ANNUAL PROGRESS REPORT
ON
STUDIES OF MICROWAVE SCATTERING AND CANOPY ARCHITECTURE FOR BOREAL FORESTS

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RSL Technical Report 10480-1

November 1994

Sponsored by:

NASA Goddard Space Flight Center
Greenbelt MD 20771

Grant NAG 5-2344

1.0 Introduction

Our primary objectives during the last year have been to develop a helicopter-borne radar system for measuring microwave backscatter from vegetation and to use this system to study the characteristics of backscatter from the boreal forest. Our research is aimed at refining the current microwave models and using these improvements for more accurate interpretation of SAR data. SAR data are very useful for monitoring the boreal forest region because of the microwave signal's ability to penetrate clouds and to see at night.

Meeting these objectives involves several stages of development. The first stage is the design and implementation of a frequency-modulated continuous-wave (FM-CW) radar system with the capability of measuring backscatter at three frequencies and four polarizations at each frequency. These requirements necessitate a twelve-channel radar system. Using three frequencies is advantageous because it allows us to look at different parts of the canopy. For instance, the lower frequency signal penetrates deeper into the canopy and allows us to see the ground while the high frequency signal is scattered more by the leaves and needles and typically does not penetrate to the floor of the forest. We designed the radar starting with the antenna system. We then developed the intermediate frequency (IF) and radio frequency (RF) sections of the radar. Also, the need to collect data from twelve channels during each flight line presented a complex data acquisition problem that we solved by using a high-speed data acquisition board.

After construction, the radar was tested at the lab. We performed extensive testing of the IF and RF systems of the radar during this time. Once we were satisfied with the operation of the radar it was shipped to Canada for use in the second intensive field campaign (IFC-2) from July 16 - August 8, 1994. During IFC-2, we collected backscatter data over the experimental sites in the southern study area (SSA). Additionally, we used a ground-based step-frequency radar to measure the reflection coefficient of the forest floor at the old jack pine (OJP) and young jack pine (YJP) sites.
The ground-based radar data have been processed and a few examples are included in this report. We are currently processing the helicopter-borne radar data.

2.0 Radar System Development

The radar system consists of four primary subsystems. These are the antenna system, the RF section, the IF section and the data acquisition system. Figure 1 ilustrates the placement of each subsystem within the radar.

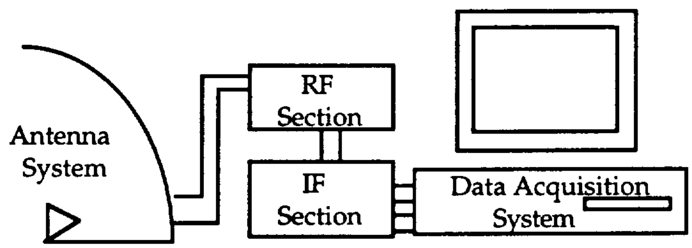

Figure 1. Block Diagram of Radar System

2.1 Antenna System

The antenna used for the radar is an offset-fed parabolic reflector. This type of antenna is a cutout of a parabolic refllector and is fed from the focal point with the feed antenna pointing toward the center of the dish. This type of set-up eliminates aperture blockage and also allows us to measure backscatter at nadir without mechanically pointing the antenna straight down. The latter advantage is mechanically convenient when operating from the helicopter because we can cover all angles starting with nadir without lowering the antenna structure below the landing gear.

We have used three feeds located on a single mount bar to excite the main reflector. The three feed antennas provide transmission and reception of the microwave signal at L (1.5 GHz), C (5.5 GHz) and X (10 GHz) bands. Because of the reflector's size (36" diameter), we were able to achieve good antenna performance at both C and X bands while still maintaining a manageable feed size and weight. At L band the reflector is electrically small and this causes degraded antenna performance. Furthermore, the feed size becomes very large and may cause problems in terms of operation from the helicopter.

We designed the C- and X- band feeds to provide a 10-dB taper at the edges of the reflector. We have used this as a means of maximizing the amount of signal radiated by the feed that is intercepted and hence reflected towards the target by the parabola. In other words we are attempting to maximize our spillover efficiency [1]. To achieve a pattern with its 10-dB points at the edges of the reflector, we used a conical horn with a 10-dB beamwidth of 75° found in *Electromagnetic Horn Antennas* [2]. The dimensions for this antenna are given in terms of wavelength in [2] and they were used for both the C- and X-band feeds. We also designed a waveguide for each of the horns that provides propagation of the microwave signal from coaxial cable to waveguide and finally to the antenna with minimal attenuation at the center frequency. This waveguide was used as an orthomode transducer to provide both vertically and horizontally polarized fields to the antenna. Additionally, the backplate of the conical horns is an adjustable short circuit that provides a variable reactance for tuning the antenna to the correct center frequency.

