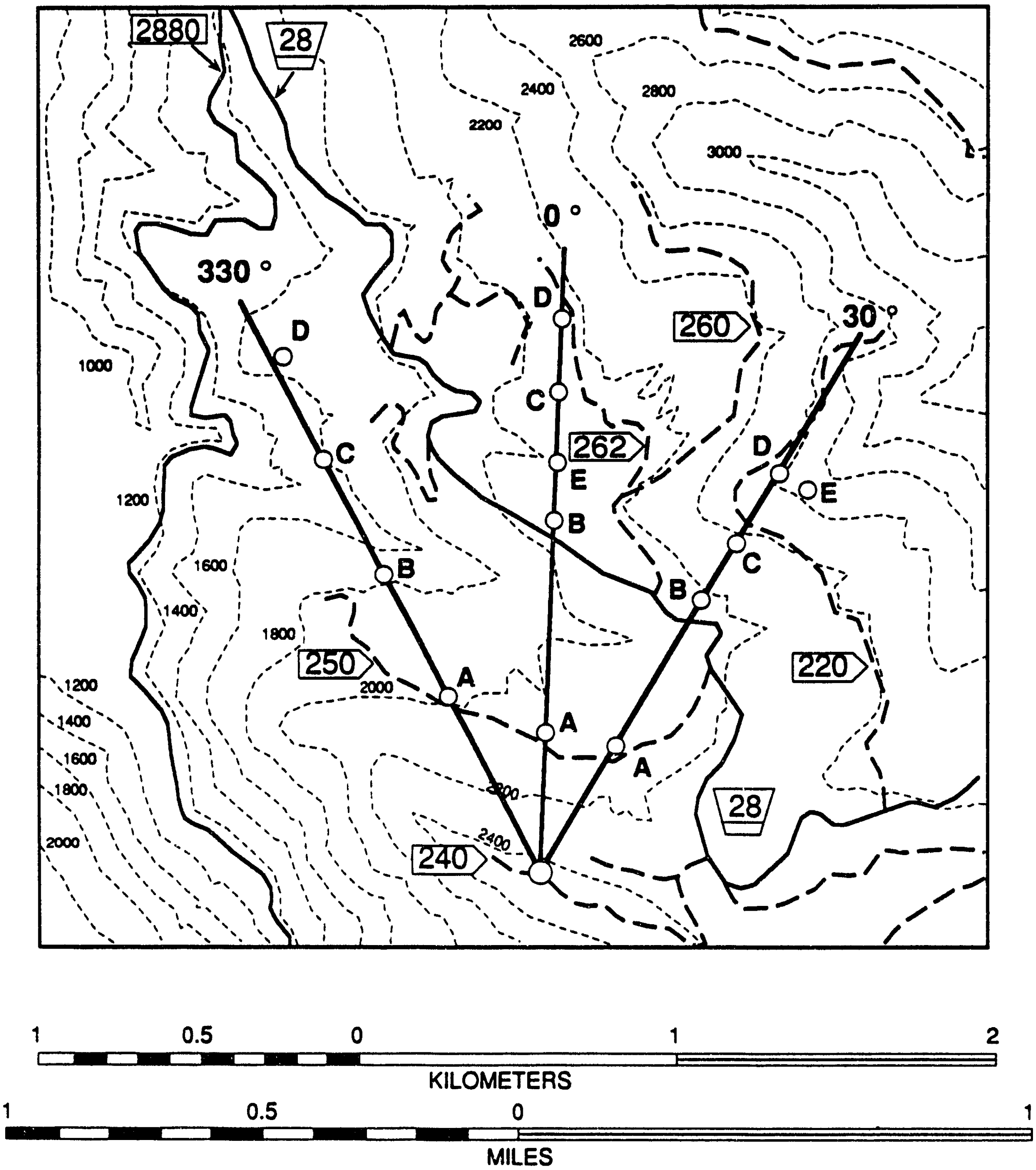


FIGURE 2. Location of Transects and Field Sampling Plots within the Study Area

A field data form (Figure 3) was used to record general characteristics of each stand and specific vegetation characteristics of the sampling plots. Overstory vegetation was categorized using 5 stem diameter classifications: 0-2, >2-6, >6-12, and >16 inches. All diameters were measured at a standard height of 4.5 ft. Trees which did not have a measurable stem at his height were tallied as shrubs. Major and minor species represented in the plot were recorded along with an ocular estimate of the average tree height by stem size classification. Due to the variability of heights and multiple trees per class in many of the sampling plots, these estimates should be considered very coarse. Occasional tree heights were measured using a clinometer in order to calibrate the ocular estimates.

Each site was further described in terms of the vegetation for both ground cover and overstory coverage. Vegetation was classified as either litter/bare ground, grasses/forbs, shrubs, or one of the five tree-stem classifications. The ground cover survey described the percentage of the plot covered by each of these vegetation classifications. Only the cross-sectional diameters of the woody stems of trees were evaluated in the percentage cover estimates for this survey. Shrubs were tallied as ground cover unless they were tall enough to be included in the estimates of overstory coverage. In these cases, the shrubs were considered small trees and categorized by stem diameters. The percent overstory surveys were conducted as if the plot was viewed from above. In areas where there was multiple overstory layering, the uppermost canopy was recorded in the appropriate stem diameter classification. Thus, for both surveys the overall coverage totalled, but did not exceed, 100%.

Moisture conditions were described for each site in terms of the depth and composition of accumulated litter. The objective was to obtain an estimate of the relative "wetness" of each plot. A relative score, ranging from one (driest) to five (wettest), was given to each of the plots. Rainfall during the conduct of the radar experiment was measured by placing rain gauges in the center of three plots from each transect. The rain gauges were monitored twice at weekly intervals from 27 September to 11 October.

UWB CLUTTER EXPERIMENT

Observer ____________ Date ____________

Transect ____________ Sampling Station ____________

Site Description: ____________

Slope: ____________ Overall Canopy Cover: ____________

General Over/Under Story Description: ____________

(Major Species/Woody Fuels/Litter) ____________

Photo Log: N ____ E ____ S ____ W ____ C ____

Note: Photographs will be taken at each compass direction and at the canopy.

Rainfall/ Moisture Description: ____________

Stand Data: Plot Radius = 16.7 FT 1/50 ACRE

	Litter/ Bare Ground	Grasses/ Forbs	Shrubs	0-2 DBH	>2-6 DBH	>6-12 DBH	>12-16 DBH	>16 DBH
% Ground Cover								
% Overstory								
Number/Class	·	·	·					
Average Height	·	·	·					
Major Species	·	·	·					
Minor Species	·	·	·					

Reviewed By: ____________

Notes:

1) Percent ground cover and percent overstory will each total 100%.

2) Percent ground cover will be viewed as the percent of stems and ground vegetation.

3) Percent overstory will be viewed as the canopy as observed from above.

Species Key:

DF - Douglas Fir

WH - Western Hemlock

WRC - Western Red Cedar

PSF - Pacific Silver Fir

M - Madrone

DEC - Deciduous Species

FIGURE 3. Sample Field Data Form Used to Record Vegetation Characteristics

Statistical Analysis

Data from each of the field survey forms were entered into a commercial spreadsheet program (Microsoft Excel Version 3.0 for the Macintosh). Plots were generated using Excel and the charting program Deltagraph (Version 1.5, DelaPoint, Inc.). Data were summarized by both stand classification and by individual transect.

Three stand classes were used to characterize the 13 sample plots. Stands were classified as Class 1 if the major tree component was absent or could be characterized as seedling/sapling with a diameter of $\leq$2 inches, Class 2 if the major tree component could be harvested as pole timber (diameters $\leq$ 12 inches), or Class 3 if the major tree component could be harvested as saw timber (diameters >12 inches). All sampling plots were categorized within one of the stand classes in order to estimate the mean and standard deviation for each of the stand parameters measured.

RESULTS AND DISCUSSION

A spreadsheet of the raw data taken from the original field data forms has been attached as Appendix A. Photographs taken within each of the plots are provided in Appendix B. A summary of the general vegetation characteristics, litter depth, overall canopy cover, and estimates of relative moisture levels within each of the field plots, is provided in Table 1. Mean estimates of relative moisture, litter depth, and canopy cover for the three general stand classes, are provided in Figure 4.

Aerial photographs, a USGS topographic map, and ground truthing surveys were used to create a map of the general vegetation categories found within the radar target area (Figure 5). The absolute distance (uncorrected for slope) of each stand type from the radar site and the lengths of each stand type along the transect lines, were calculated from the vegetation map (Table 2). Slope-corrected lengths for each stand and distances of each stand from the radar site, were calculated according to the following formula:

$$\text{corrected distance} = \text{SQRT}(\ (\text{absolute distance})^2 + (\text{change in elevation})^2\ )$$

If an individual stand contained areas of both positive and negative slope, then corrected distances were calculated for each upsloping and downsloping segment.

TABLE 1. Summary of General Vegetation Characteristics, Litter Depths, Canopy Cover, and Moisture Levels for Field Sampling Plots

Transect	Site	General Vegetation Category	Stand Class	Litter Depth (cm)	Overall Canopy (%)	Moisture Level	Rainfall (cm) 27 Sept-11 Oct
30 Degrees	A	Small Pole	2	41	65	5	not measured
30 Degrees	B	Sapling/Small Pole	2	30	10	2	0
30 Degrees	C	Clearcut	1	3	0	3	0
30 Degrees	D	Pole/Doghair	2	20	95	2	0
30 Degrees	E	Small Pole/Branchy	2	15	70	3	not measured
0 Degrees	A	Small Pole/Doghair	2	8	95	3	0
0 Degrees	B	Saw/Large Pole	3	41	85	2	0
0 Degrees	C	Clearcut	1	8	0	2	0
0 Degrees	D	Large Pole/Saw	3	30	75	3	not measured
0 Degrees	E	Small Pole/Branchy	2	20	90	3	0
330 Degrees	A	Small Pole	2	41	50	3	0
330 Degrees	B	Saw/Old Growth	3	61	90	3	not measured
330 Degrees	C	Small Pole/Sapling	2	15	10	3	0
330 Degrees	D	Small Pole/Branchy	2	10	15	2	not measured

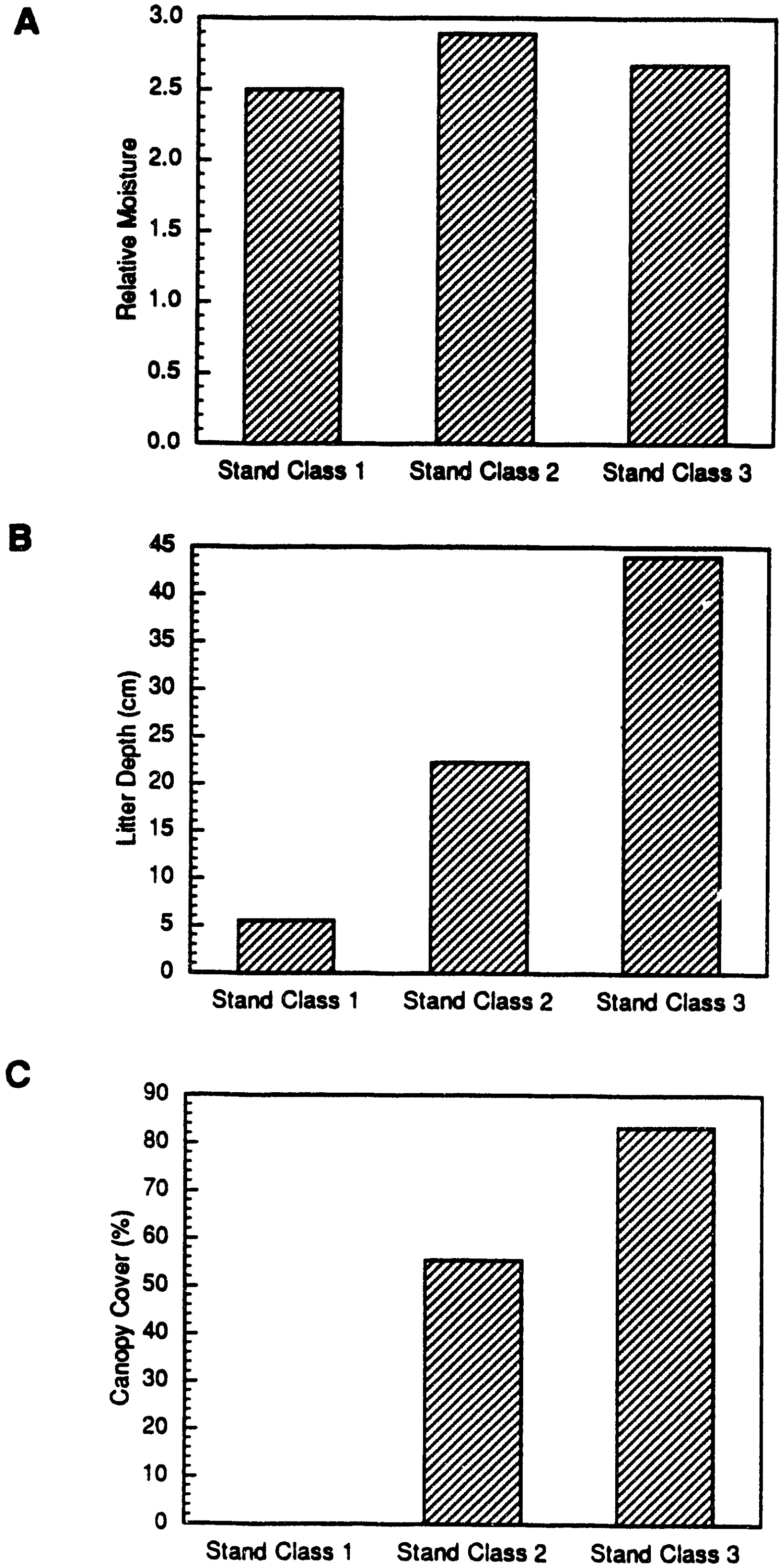


FIGURE 4. Average Stand Characteristics Including A) Relative Moisture, B) Litter Depth, and C) Canopy Cover Based on Circular Plots with a 16.7 ft Radius

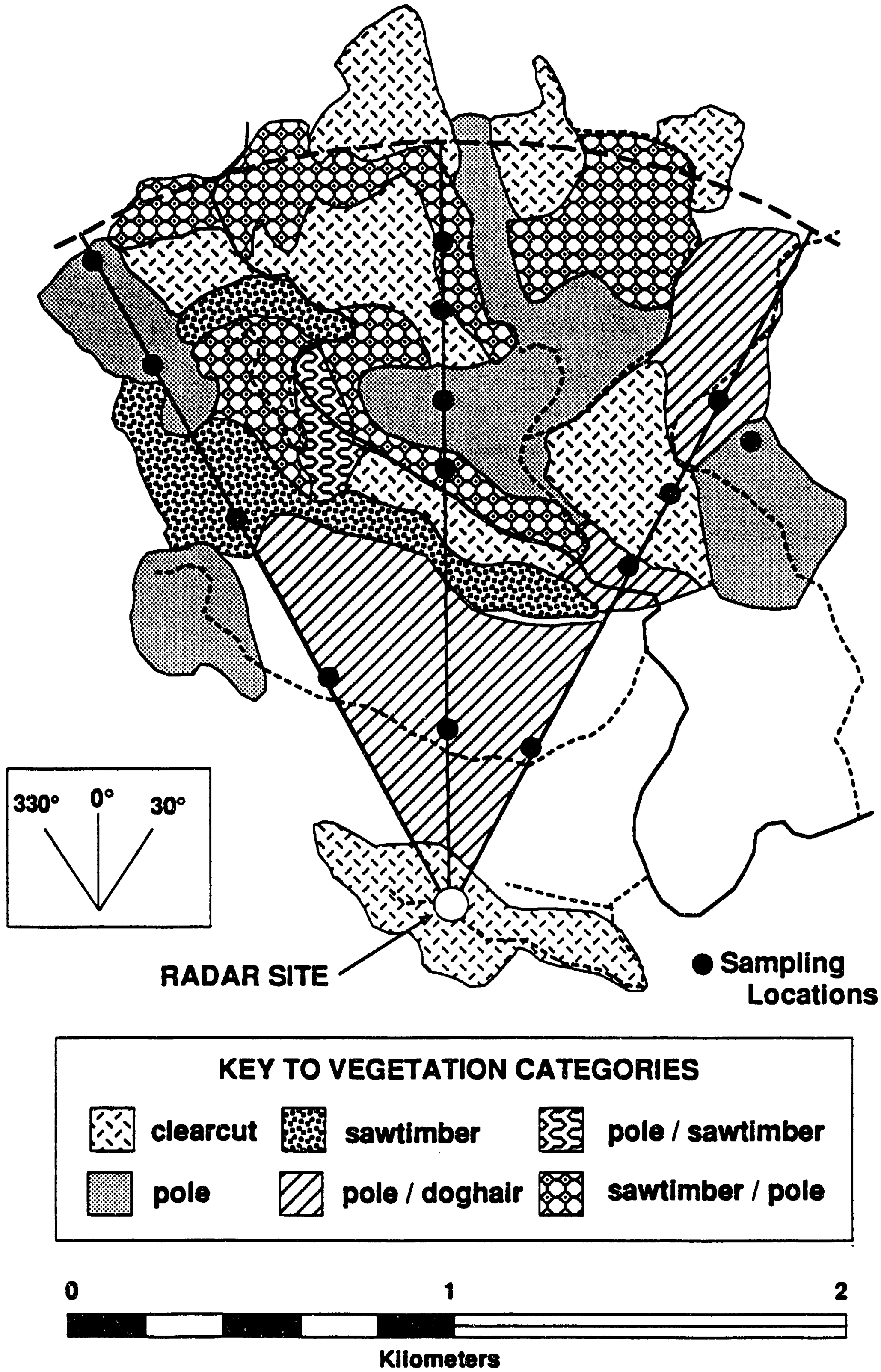


FIGURE 5. General Vegetation Zones Within the Study Area

TABLE 2. Estimates of Stand Lengths and Distances from Radar Site

Transect	(a) General Vegetation Category	(b) Uncorrected Distance From Radar (m)	(c) Uncorrected Distance Along Transect (m)	(d) Net Change in Elevation (m)	(e) Corrected Distance Along Transect (m)	(f) Corrected Distance From Radar (m)
30 Degrees	clearcut	0	114	-30.48	118	0
30 Degrees	pole/doghair	114	929	-54.86	931	118
30 Degrees	clearcut	1,043	257	79.25	269	1,049
30 Degrees	pole/doghair	1,300	656	73.15	660	1,318
0 Degrees	clearcut	0	143	-42.67	149	0
0 Degrees	pole/doghair	143	686	-121.92	697	149
0 Degrees	sawtimber	829	86	12.19	87	846
0 Degrees	clearcut	915	143	24.38	145	933
0 Degrees	sawtimber/pole	1,058	100	18.29	102	1,078
0 Degrees	pole	1,158	214	-6.10	214	1,180
0 Degrees	clearcut	1,372	157	0.00	157	1,394
0 Degrees	sawtimber/pole	1,529	343	18.29	343	1,551
0 Degrees	clearcut	1,872	71	30.48	77	1,894
330 Degrees	clearcut	0	186	-54.86	194	0
330 Degrees	pole/doghair	186	886	-146.30	898	194
330 Degrees	sawtimber	1,072	343	-73.15	351	1,092
330 Degrees	pole	1,415	557	36.58	558	1,443

(a): General vegetation category from Figure 5 ordered by increasing distance from the radar site
(b): Measured distance from radar site to the beginning of the vegetation category, distance is not corrected for slope
(c): Length of the vegetation category along the transect line, length is not corrected for slope
(d): Change in elevation across the vegetation category
(e): Length of the vegetation category along the transect line, corrected for slope
(f): Distance from the radar site to the beginning of the vegetation category, corrected for slope

The net change in elevation was estimated by calculating a weighted mean for all segments, where the length of each segment was used as the weighting factor.

Each of the stands from Figure 5 were grouped into one of the three stand categories, and the corrected lengths from Table 2 were used to calculate the percent coverage of each stand type along each of the transects. Estimates of percent coverage of the dominant stand categories are presented in Figure 6.

The dominant stand type throughout the study area was pole timber, which is not surprising considering that much of the area has been logged recently. The pole timber stands surveyed in this study were found to be highly variable in terms of average tree size, stocking density, and the relative percentages of overstory and understory cover. Stands which were located in replanted clearcut areas tended to have trees which were more uniformly spaced, had larger diameters in relation to height, and had a higher ratio of foliage to overall biomass. In many cases, these stands had branches which extended from near ground level to the canopy, and greater development of the understory component. Other pole stands, especially those with a greater percentage of doghair, exhibited higher densities (in some cases up to 12,000 to 15,000 stems per acre), and tended to be very thin and tall with few branches at the canopy level.

The sawtimber stands were confined to narrow bands within the study area, primarily along steep slopes associated with drainages. It was generally more difficult to characterize sawtimber stands with a single sampling plot because of the low density of trees encountered and the relatively large differences in height noted between tree species within this stand type. Sawtimber stands typically displayed the greatest canopy development and had considerably higher litter accumulation. Despite wide differences in the quality and amount of accumulated litter between stand types, differences in the average moisture content between stands were negligible. Rainfall was not recorded at any of the sampling stations while the clutter experiment was being conducted.

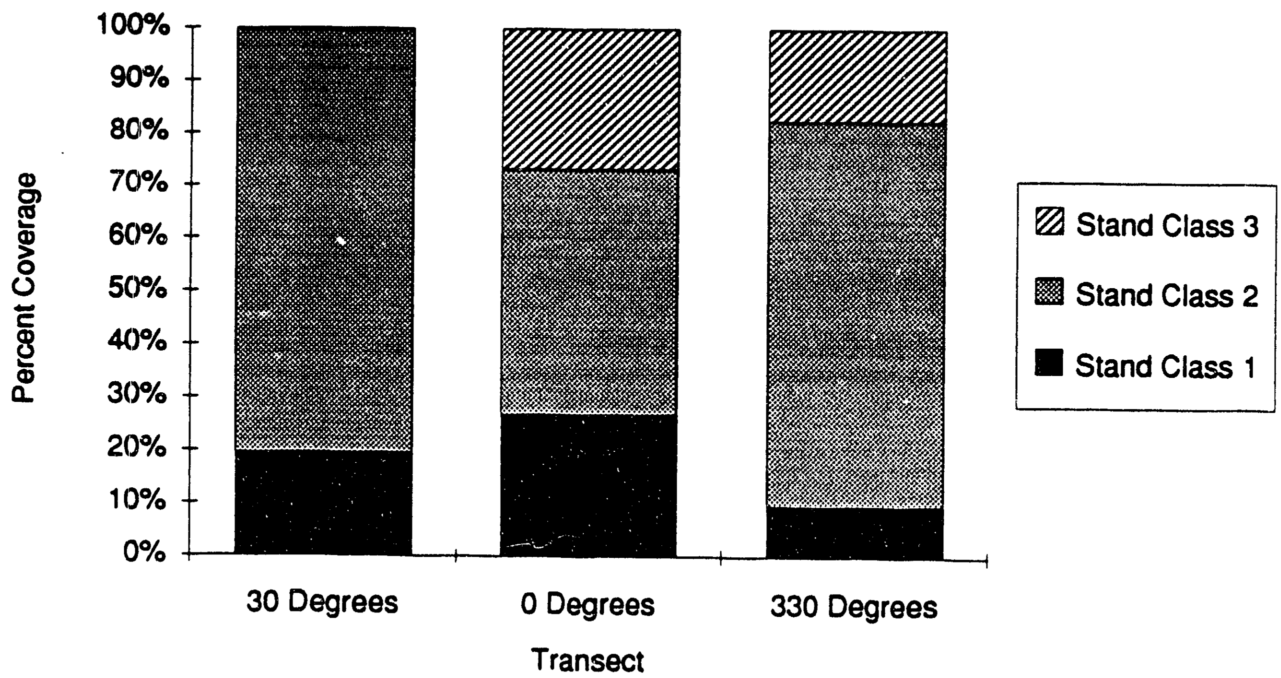


FIGURE 6. Relative Importance of Dominant Stand Classes Along Transects

APPENDIX A. Summary of Raw Data From Field Data Forms

Transect	Site	Vegetation	Stand Class	Ground Cover (%)	Overstory (%)	Number Per Class	Average Height (m)	Dominant Taxa	Minor Taxa
30 Degrees	A	LBG	1	20	0				
30 Degrees	A	GF	1	25	0				
30 Degrees	A	SB	1	50	5				
30 Degrees	A	DBH 0-2	1	0	0	0			
30 Degrees	A	DBH 2-6	2	1	20	2	10.67	PSF	DF
30 Degrees	A	DBH 6-12	2	3	50	3	13.72	PSF	DEC-ALDER
30 Degrees	A	DBH 12-16	3	1	25	1	18.29	WH	
30 Degrees	A	DBH 16+	3	0	0	0			
30 Degrees	B	LBG	1	35	0				
30 Degrees	B	GF	1	40	0				
30 Degrees	B	SB	1	15	5				
30 Degrees	B	DBH 0-2	1	7	35	38	3.05	PSF	WH
30 Degrees	B	DBH 2-6	2	3	60	5	7.62	DEC-ALDER	WH
30 Degrees	B	DBH 6-12	2	0	0	0			
30 Degrees	B	DBH 12-16	3	0	0	0			
30 Degrees	B	DBH 16+	3	0	0	0			
30 Degrees	C	LBG	1	65	0				
30 Degrees	C	GF	1	30	0				
30 Degrees	C	SB	1	5	100				
30 Degrees	C	DBH 0-2	1	0	0	0			
30 Degrees	C	DBH 2-6	2	0	0	0			
30 Degrees	C	DBH 6-12	2	0	0	0			
30 Degrees	C	DBH 12-16	3	0	0	0			
30 Degrees	C	DBH 16+	3	0	0	0			
30 Degrees	D	LBG	1	85	0				
30 Degrees	D	GF	1	0	0				
30 Degrees	D	SB	1	0	1				

APPENDIX A. (Continued)

Transect	Site	Vegetation	Stand Class	Ground Cover (%)	Overstory (%)	Number Per Class	Average Height (m)	Dominant Taxa	Minor Taxa
30 Degrees	D	DBH 0-2	1	3	9	17	4.57	WRC	WH
30 Degrees	D	DBH 2-6	2	5	40	16	18.29	DF	WRC
30 Degrees	D	DBH 6-12	2	7	50	10	25.91	DF	WH
30 Degrees	D	DBH 12-16	3	0	0	0			
30 Degrees	D	DBH 16+	3	0	0	0			
30 Degrees	E	LBG	1	50	0				
30 Degrees	E	GF	1	25	0				
30 Degrees	E	SB	1	20	10				
30 Degrees	E	DBH 0-2	1	0	0	0			
30 Degrees	E	DBH 2-6	2	2	30	5	10.67	DF	DEC-SPP.
30 Degrees	E	DBH 6-12	2	3	60	3	15.24	DF	
30 Degrees	E	DBH 12-16	3	0	0	0			
30 Degrees	E	DBH 16+	3	0	0	0			
0 Degrees	A	LBG	1	74	0				
0 Degrees	A	GF	1	5	0				
0 Degrees	A	SB	1	0	0				
0 Degrees	A	DBH 0-2	1	10	55	Ca. 175	13.72	PSF	DF
0 Degrees	A	DBH 2-6	2	10	30	Ca. 65	15.24	DF	PSF
0 Degrees	A	DBH 6-12	2	1	15	1	18.29	PSF	
0 Degrees	A	DBH 12-16	3	0	0	0			
0 Degrees	A	DBH 16+	3	0	0	0			
0 Degrees	B	LBG	1	26	0				
0 Degrees	B	GF	1	25	0				
0 Degrees	B	SB	1	40	3				
0 Degrees	B	DBH 0-2	1	0	0	1	1.83	PSF	
0 Degrees	B	DBH 2-6	2	0	2	1	3.05	WRC	
0 Degrees	B	DBH 6-12	2	3	30	6	18.29	WRC	WH

APPENDIX A. (Continued)

Transect	Site	Vegetation	Stand Class	Ground Cover (%)	Overstory (%)	Number Per Class	Average Height (m)	Dominant Taxa	Minor Taxa
0 Degrees	B	DBH 12-16	3	1	25	1	24.38	WRC	DF
0 Degrees	B	DBH 16+	3	5	40	1	39.62	DF	WH
0 Degrees	C	LBG	1	25	0				
0 Degrees	C	GF	1	40	0				
0 Degrees	C	SB	1	30	86				
0 Degrees	C	DBH 0-2	1	5	14	3	1.52	DEC-ALDER	
0 Degrees	C	DBH 2-6	2	0	0	0			
0 Degrees	C	DBH 6-12	2	0	0	0			
0 Degrees	C	DBH 12-16	3	0	0	0			
0 Degrees	C	DBH 16+	3	0	0	0			
0 Degrees	D	LBG	1	30	0				
0 Degrees	D	GF	1	15	0				
0 Degrees	D	SB	1	50	2				
0 Degrees	D	DBH 0-2	1	0	3	2	3.05	DEC-SPP.	WH
0 Degrees	D	DBH 2-6	2	1	15	5	22.86	WH	WRC
0 Degrees	D	DBH 6-12	2	2	30	4	28.96	DF	WRC
0 Degrees	D	DBH 12-16	3	3	50	2	35.05	DF	WH
0 Degrees	D	DBH 16+	3	0	0	0			
0 Degrees	E	LBG	1	65	0				
0 Degrees	E	GF	1	15	0				
0 Degrees	E	SB	1	15	5				
0 Degrees	E	DBH 0-2	1	2	0	7	9.14	DEC-ALDER	
0 Degrees	E	DBH 2-6	2	1	25	12	10.67	DEC-ALDER	DF
0 Degrees	E	DBH 6-12	2	2	60	7	15.24	DF	
0 Degrees	E	DBH 12-16	3	0	0	0			
0 Degrees	E	DBH 16+	3	0	0	0			
330 Degrees	A	LBG	1	45	0				

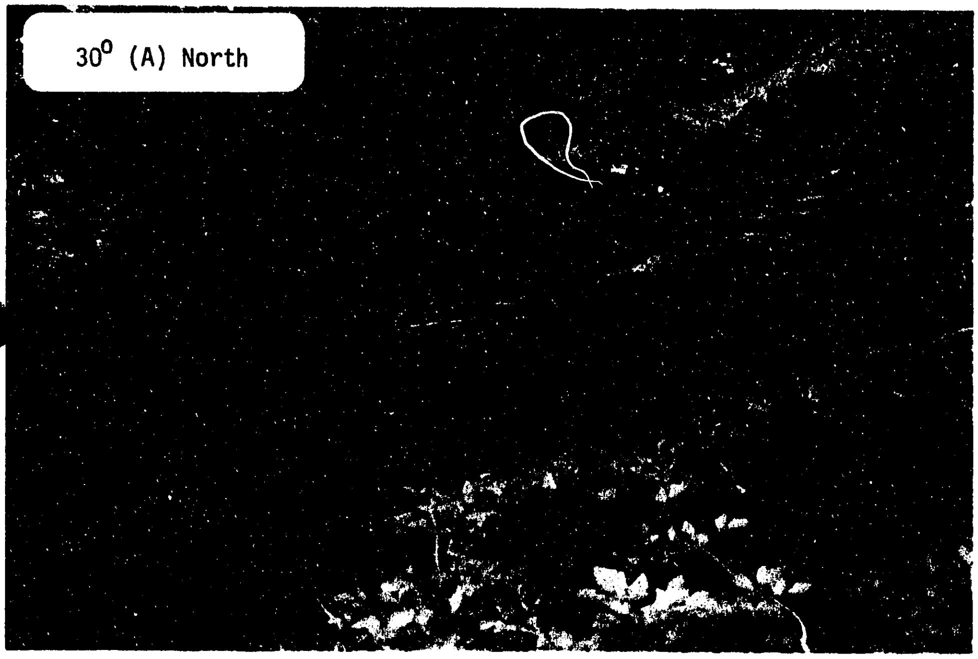
APPENDIX A. (Continued)

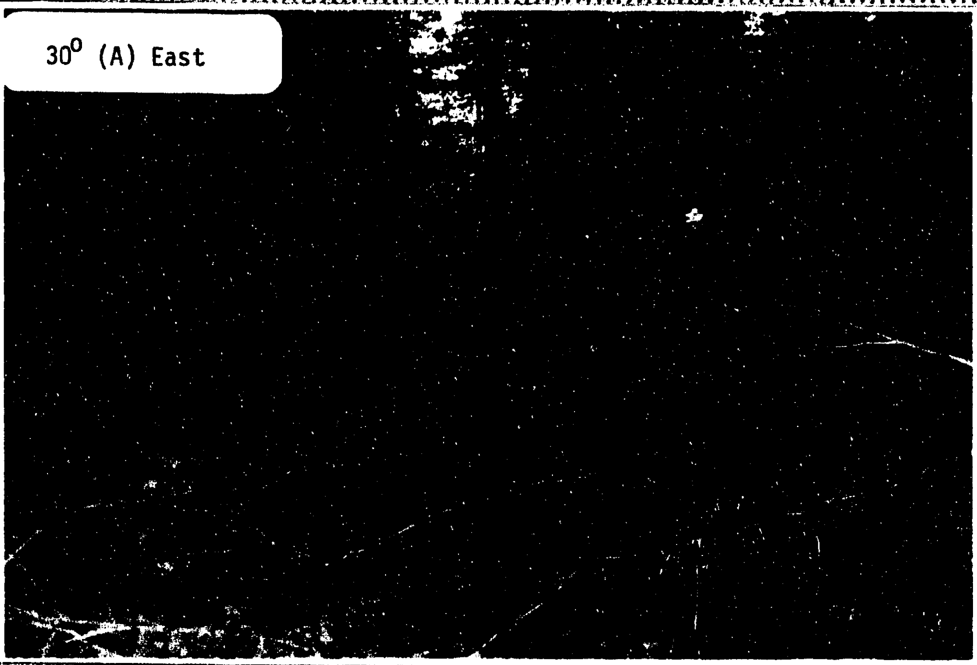
Transect	Site	Vegetation	Stand Class	Ground Cover (%)	Overstory (%)	Number Per Class	Average Height (m)	Dominant Taxa	Minor Taxa
330 Degrees	A	GF	1	35	0				
330 Degrees	A	SB	1	15	10				
330 Degrees	A	DBH 0-2	1	1	10	7	1.83	WH	
330 Degrees	A	DBH 2-6	2	2	40	4	12.19	DF	WH
330 Degrees	A	DBH 6-12	2	2	40	5	18.29	DF	WH
330 Degrees	A	DBH 12-16	3	0	0	0			
330 Degrees	A	DBH 16+	3	0	0	0			
330 Degrees	B	LBG	1	66	0				
330 Degrees	B	GF	1	20	0				
330 Degrees	B	SB	1	5	0				
330 Degrees	B	DBH 0-2	1	0	0	0			
330 Degrees	B	DBH 2-6	2	1	5	2	6.10	WH	WRC
330 Degrees	B	DBH 6-12	2	3	10	3	21.34	WH	DEC-MAPLE
330 Degrees	B	DBH 12-16	3	0	0	0			
330 Degrees	B	DBH 16+	3	5	80	2		DF	WRC
330 Degrees	C	LBG	1	10	0				
330 Degrees	C	GF	1	5	0				
330 Degrees	C	SB	1	80	0				
330 Degrees	C	DBH 0-2	1	0	0	0			
330 Degrees	C	DBH 2-6	2	2	100	2	7.62	DF	
330 Degrees	C	DBH 6-12	2	0	0	0			
330 Degrees	C	DBH 12-16	3	0	0	0			
330 Degrees	C	DBH 16+	3	0	0	0			
330 Degrees	D	LBG	1	2	0				
330 Degrees	D	GF	1	80	0				
330 Degrees	D	SB	1	17	20				
330 Degrees	D	DBH 0-2	1	0	5	5	3.05	DF	DEC-ALDER

APPENDIX A. (Continued)

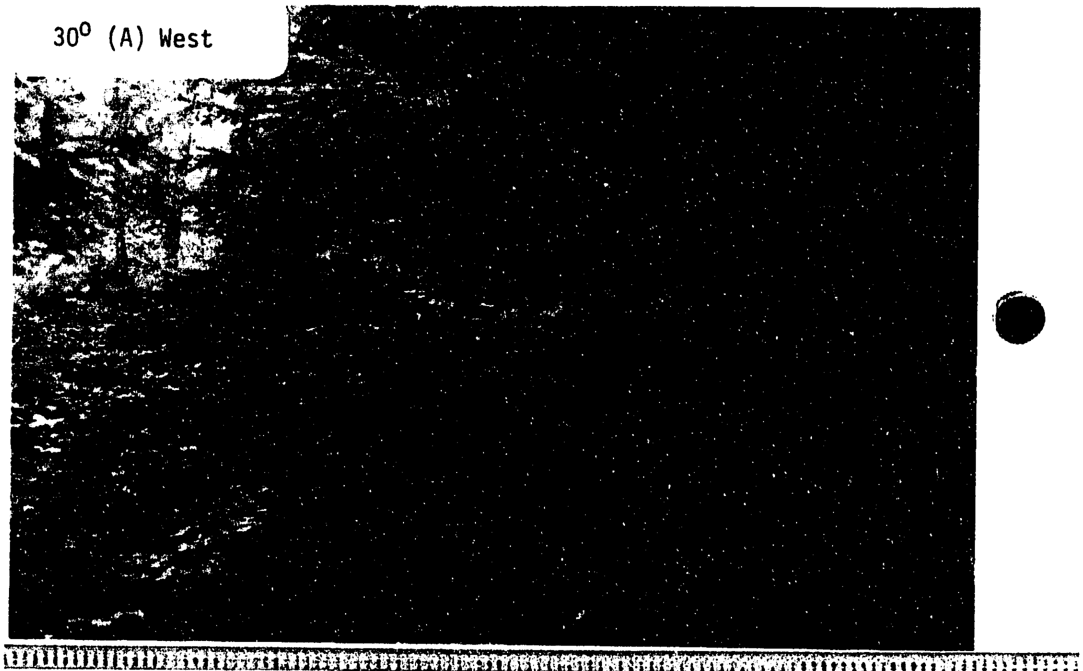
Transect	Site	Vegetation	Stand Class	Ground Cover (%)	Overstory (%)	Number Per Class	Average Height (m)	Dominant Taxa	Minor Taxa
330 Degrees	D	DBH 2-6	2	0	50	2	9.14	DF	PSF
330 Degrees	D	DBH 6-12	2	1	25	2	12.19	DF	
330 Degrees	D	DBH 12-16	3	0	0	0			
330 Degrees	D	DBH 16+	3	0	0	0			