Initially, we designed an open-ended rectangular waveguide to function as the L-band feed. This type of feed minimizes the size of the aperture but it produces a large beamwidth and therfore does not have a good spillover efficiency. During the test flight at NASA Wallops Test Flight Facility in early May 1994 we were told that this antenna was too large and could not be flown on the helicopter. We then redesigned the L-band feed using a microstrip patch antenna. This type of antenna is physically small but also has a large beamwidth. Changing the L-band feed antenna prompted several design changes. The antenna change coupled with the lack of available rack space in the helicopter promted us to change our L-band RF section. Ultimately, we were unable to have a functional L-band RF section ready for IFC-2.
We measured the return loss for each of the feed antennas individually using an HP Vector Network Analyzer (VNA). During this process, we tuned each antenna for optimal performance over the desired frequency range.

We also designed a mounting structure for the three feeds. The structure consists of three support struts that are connected to a mounting bar where all three of the feeds are mounted. We placed the feeds along the bar with the L-band feed in the center and the C- and X-band horns placed one on each side. The exact position of the C- and X-band horn on the mounting bar was determined such that in a worst case scenario the horns would not interfere with the L-band feed. Please note that at the time of this calculation the open ended waveguide was the L-band feed. The angle of the C- and X-band horns is calculated from the geometry so that they point to the center of the reflector dish. By using ray theory, we can see that this will cause the L-, C- and X-band beams to point at diferent angles. However, this does not cause a problem because the beams will overlap many times during a single flight line. Therefore, since we know the altitude and the speed of the helicopter, we can determine the time of overlap and process our data accordingly.

2.2 RF Section

The RF section is the main subsystem of the radar. Its primary task is to transmit and receive the frequency-modulated microwave signal. The C-and X-band RF sections are identical and figure 2 shows a block diagram.

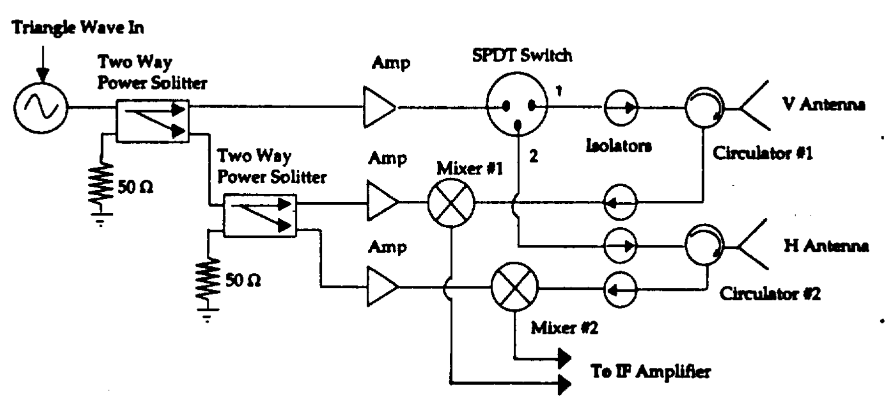

Figure 2. Block Diagram of RF Section for C and X Band

We built the RF sections for C and X band and housed them together in a Huffman box. We used discrete components and flexible coaxial cable suitable for use at the desired frequencies for interconnecting the components.

We have built the radar in a manner that allows us to collect data at two polarizations simultaneously while still maintaining good polarization purity. Specifically, we have used a SPDT switch along with two circulators and four isolators to achieve this mode of operation. When the switch is in position 1 (see figure 2 above) the radar is transmitting vertical polarization and receiving both vertical and horizontal polarizations. In other words, we are simultaneously measuring the VV and the VH channels. Similarly, if the switch is in position 2, we are simultaneously measuring HH and HV.

The L-band RF section is similar in block diagram form to that of the C- and X-band systems. The primary difference is that we decided to implement the L-band portion of the RF section using surface mount components with microstrip line as the method of interconnecting the components. Because of the time constraints placed on us by the alteration of our original L-band antenna, we were unable to get this portion of the radar to work during IFC-2. However, for IFC-3 we have taken a two-pronged approach to solve this problem. We will build two versions of the L-band RF section--one using discrete parts and the other using microstrip.