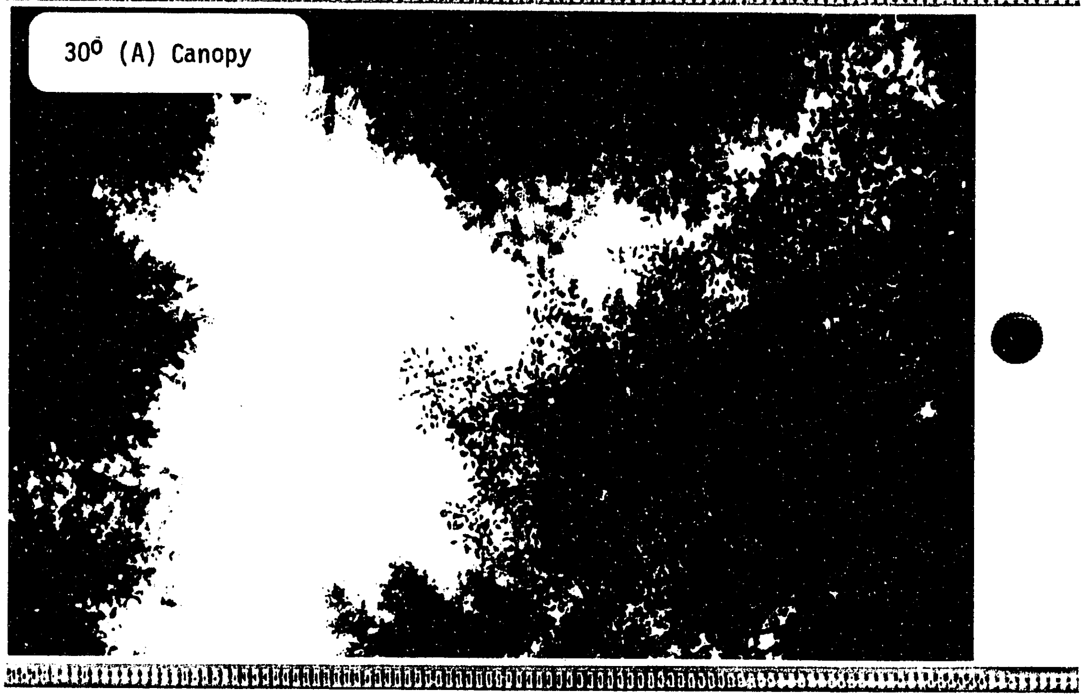
APPENDIX B

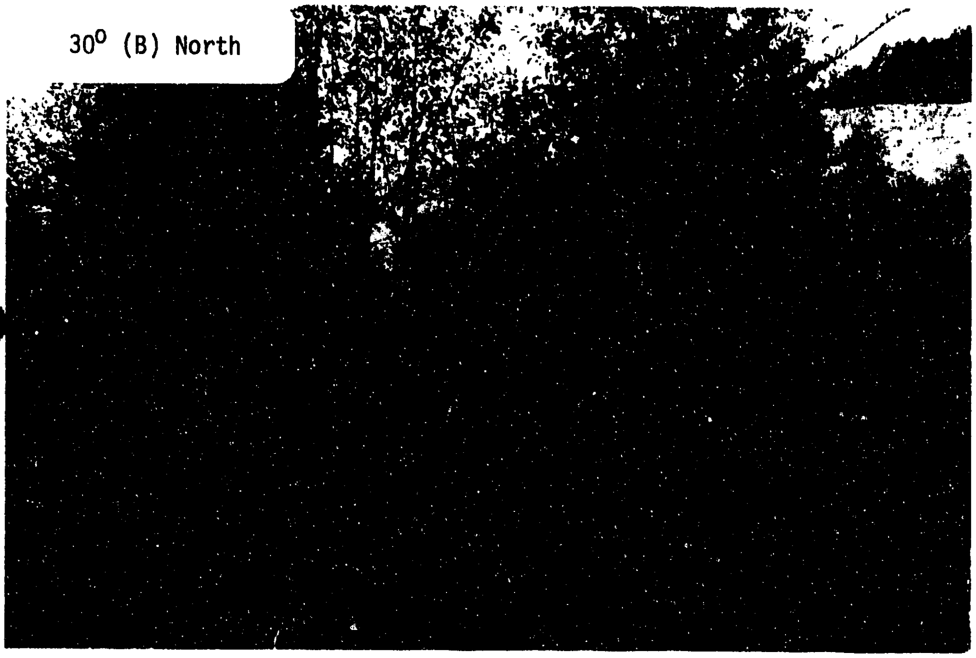

30° (A) North

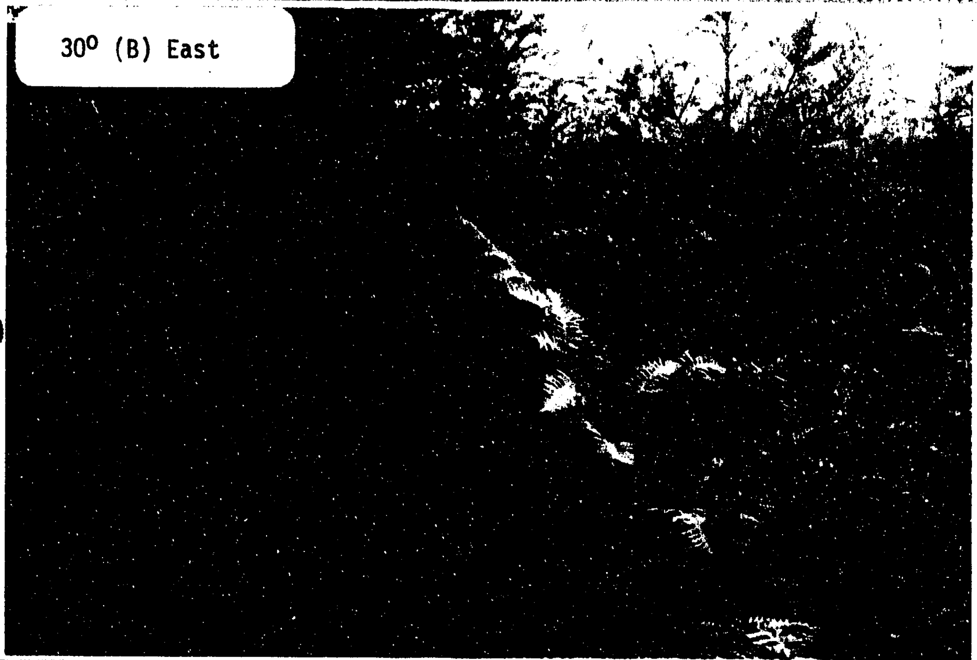

30° (A) East

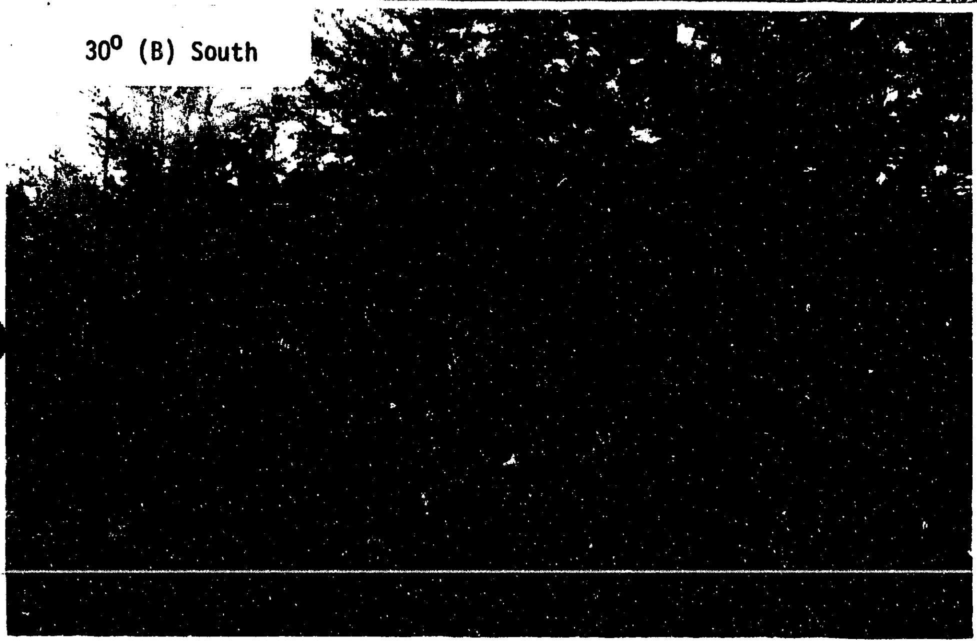

30° (A) South

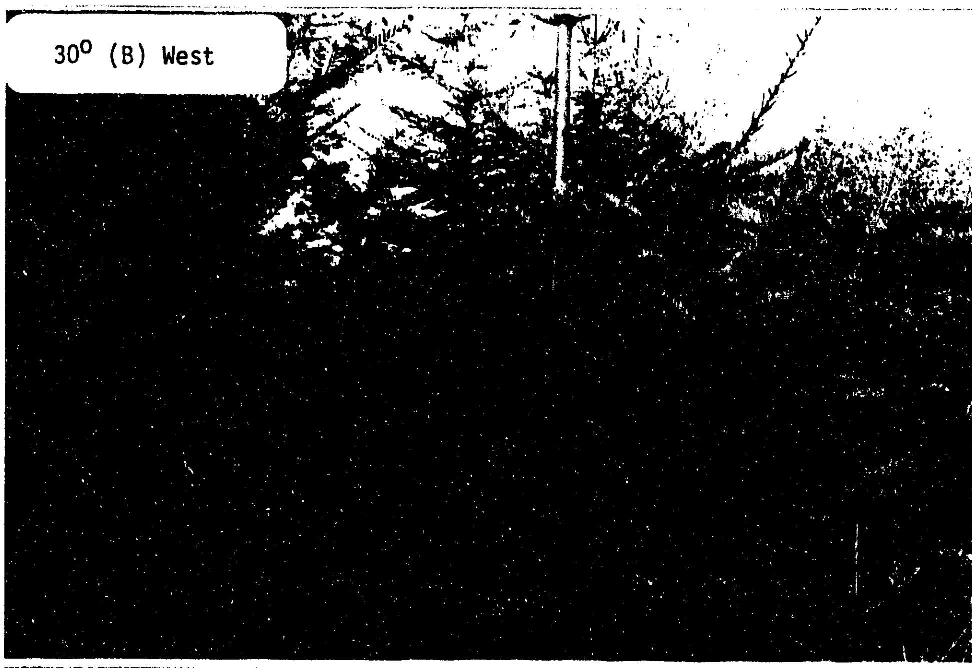

30° (A) West

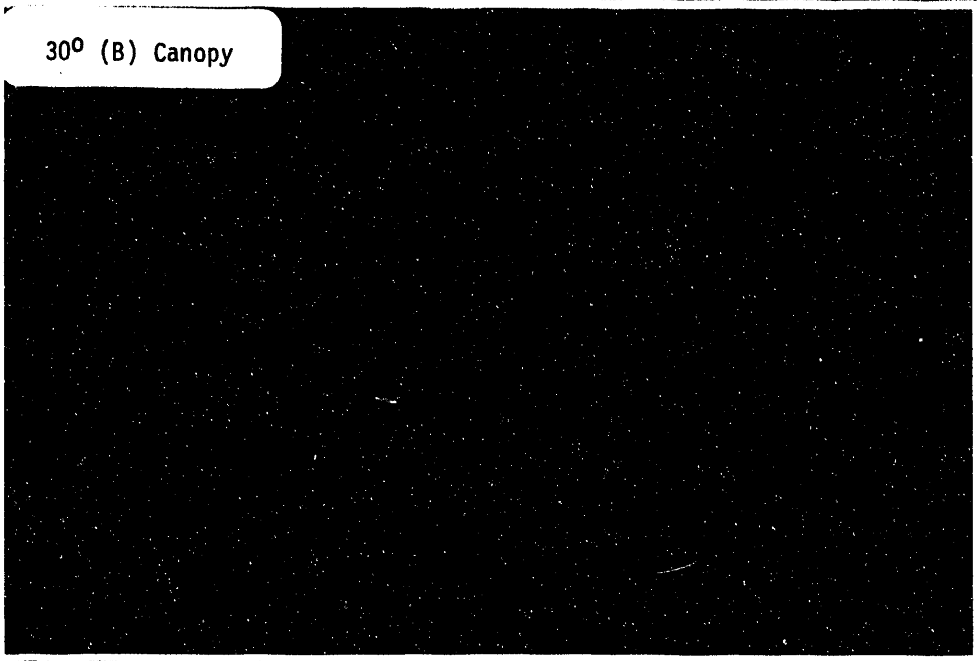

30° (A) Canopy


30° (B) North

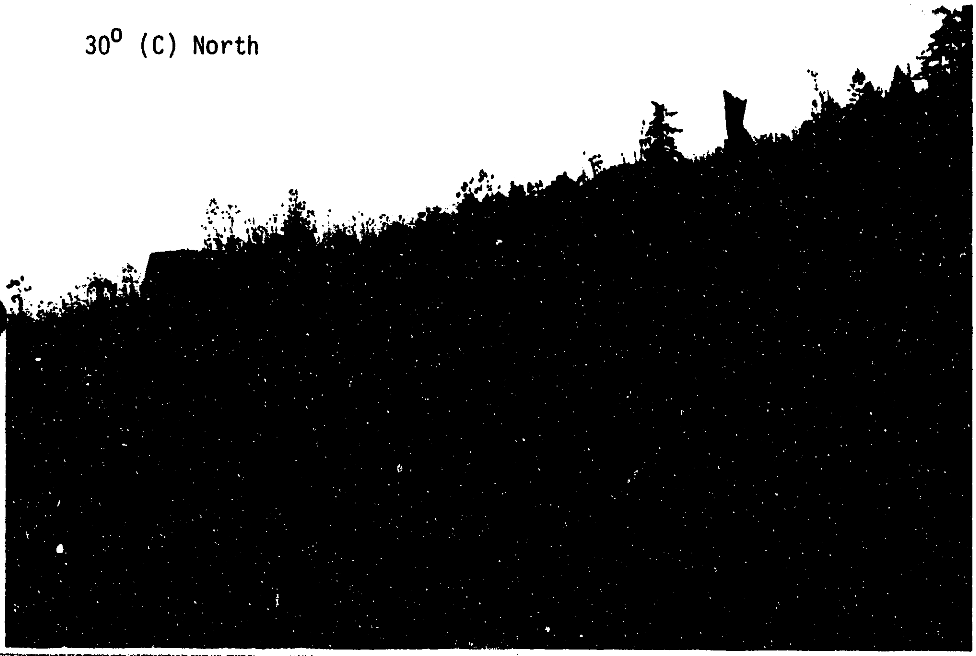

30° (B) East

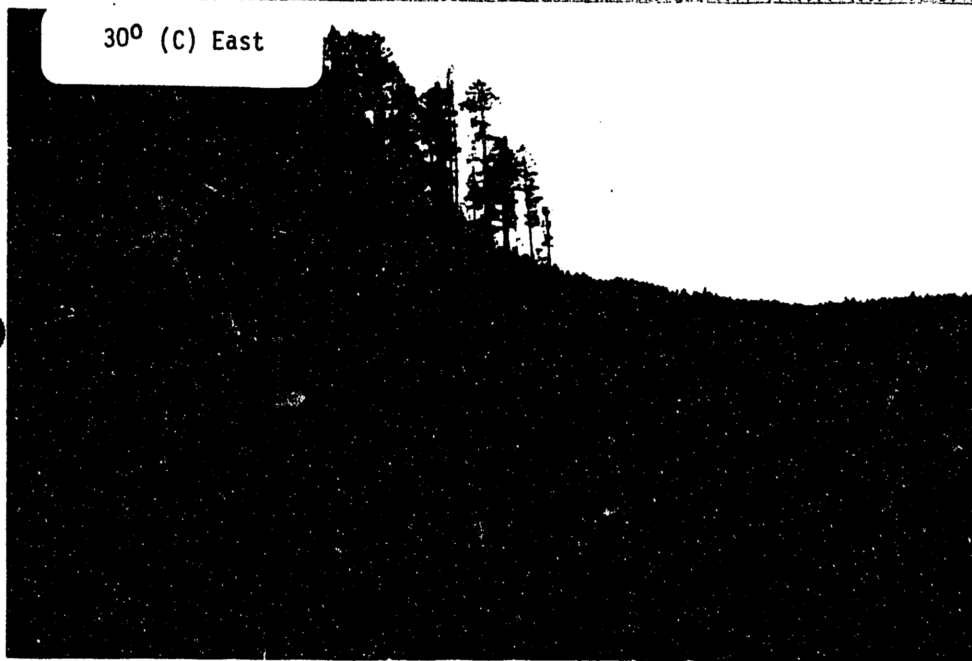

30° (B) South


30° (B) West

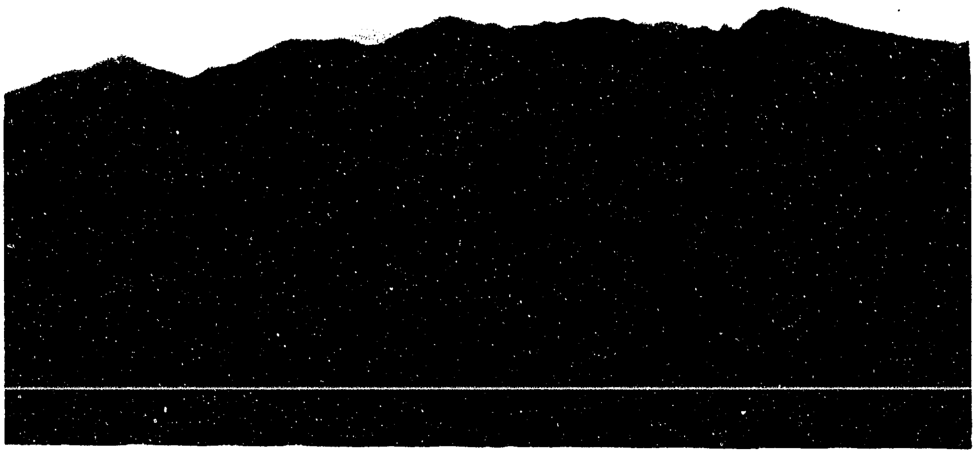

30° (B) Canopy

30° (C) North

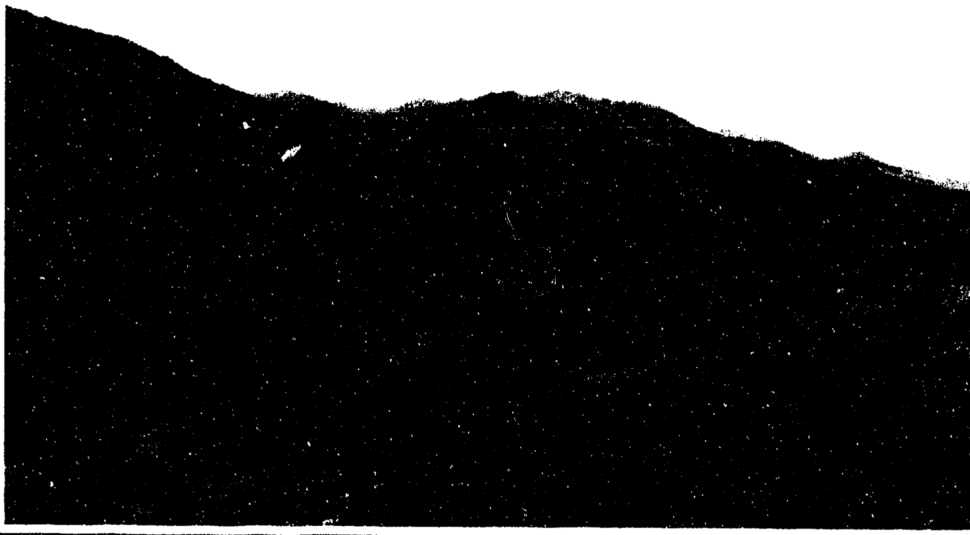



30° (C) East

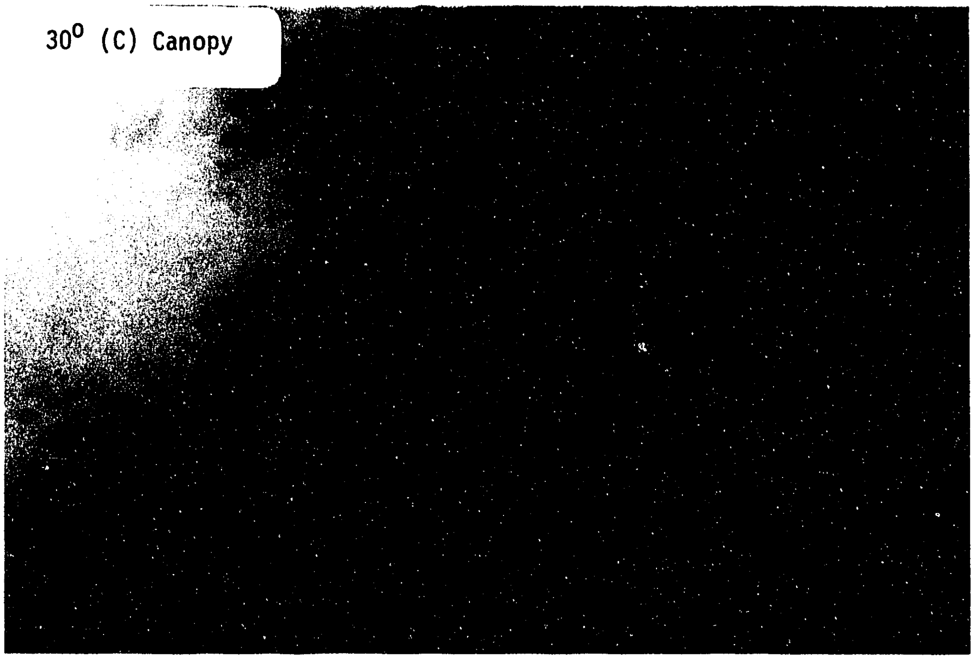
30° (C) South

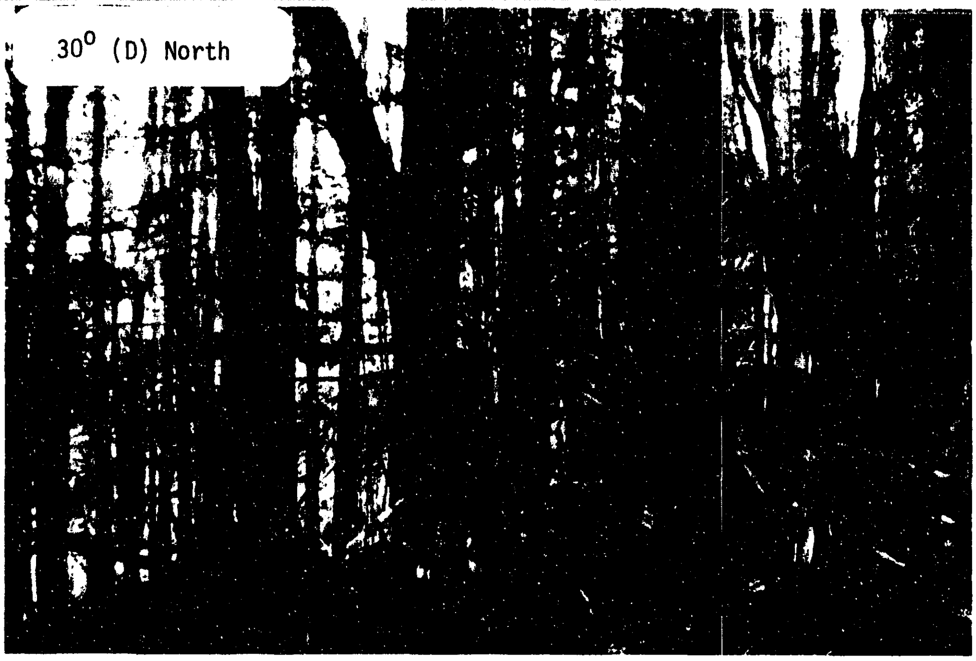


30° (C) West

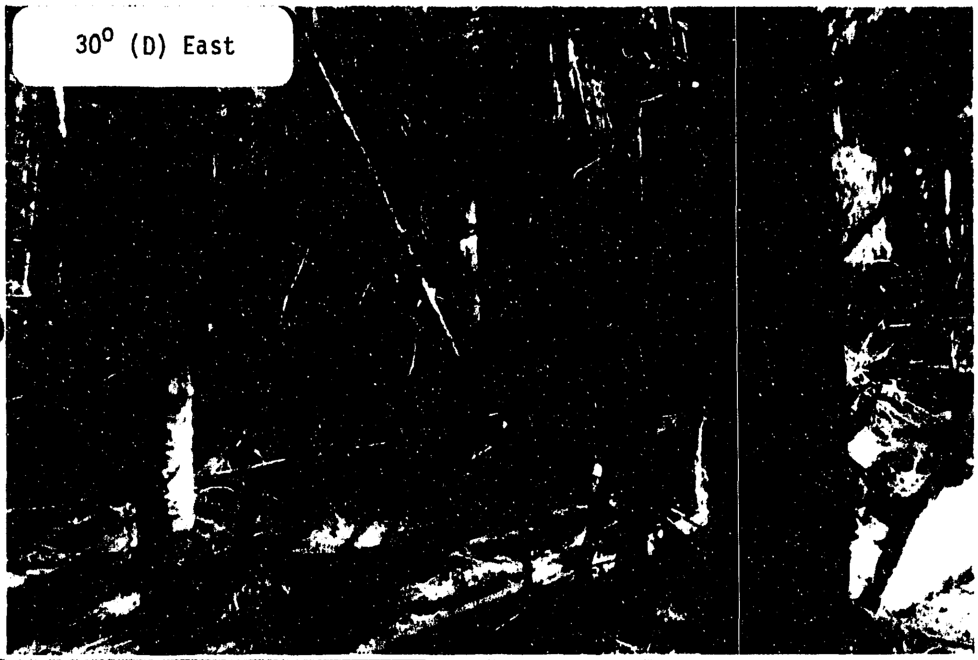


30° (C) Canopy

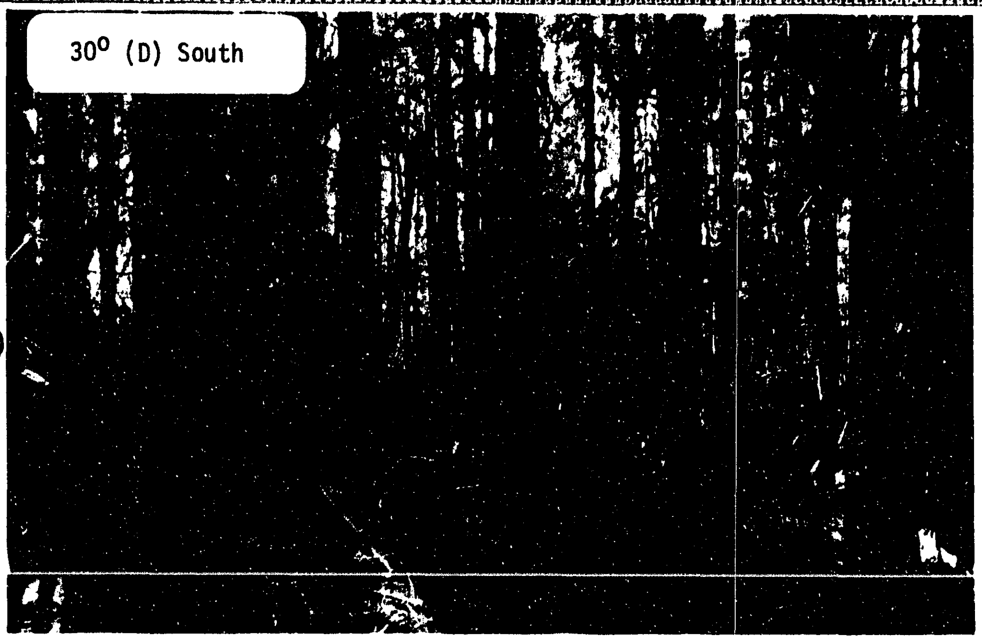




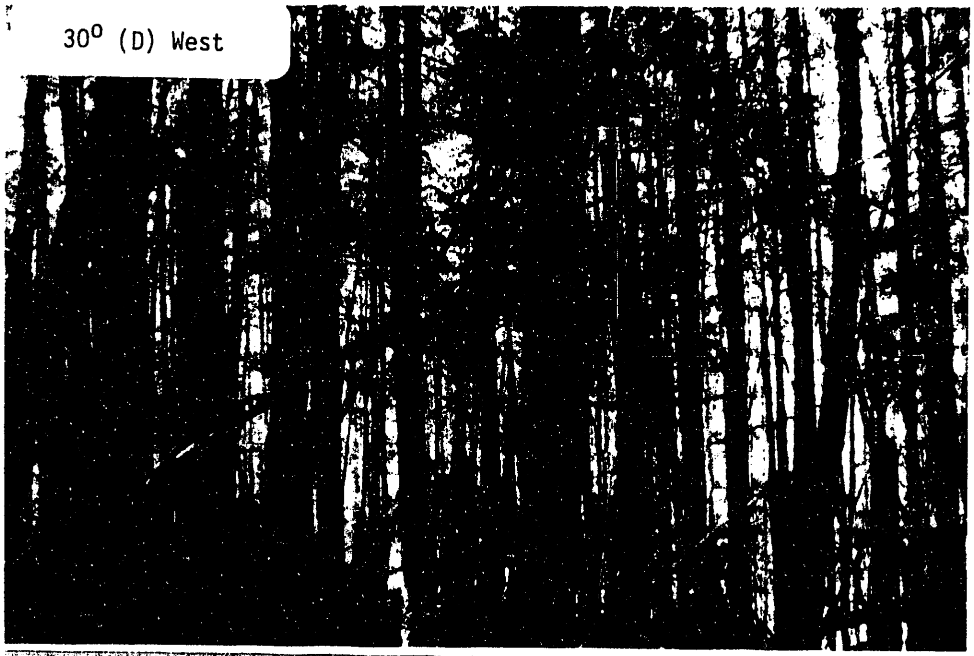
30° (D) North

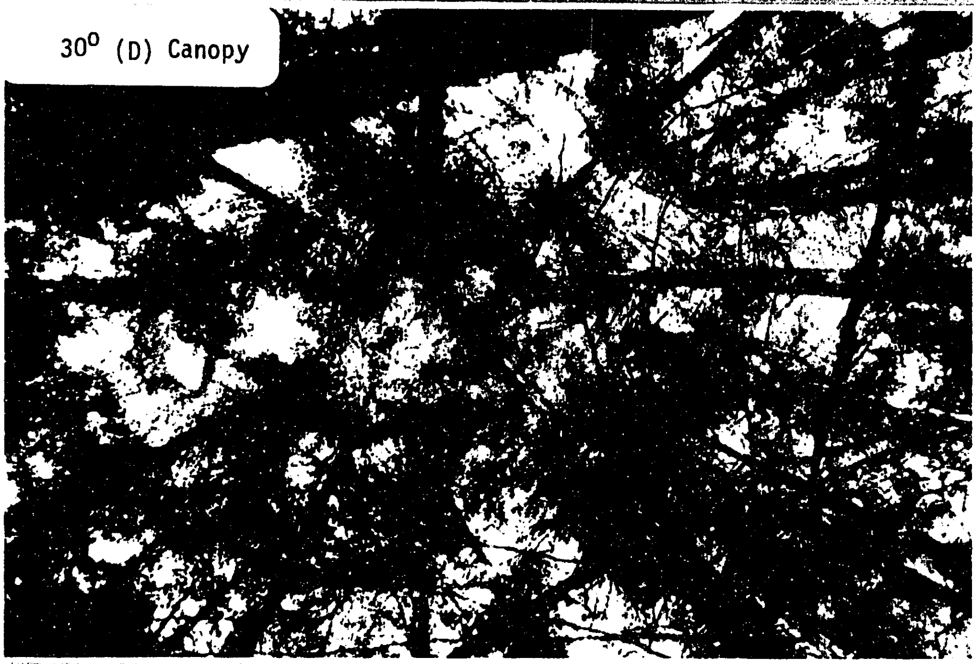


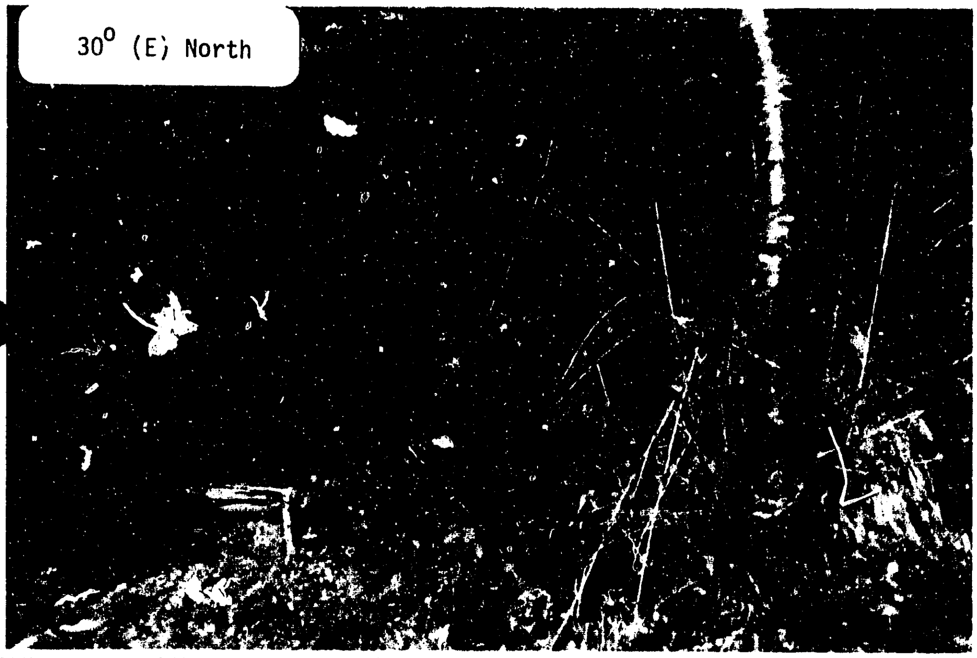
30° (D) East



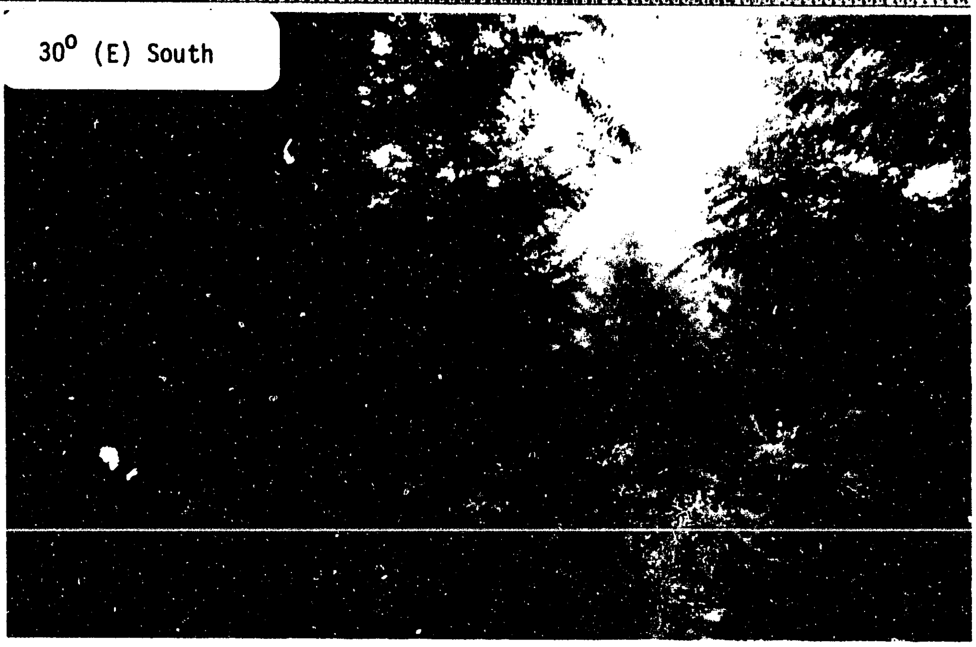
30° (D) South


30° (D) West


30° (D) Canopy

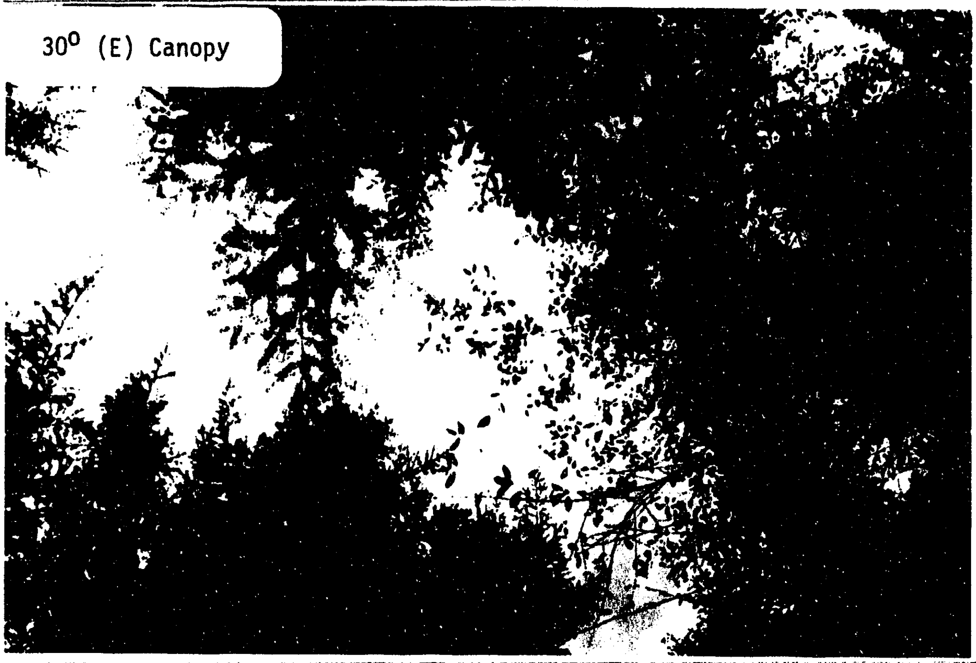

30° (E) North

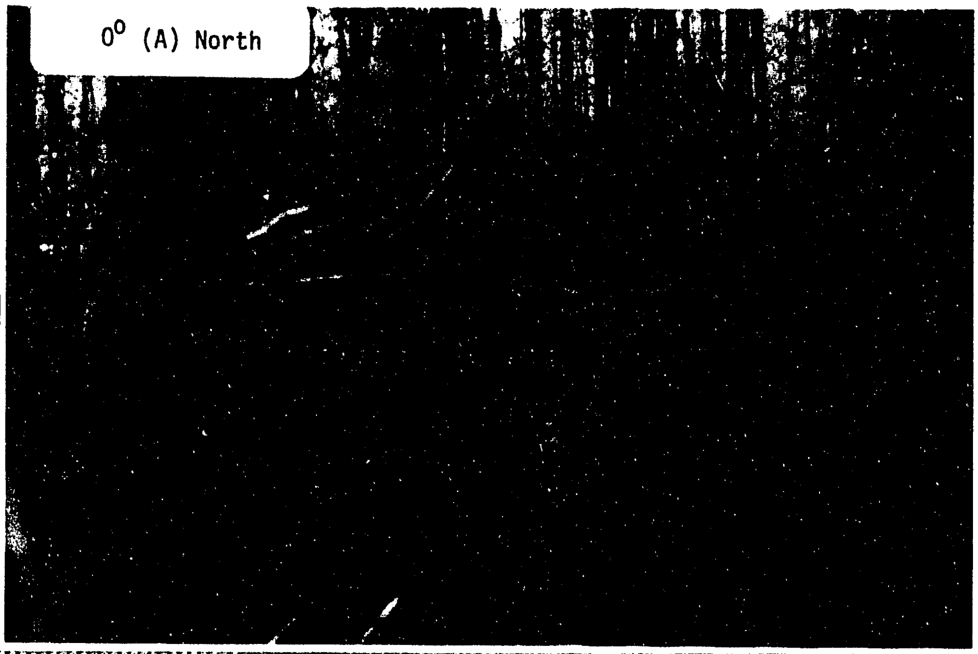

30° (E) East

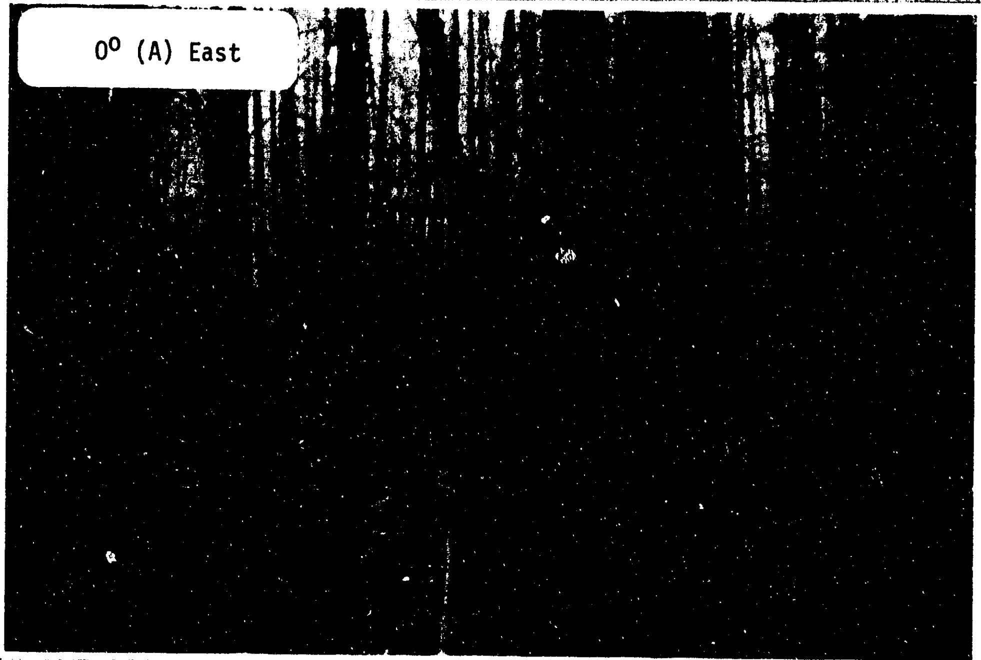

30° (E) South

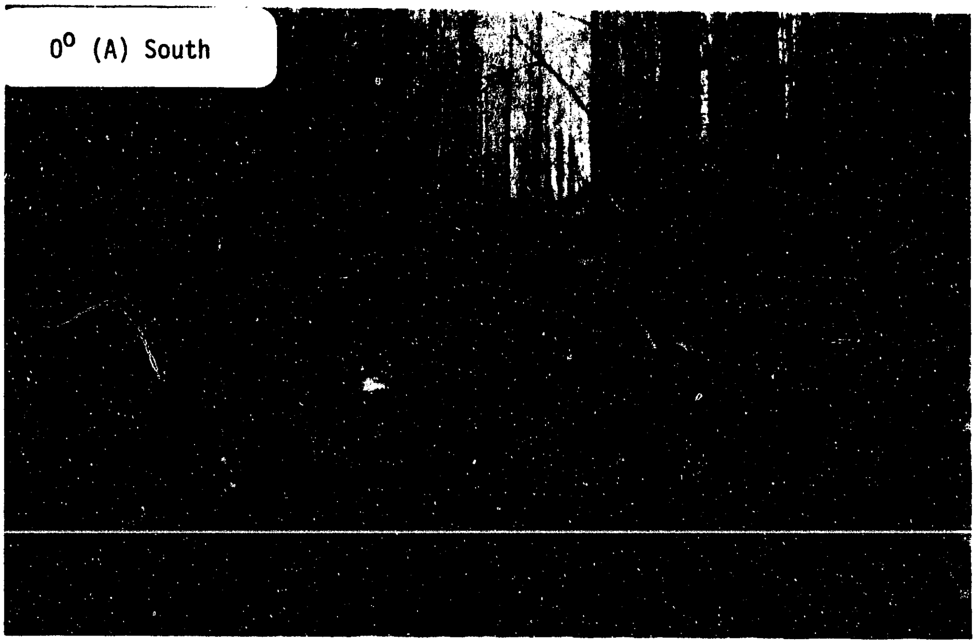
30° (E) West

30° (E) Canopy

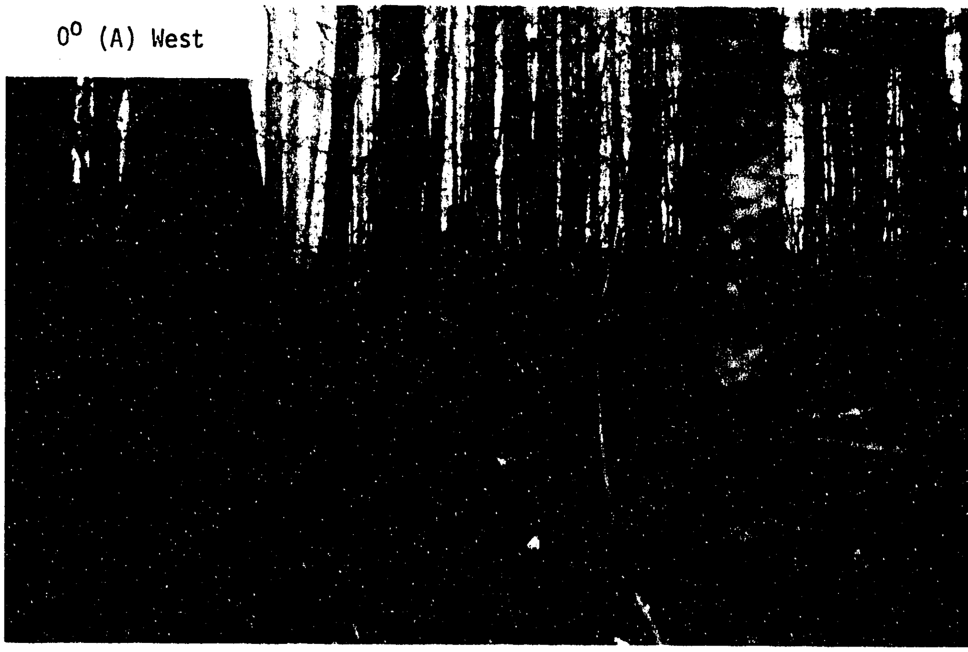



0° (A) North

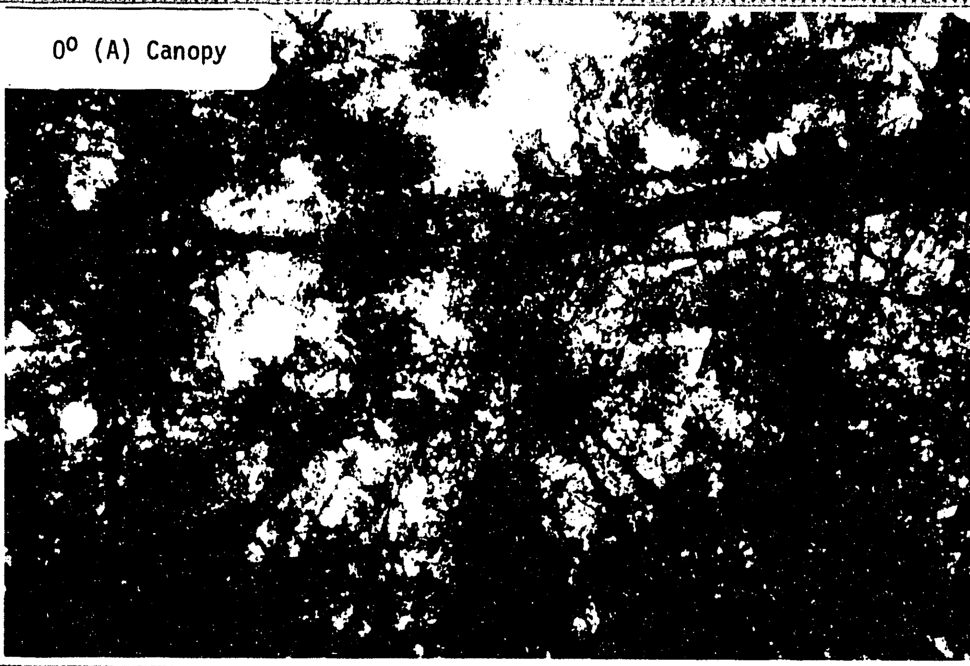

0° (A) East