2.3 IF Section

The IF section consists of two three-stage switchable gain amplifiers that operate from DC to 26 kHz. The amplifiers are used to condition the low-level signals provided by the IF ports of the V and H receive channels of the RF section. We have placed a DPDT switch before the amplifier stages to direct the like-polarization signals (VV and HH) and the cross-polarization signals (VH and HV) to separate amplifiers. Thus, we can set different gains for the like- and cross-polarization channels and more efficiently utilize the dynamic range of the data acquisition system.

2.4 Data Acquisition System

The data acquisition system is used to collect data from each of the 12 data channels during the helicopter flights. We collect the data using a data acquisition board (A/D board) manufactured by Datel called the PC414-B2. We chose this board because of its capability to digitize four channels simultaeously at 14 bits per sample with sampling rates up to 5 MHz. Also, the board has a first in first out memory (FIFO) built in for easy transfer of the data from the A/D converter to the personal computer's memory.

We used the simultaneous four-channel sampling mode along with a switching scheme to collect data from all 12 channels during the flights. Channels 0 and 1 of the A/D board are dedicated to C-band V receive and C-band H receive respectively. Channel 2 switches between L-band V receive and X-band V receive and channel 3 switches between L-band H receive and X-band H receive. The switching between L and X band is performed once every four periods of the modulation waveform (a 50-Hz triangle wave). During the upsweeps of the modulation waveform , we kept the SPDT switch in position 1. This means that we collect CVV, CVH, LVV or XVV and LVH or XVH during the upsweeps. During the downsweeps, the computer switches the SPDT switch to position 2 and we collect CHV, CHH, LHV or XHV and LHH or XHH. Using this switching scheme and data acquisition mode, we obtain several independent samples of the backscatter for each frequency and polarization combination. Figure 3 illustrates the switching scheme and shows how all 12 channels are sampled multiple times during every flight line.

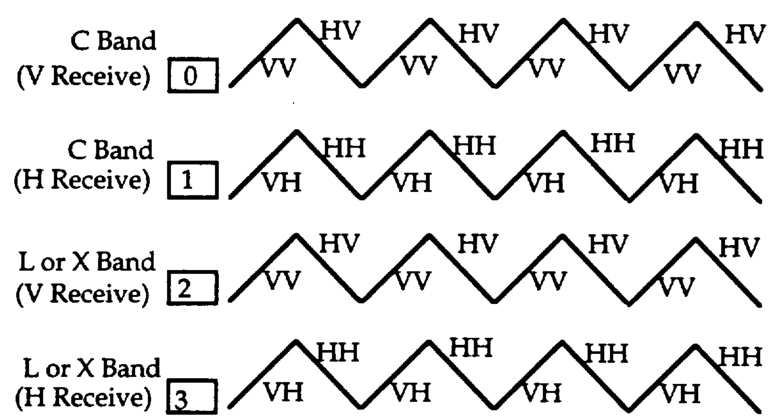

Figure 3. Data Acquisition Scheme for Measuring 12 Channels

We chose a sampling rate of 160 KHz and a flight line time of 40 secods. Therefore, for every flight line we collect 12 Mbytes of data. Each flight line must be flown six times for collection of backscatter data at varying incidence angles, which results in a total of 72 Mbytes minimum for each flight line.

2.5 Systems Integration

We tested each subsystem of the radar individually until it performed to our satisfaction. Then, we integrated the entire radar system and fine tuned the individual subsystems for optimal performance. These tests were performed on the ground at The University of Kansas Radar Systems and Remote Sensing Laboratory.

After the ground-testing phase was complete, we shipped the radar to Canada for use during IFC-2.

3.0 Microwave Backscatter Measurements During IFC-2

During IFC-2, we performed two types of microwave backscatter measurements. We collected helicopter-based scatterometer data at several sites in the SSA, and we collected ground reflection data at the OJP and YJP sites using a ground-based vector network analyzer (VNA) step-frequency radar system.

3.1 Helicopter-Based Scatterometer Measurements

We collected data at C and X band with all four linear polarizations during IFC-2. Flight lines at the old aspen (OA), young aspen (YA), old black spruce (OBS), young jack pine (YJP) and old jack pine (OJP) were chosen by Dr. K. Jon Ranson, Dr. Roger Lang and Dr. Narinder Chuahan to coincide with their ground-based canopy architecture measurements. Each of the flight lines is approximately 800 meters in length and was marked whenever possible with flourescent orange flags. Table 1 gives an overview of the data collected during the four microwave helicopter missions.