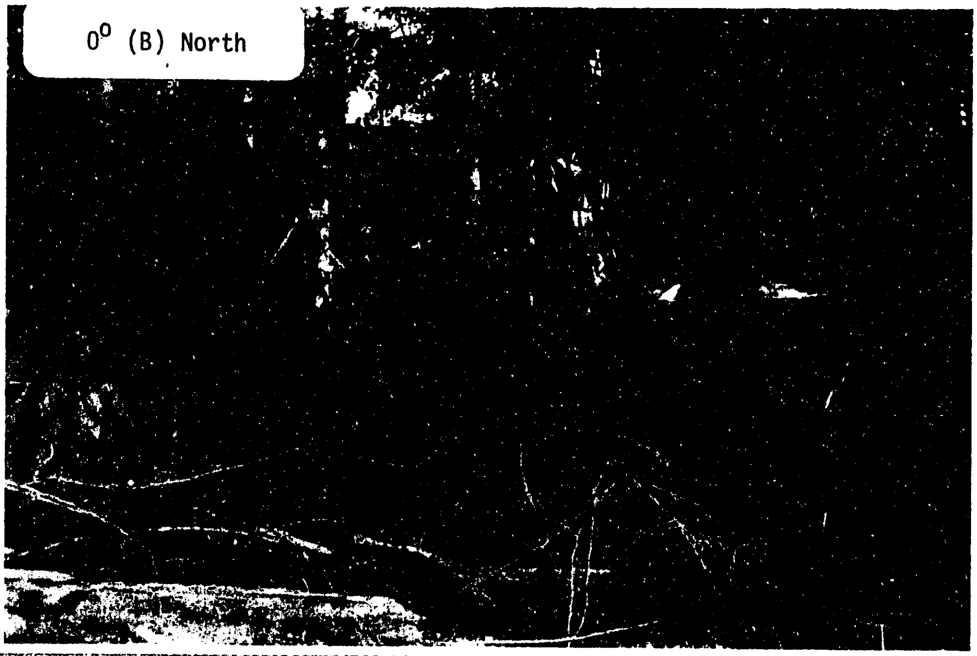

0° (A) South

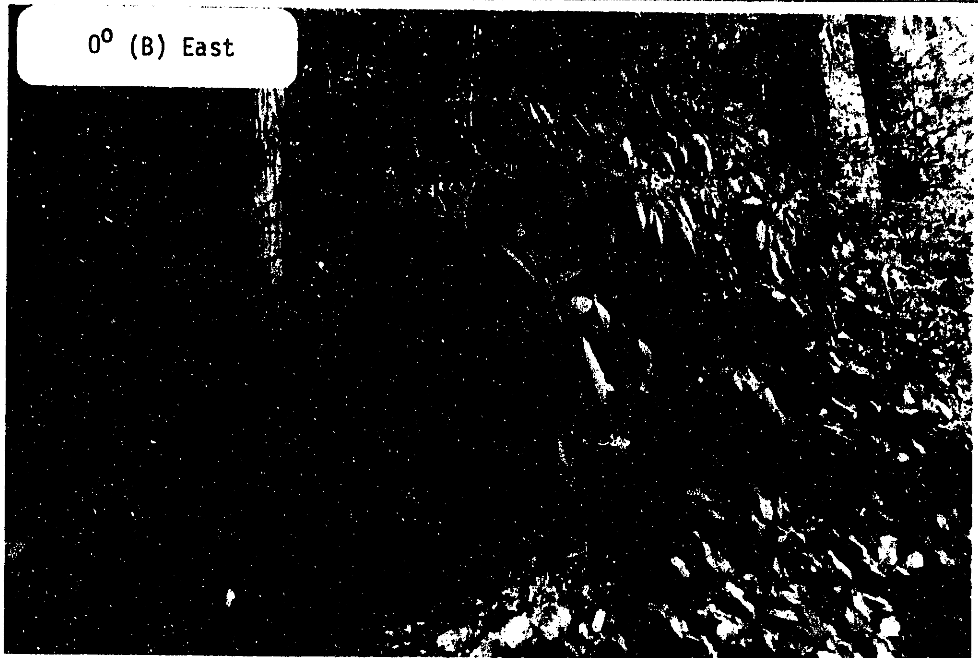
0° (A) West

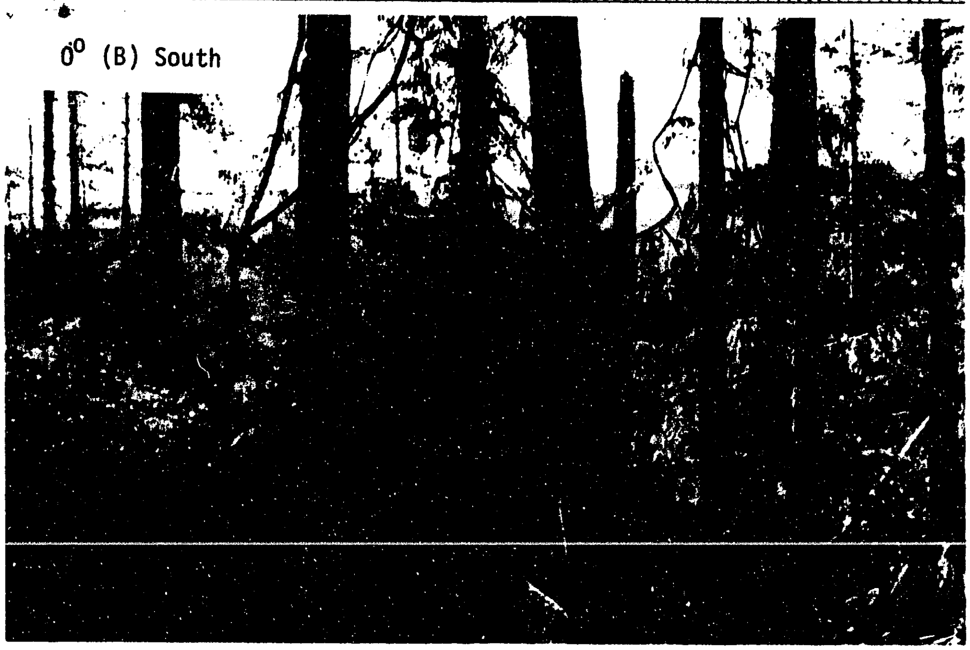


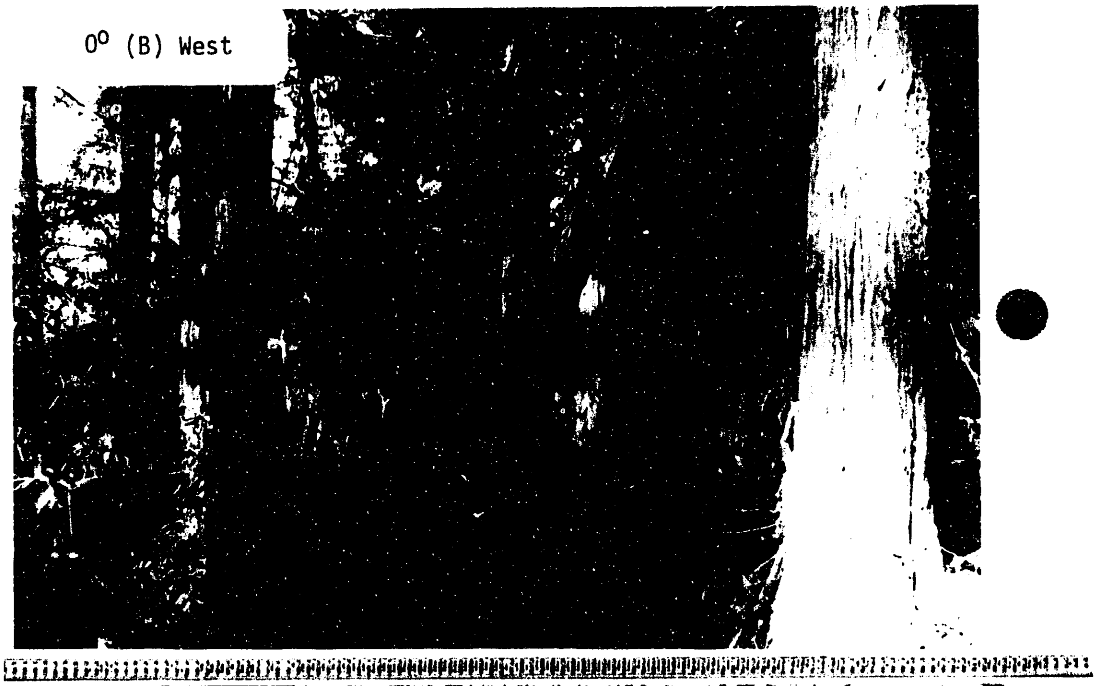
0° (A) Canopy



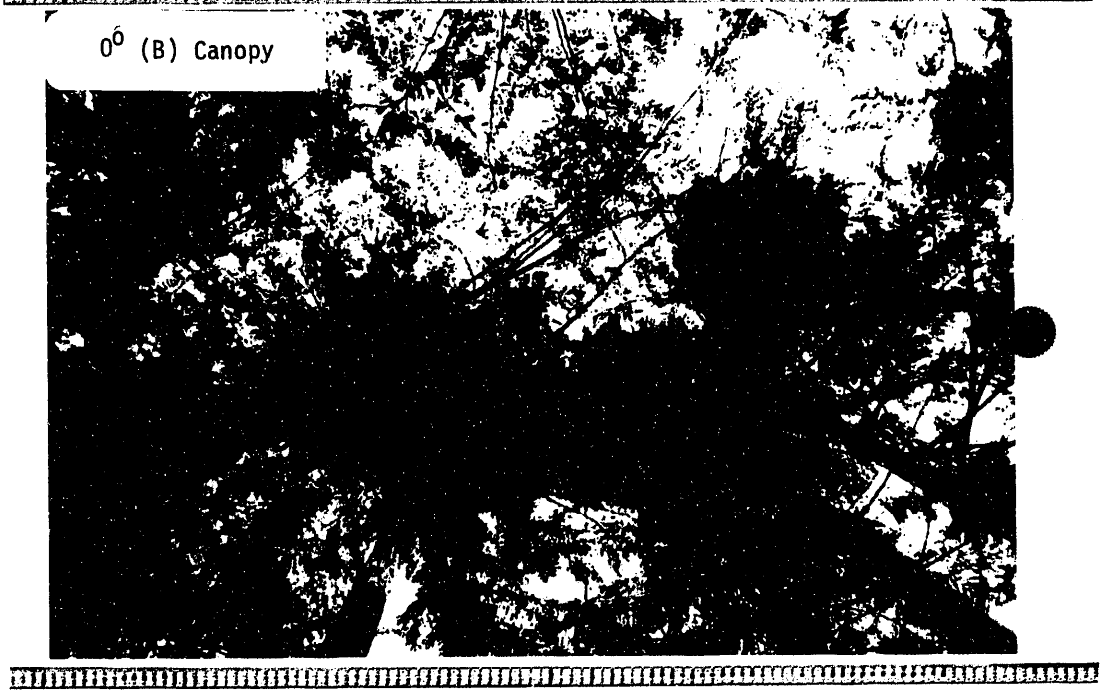

0^{o} (B) North


0^{o} (B) East


0^{o} (B) South

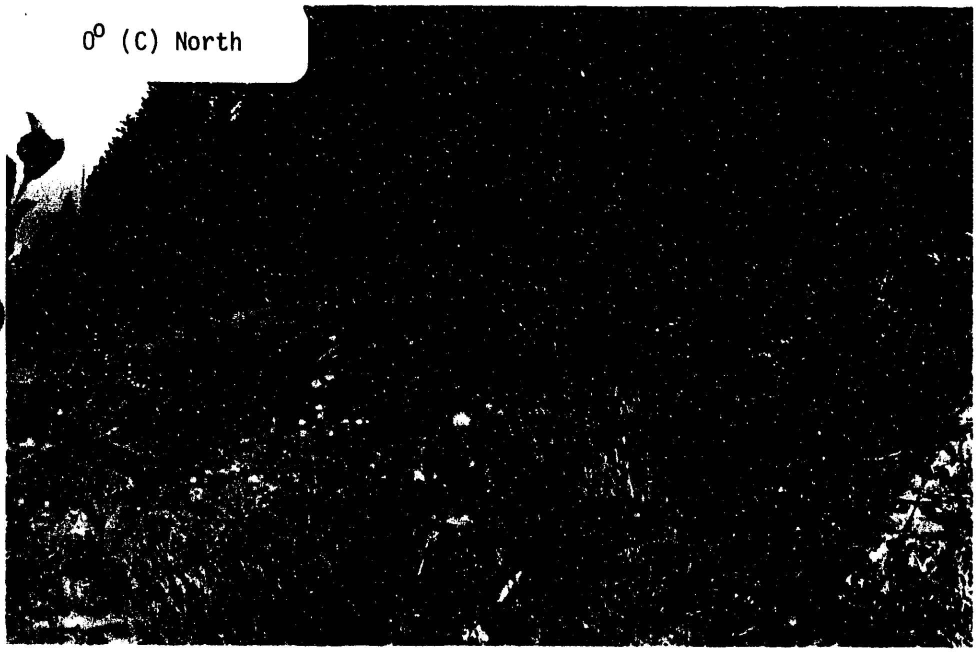


0° (B) West

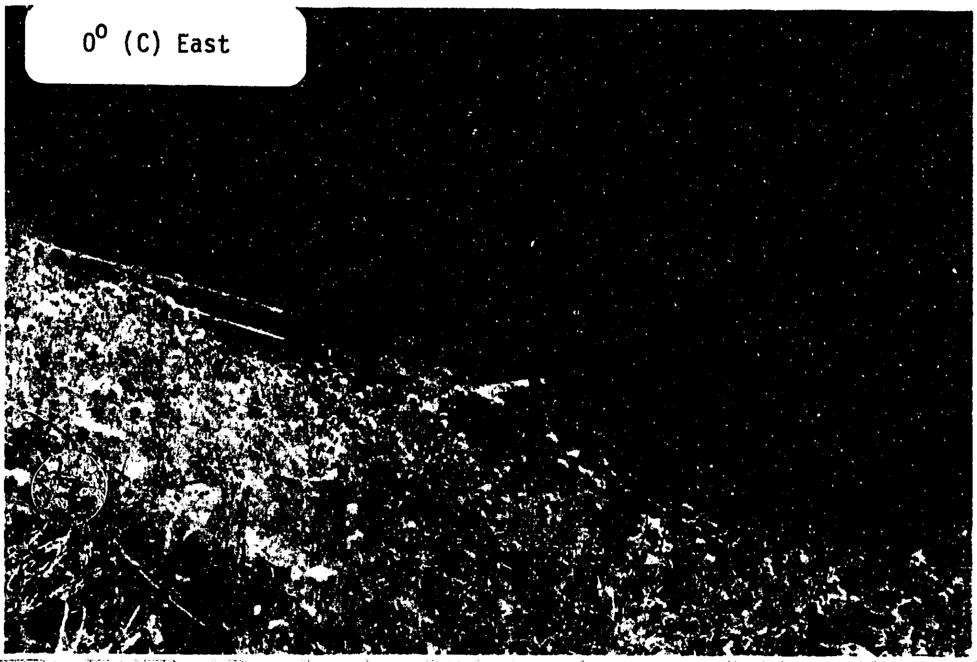


0° (B) Canopy

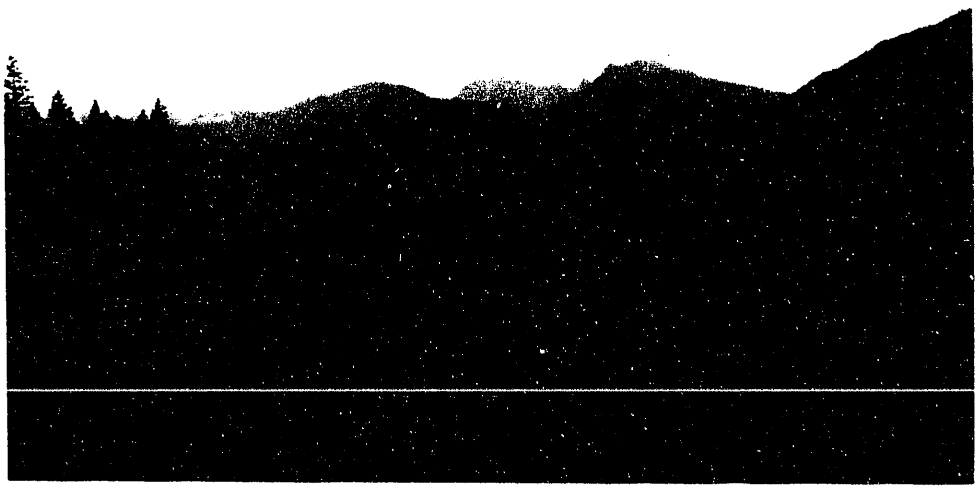
0^o (C) North



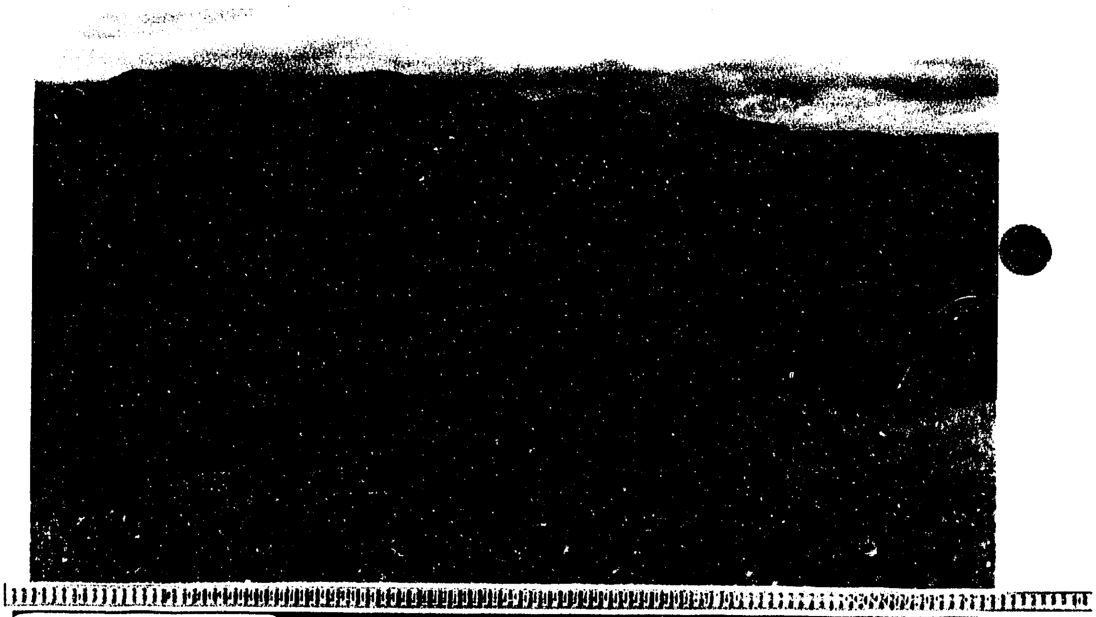
0^o (C) East



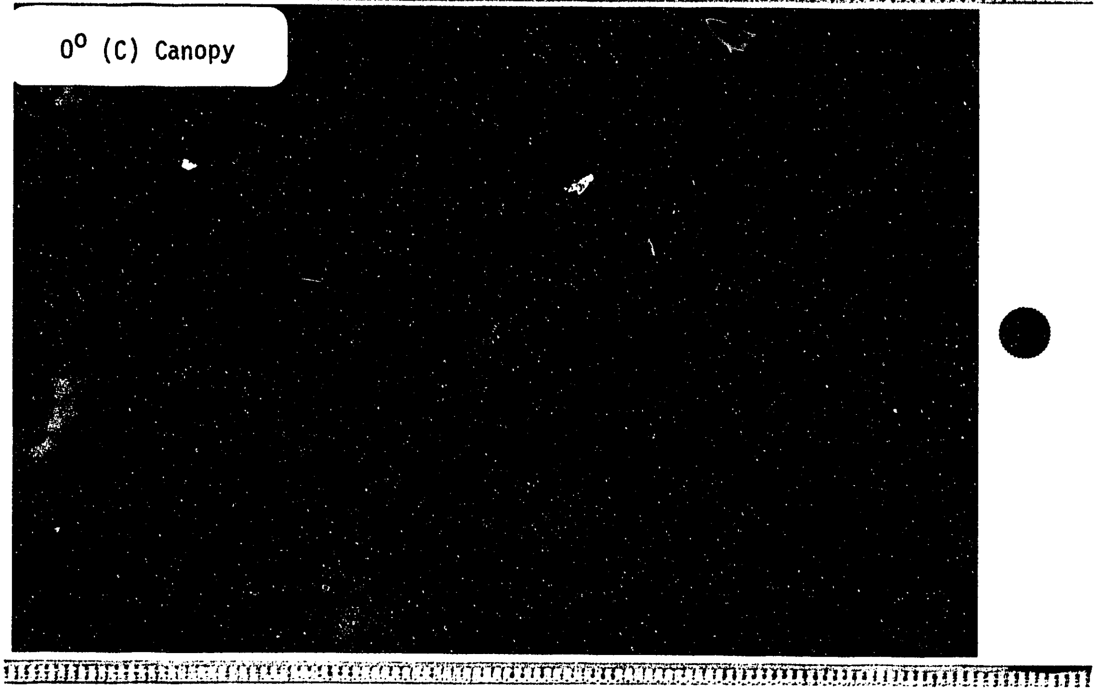
0^o (C) South

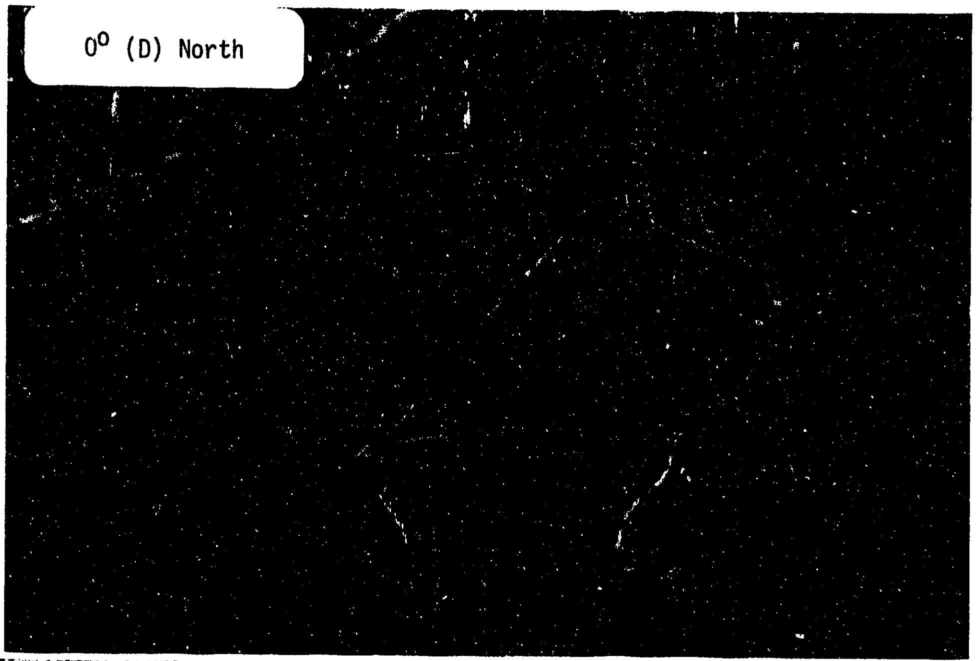


0° (C) West

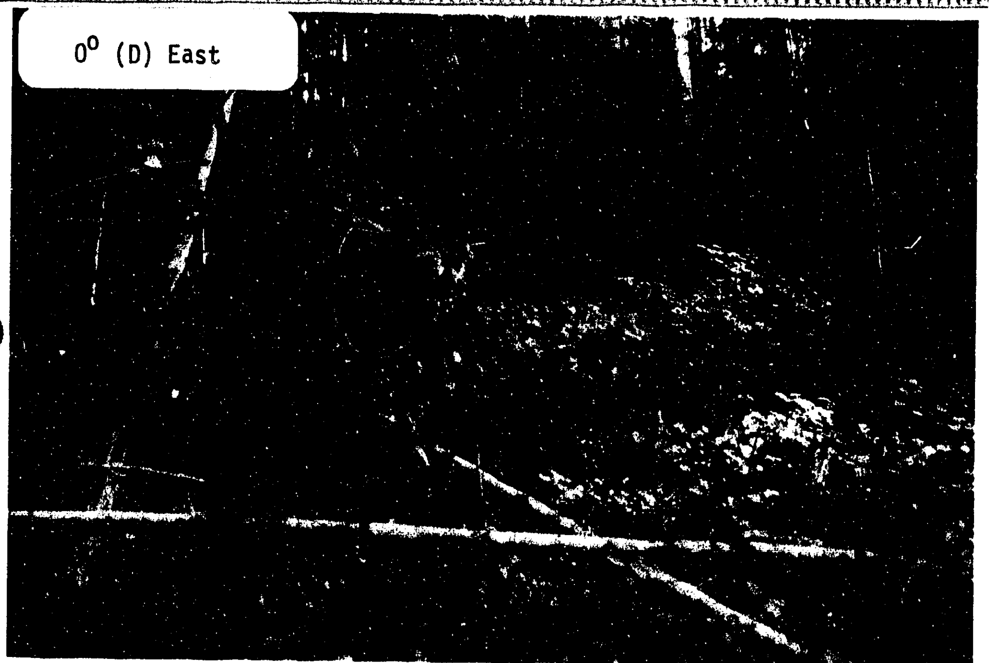


0° (C) Canopy

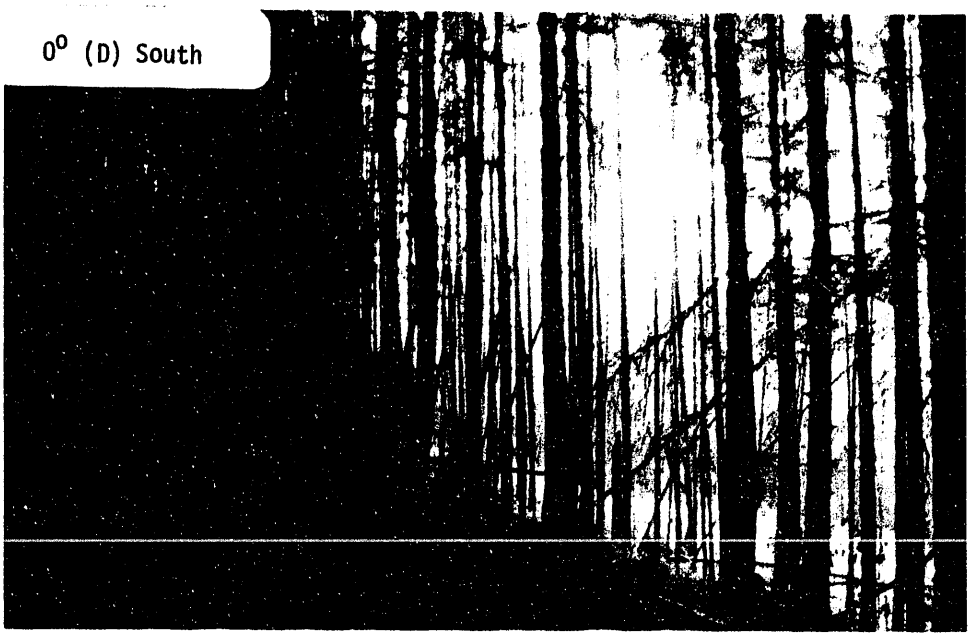




0° (D) North

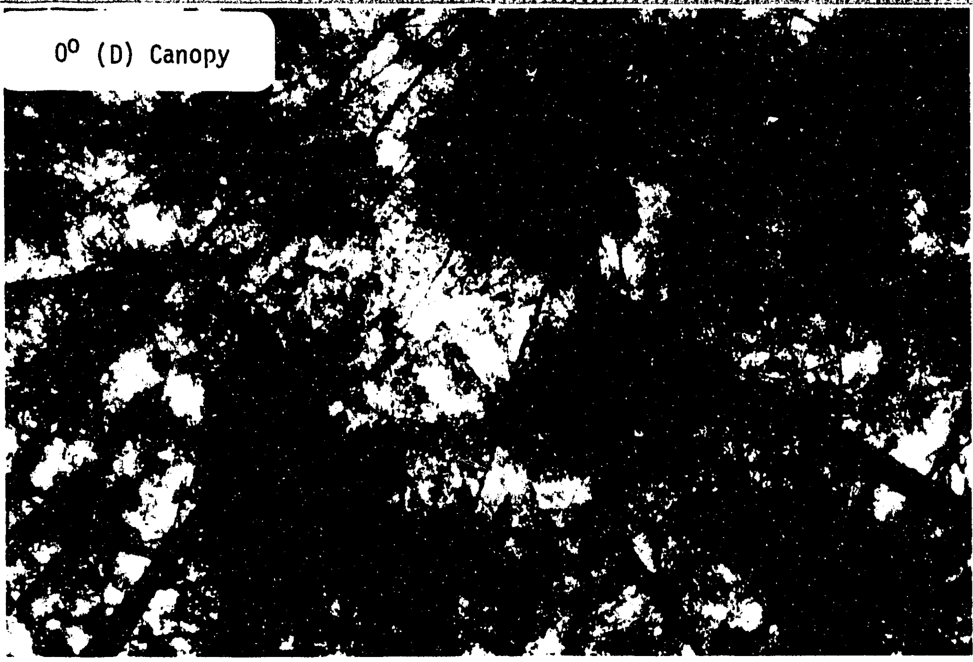


0° (D) East

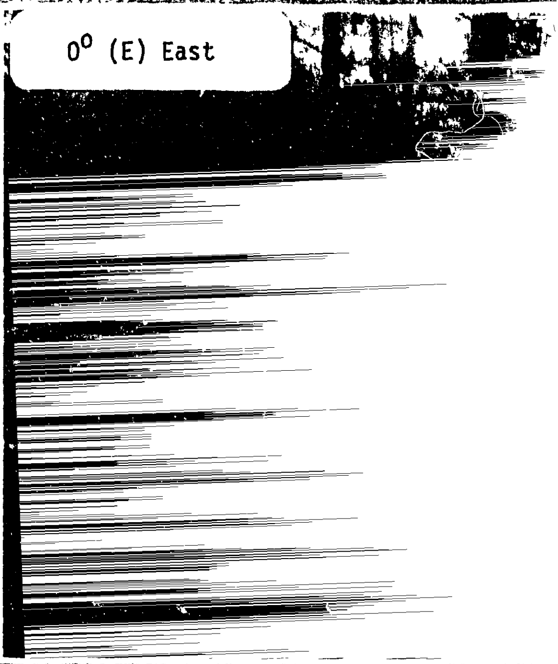


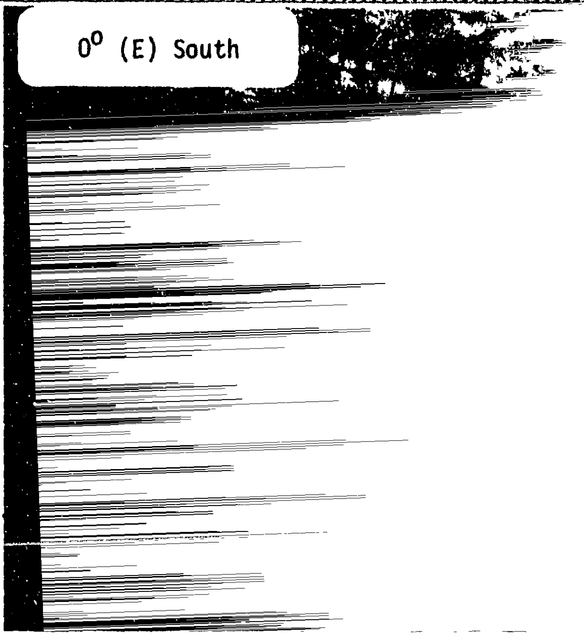
0° (D) South

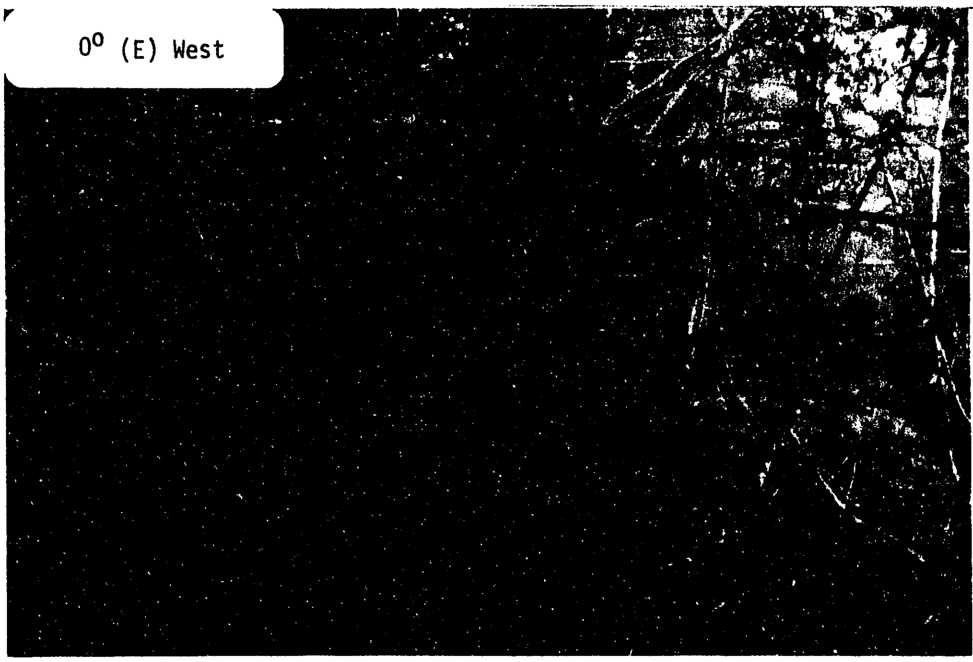

0^{o} (D) West

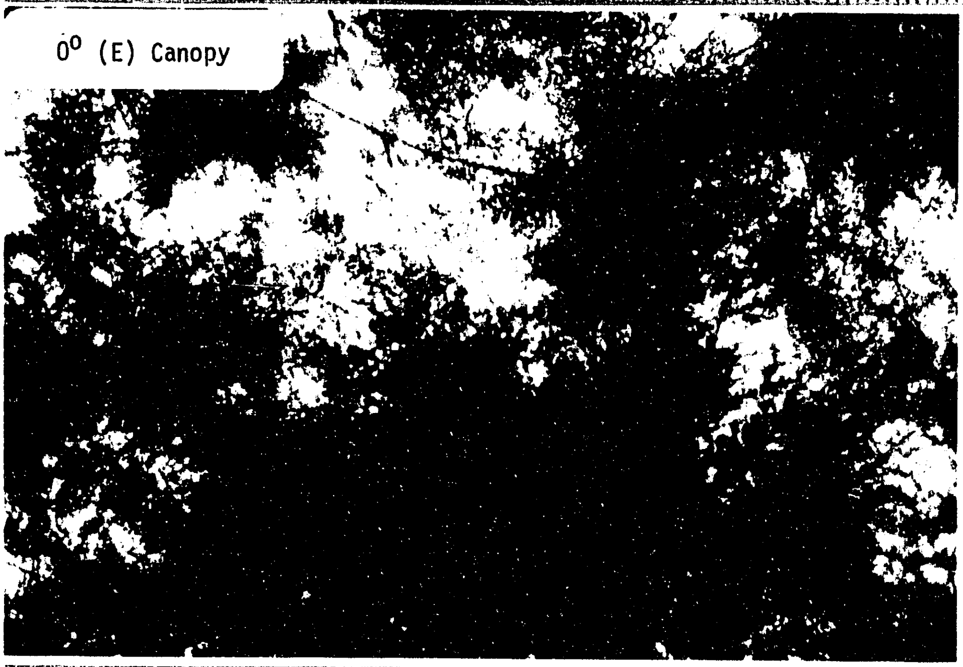

0^{o} (D) Canopy

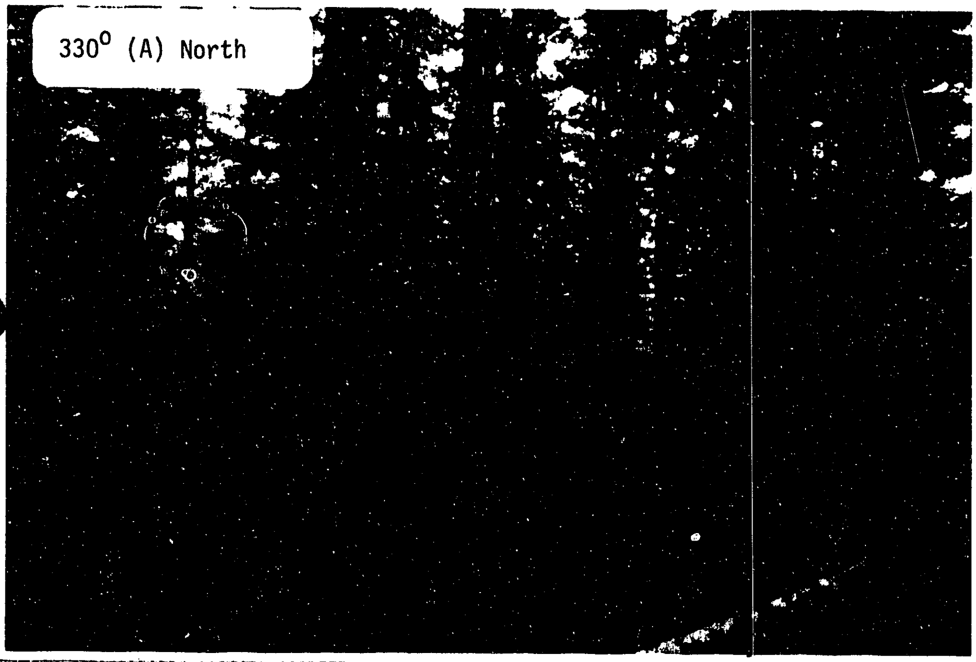

0° (E) North


0° (E) East

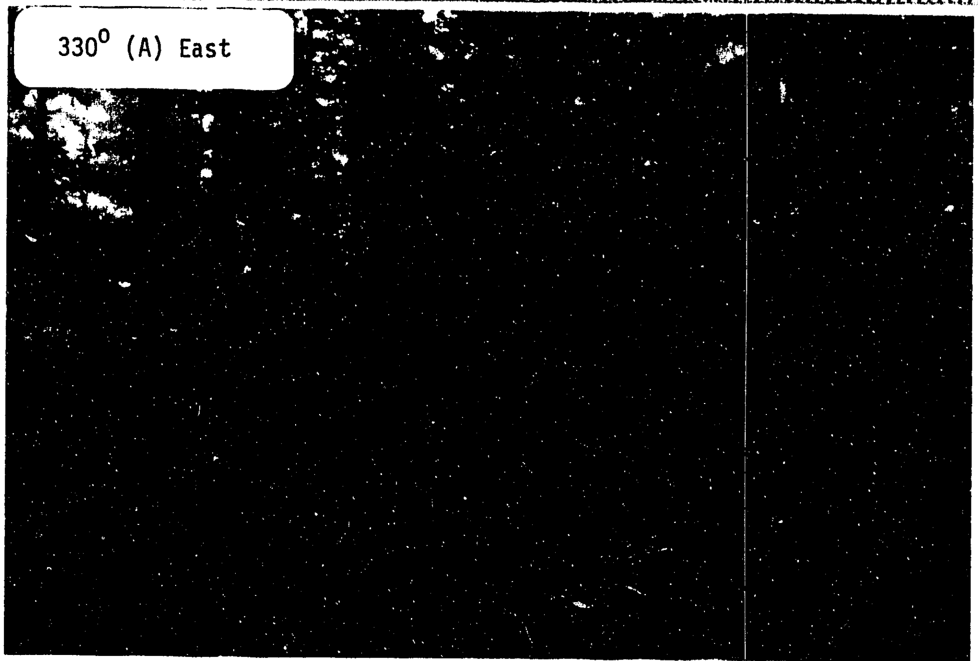

0° (E) South


0° (E) West

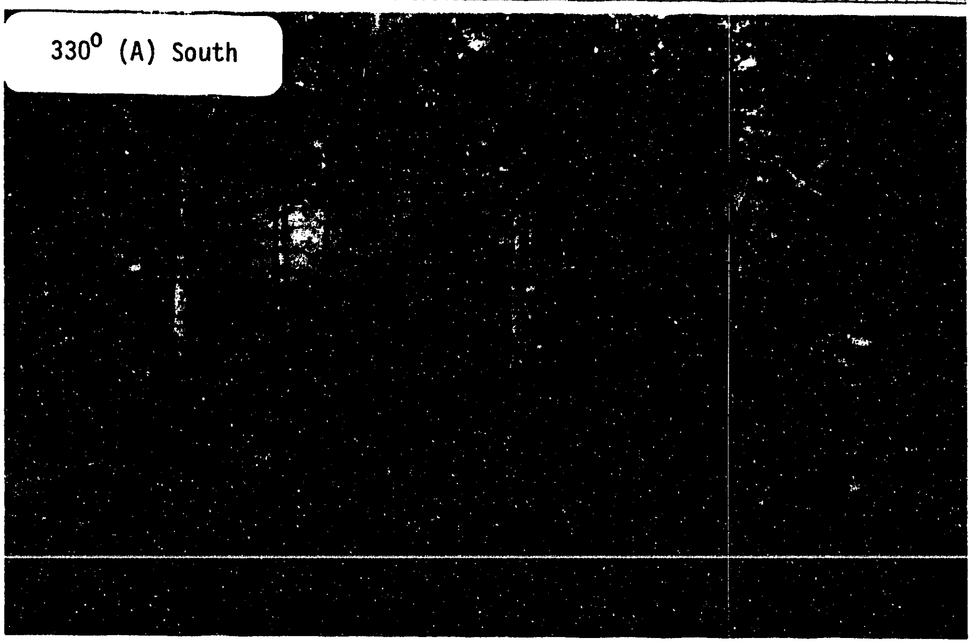

0° (E) Canopy



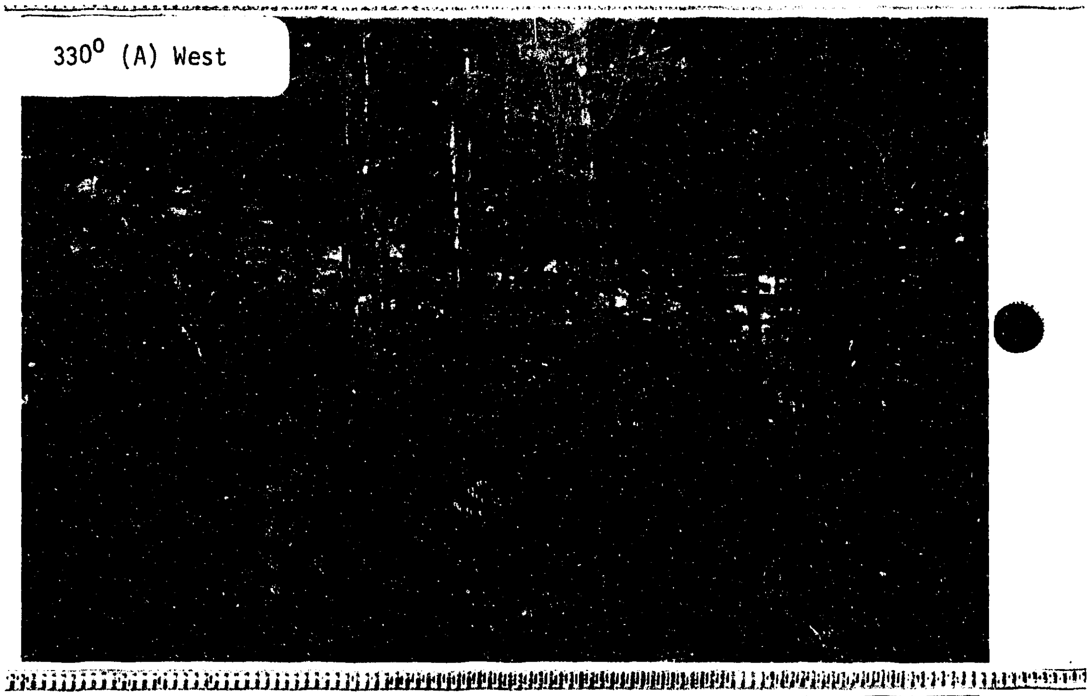
330° (A) North

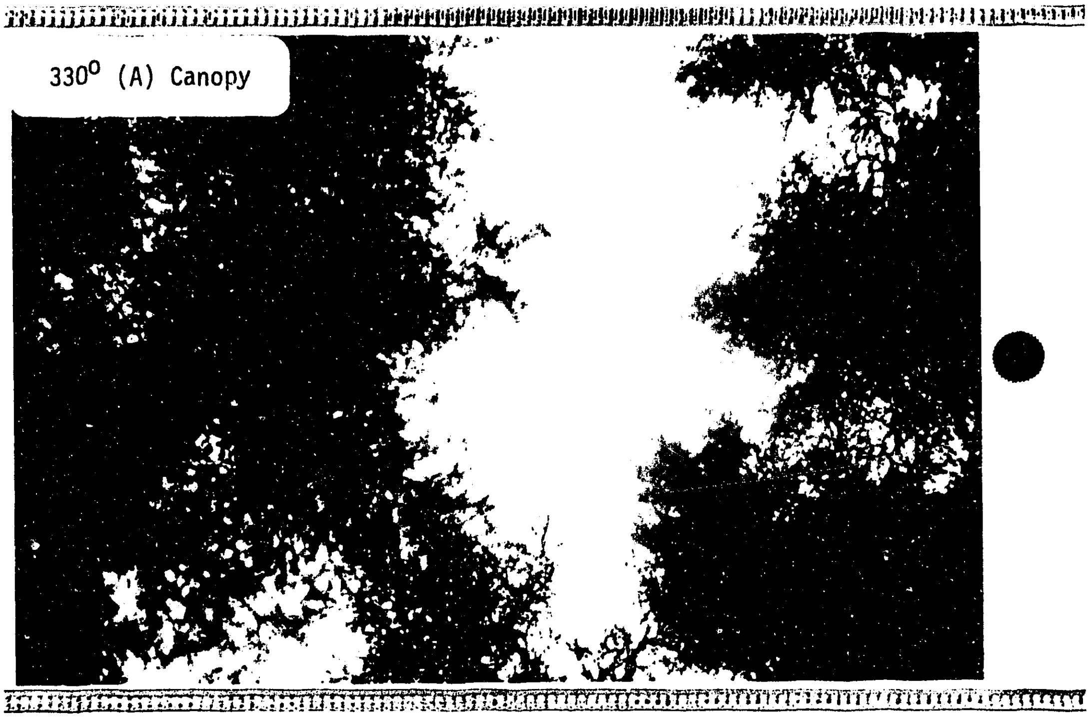


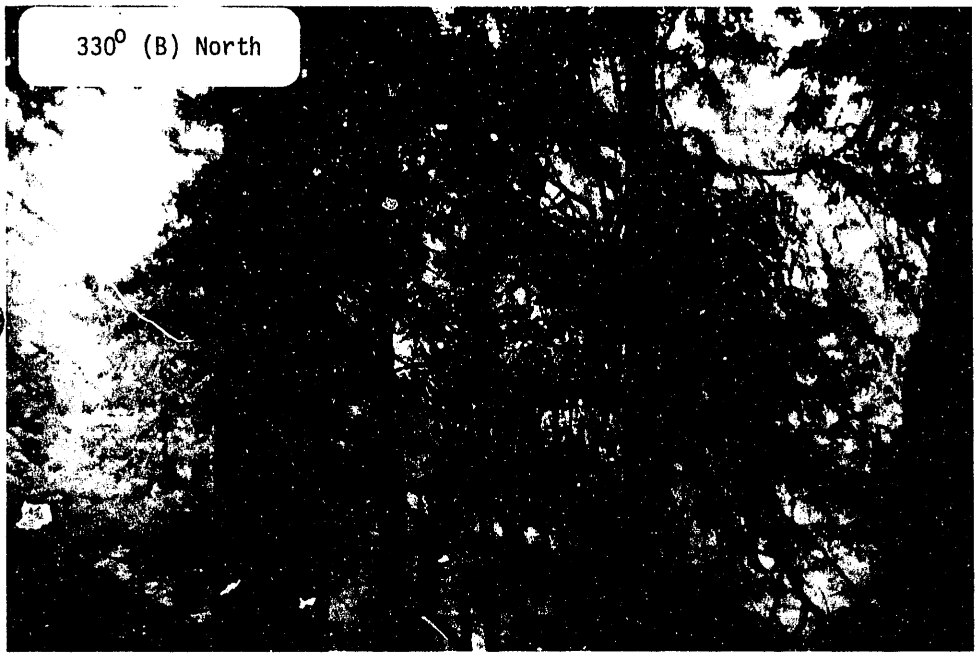
330° (A) East



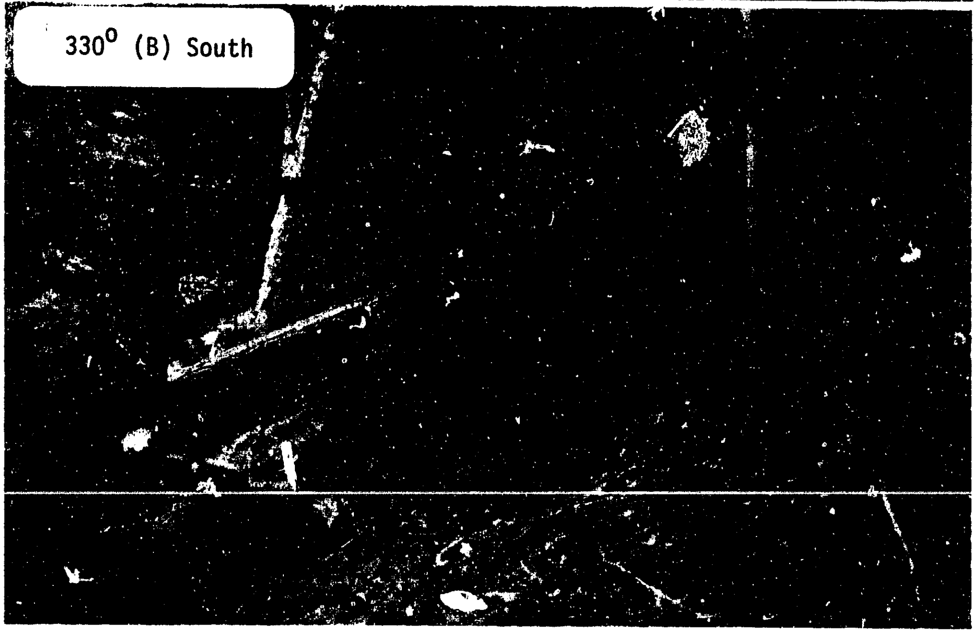
330° (A) South


330° (A) West

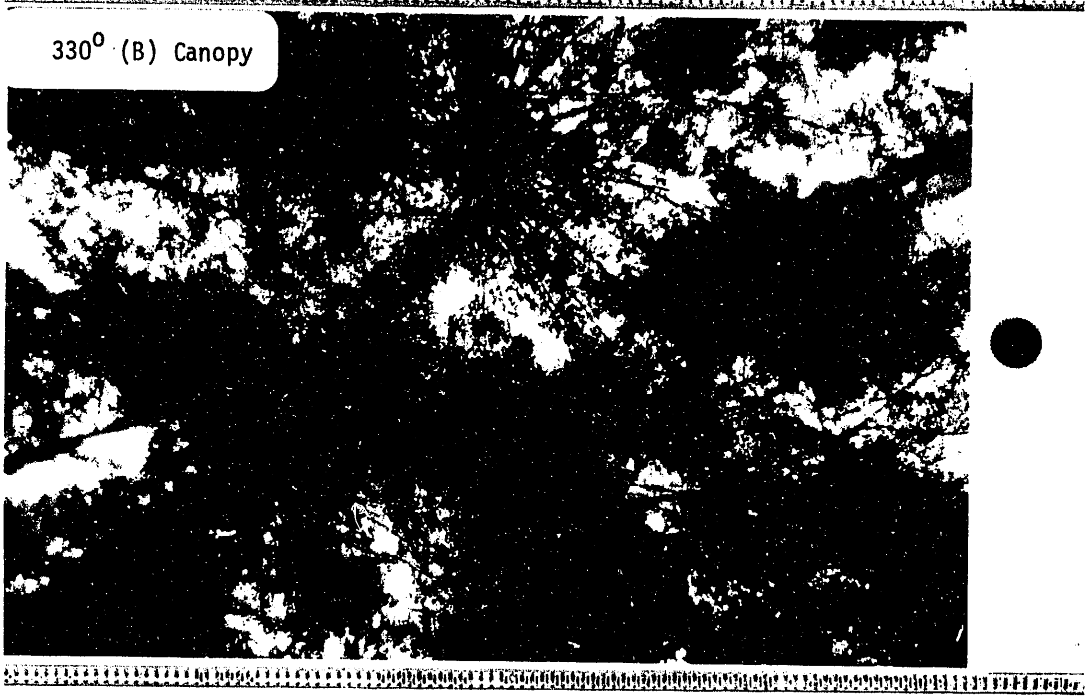

330° (A) Canopy

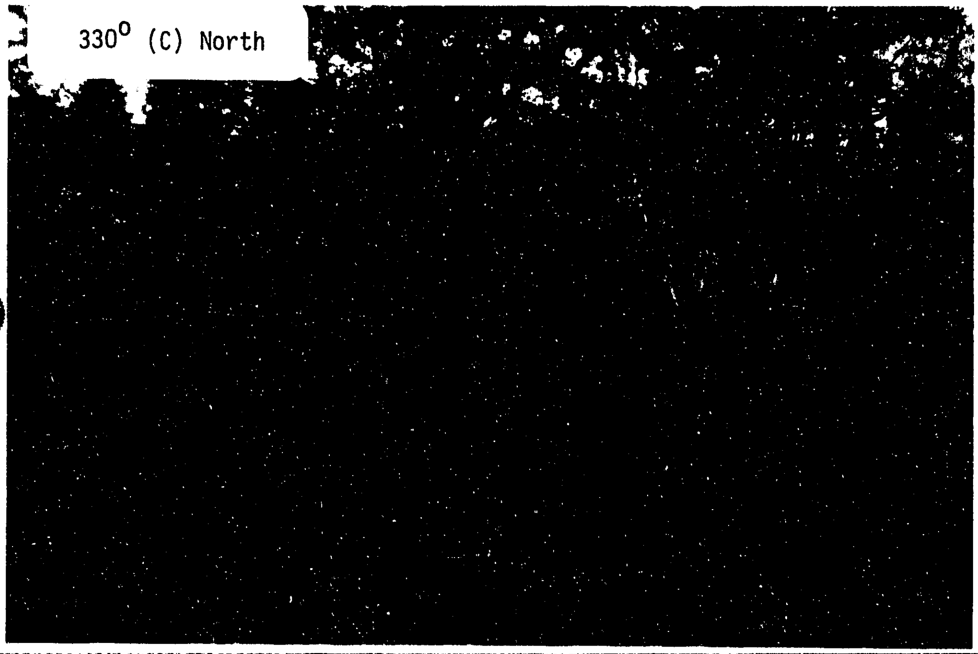

330^{0} (B) North

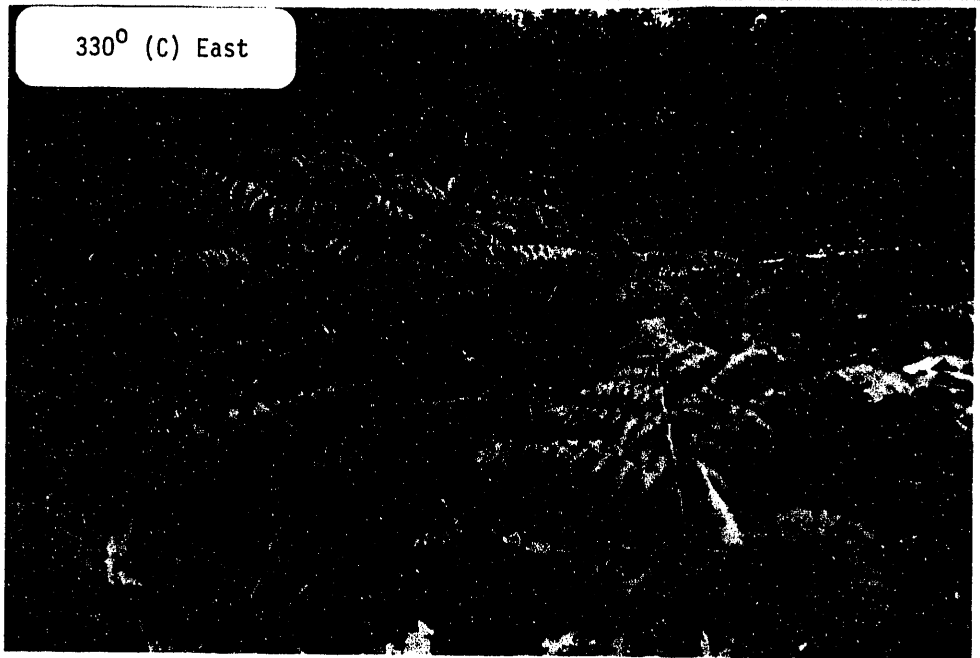

330^{0} (B) East

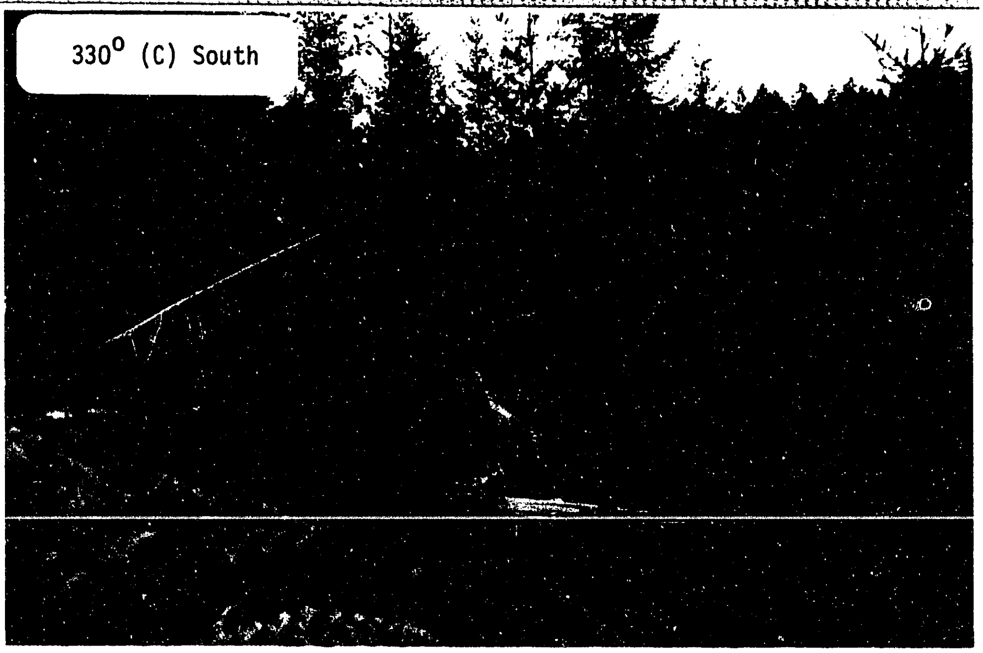

330^{0} (B) South


330° (B) West

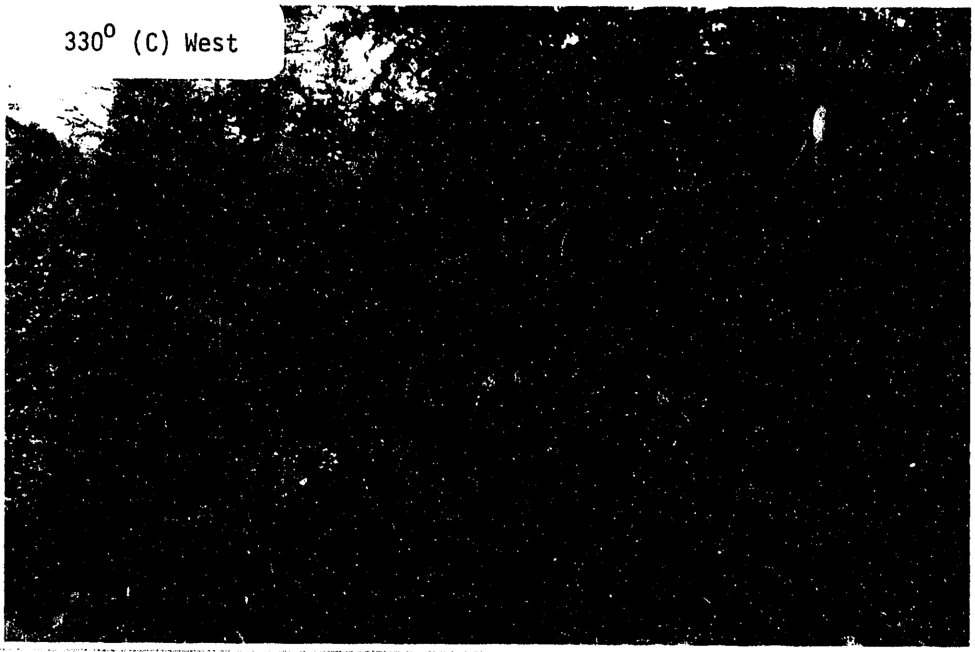

330° (B) Canopy


330° (C) North

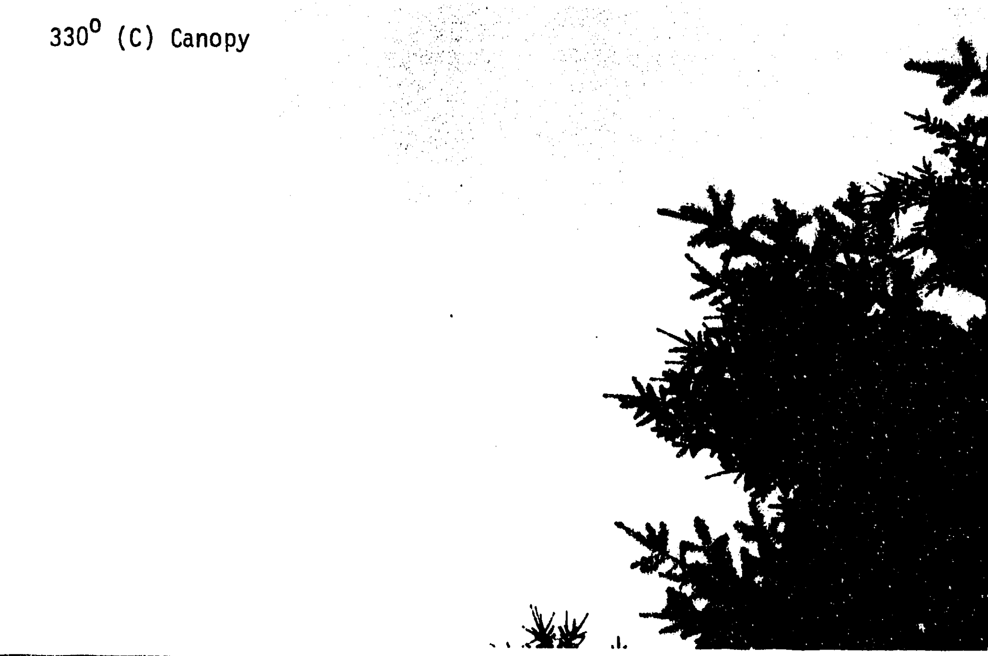

330° (C) East

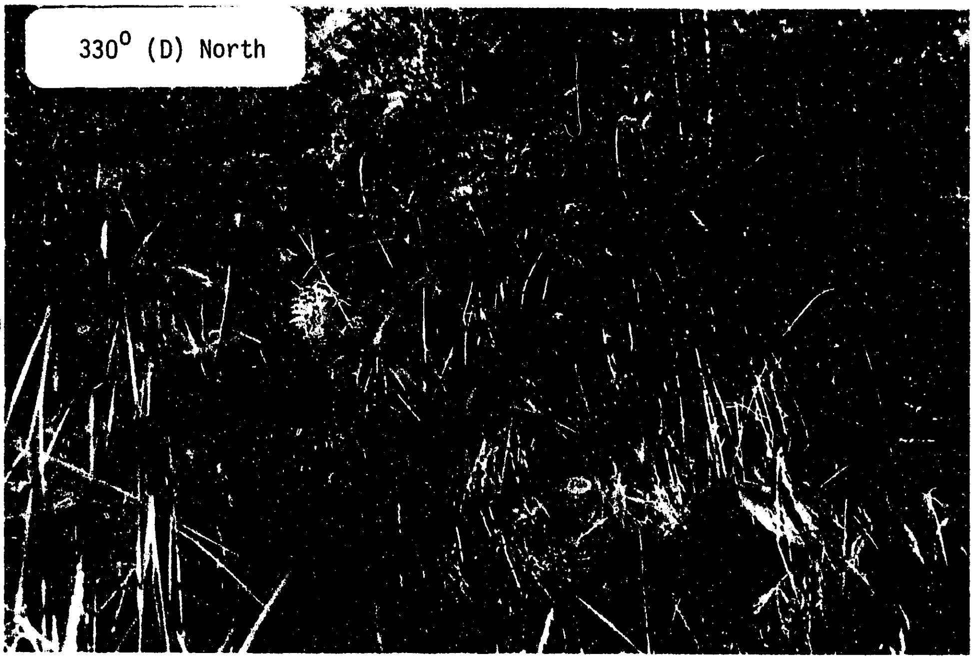

330° (C) South

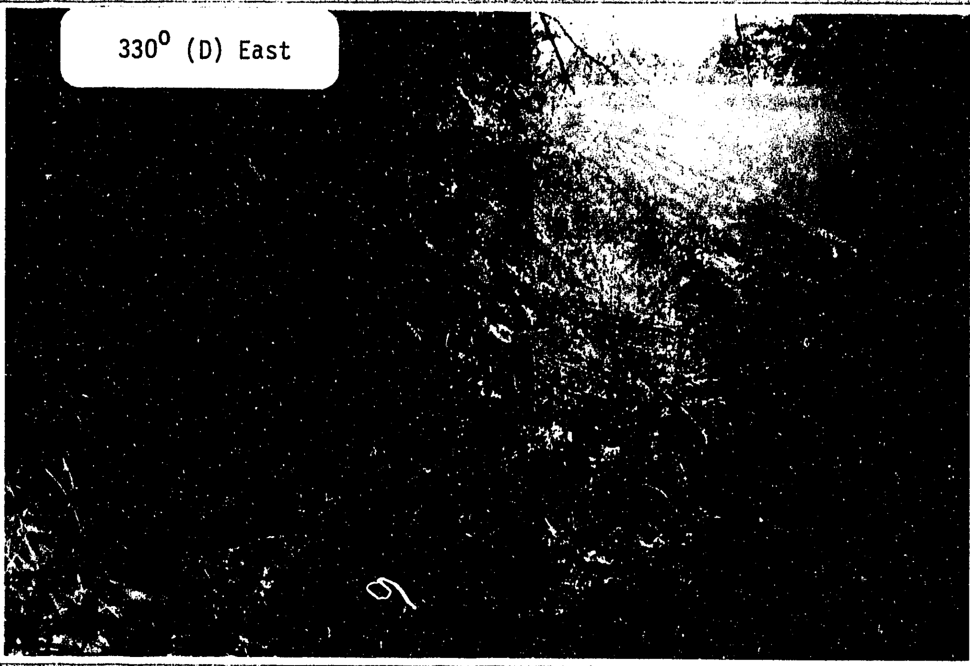
330° (C) West



330° (C) Canopy



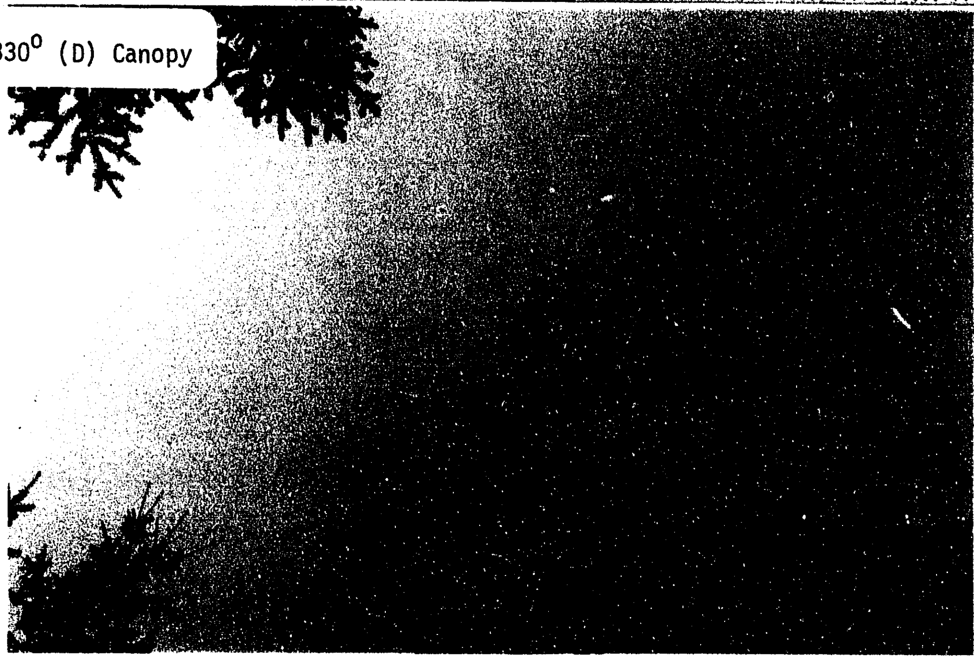

330° (D) North


330° (D) East


330° (D) South

330° (D) West

330° (D) Canopy



Distribution

No. of
Copies

OFFSITE

2 DOE/Office of Scientific and
Technical Information

4 D. Giglio
Department of Defense, DARPA
3701 North Fairfax Drive
Arlington, VA 22203-1714

J. M. Ralson
Inst. for Defense Technologies
1801 N. Beauregard Street
Alexandria, VA 22331

G. T. Ruck
Battelle Columbus Office
505 King Avenue
Columbus, OH 43201-2693

M. T. Tuley
GTRI/MAL CRB 564
Georgia Technology
Atlanta, GA 30332-0800

No. of
Copies

ONSITE

DOE Richland Operations Office

J. J. Sutey, A5-90

22 Pacific Northwest Laboratory

J. C. Becker, K7-02
H. D. Collins, K2-31
K. C. Davis, K5-25
R. H. Severtsen, K2-31
D. M. Sheen, K2-31 (12)
Publishing Coordination
Technical Report Files (5)

END

DATE FILMED

10 / 5 / 93