Flight Number	Site Code	Incidence	Polarizations	Notes
1 (7/21/94)	OA	-----------	-----------	Unable to locate flight lines
1 (7/21/94)	OBS	0°, 5°, 20°, 40°	VV and VH	Problems with 15 volt supply
2 (7/22/94)	YJP (Line 0)	0°, 10°, 20°, 30°, 40°, 46°	HH and HV	XMS error was present and manual polarization switching used
2 (7/22/94)	YJP (Line 0)	0°, 10°, 20°, 30°, 40°, 46°	VV and VH	same as above
2 (7/22/94)	YJP (Line 1)	30°, 40°, 46°	VV,HH,VH and HV	same as above
2 (7/22/94)	Transit Data	0 °	VV and VH	
3 (7/23/94)	YJP (Line 0)	0°, 10°, 20°, 30°, 40°, 50°	VV, HH, VH and HV	Switching done by computer
3 (7/23/94)	OBS	0°, 10°, 20°, 30°, 40°, 50°	VV, HH, VH and HV	same as above
3 (7/23/94)	OA	0°, 10°, 20°, 30°, 40°, 50°	VV, HH, VH and HV	same as above
4 (7/24/94)	YJP (Line 1)	0°, 10°, 20°, 30°, 40°, 50°	VV, HH, VH and HV	same as above
4 (7/24/94)	YJP (Line 1)	0°, 10°, 20°, 30°, 40°, 50°	VV, HH, VH and HV	same as above

Table 1. Summary of Helicopter Data Collected During IFC-2

3.2 Ground-Based Vector Network Analyzer Radar Measurements

After completing the helicopter missions for IFC-2, we took measurements using a ground-based VNA step-frequency radar operating from 2 to 18 GHz to determine the reflection coefficient of the forest floor at the OJP and YJP sites. We set up behind the hut at OJP and took measurements over four spots that were chosen as representative of the typical ground cover at the site. We took pictures of each spot and noted the type of ground cover present. After finishing the four spots with the ground cover intact, we removed the lichen layer carefully and repeated the measurements at each of the four spots. The same type of experiment was performed at the YJP site, but we did not remove the ground cover. We have included a few typical results and an explanation of their meaning in Appendix I.

4.0 Future Work

After our experience in the field during IFC-2, we discovered that tthe radar performance could be enhanced by making several changes in both hardware and software. Upon return from IFC-2 we first altered the IF section in order to provide a larger range of gain settings. During the IFC-2 flights, we observed that our IF signal was peaking at about ± 1 volt while the input range for the A/D board is ± 5 volts. Therefore, we made changes in our amplifier to provide the extra gain needed to utilize the full range of the A/D board.

We also added an option to our data acquisition software that allows us to view the data on the computer monitor during the helicopter flights. This feature allows us to check the entire system's performance before we begin taking data over a flight line. A third adjustment that we are planning to make is to change the angle at which the C- and X-band feeds point. Originally, the pointing angle of these feeds was calculated based on the use of the open-ended waveguide as the L-band feed antenna. After we changed the L-band feed antenna we noticed that there was quite a bit of room left to adjust the C- and X-band feeds, but time did not allow for this change to take place before IFC-2. This change will enhance the performance of the antenna and enlarge the area of overlap of the three beams at a given point in time.

We have also taken a new approach to building the L-band RF section to insure that we are able to collect data at this frequency during IFC-3. Our approach involves building two L-band systems. First, we will build an RF section using discrete parts, and then we will build a microstrip version. The discrete version is easy to implement but is relatively heavy, while the microstrip version takes more time to implement but is very lightweight.

After these changes to the radar system have been made we will ship the radar back to Canada for use in IFC-3. We plan to fly several helicopter missions during IFC-3 and collect backscatter data at L, C and X band. As in IFC-2, the SSA will be the focus of our measurements.

We have also planned to make more ground-based measurements during IFC-3. We will use the same RF system as that used during IFC-2. However, we will use an offset center-fed dish with a wideband feed to create a planar wavefront rather than the spherical wavefront created by the antenna used during IFC-2. By using a plane wave system, we can separate out the return from each range bin and easily determine what components of the forest floor are contributing most significantly to the backscatter from 2 - 18 GHz.

Upon completion of IFC-3, we will begin the system evaluation and data processing stage of our research. We have made arrangements through Dr. Roger Lang to use the antenna range at NASA Goddard Space Flight Center (GSFC) in mid-September. We will cut the radiation patterns of our antenna at all three frequencies. By characterizing the antennas in this manner we will be able to interpret better the backscatter data from the helicopter overflights. After these measurements are complete, we will begin processing the data from IFC-2 and IFC-3. We will use common digital signal processing techniques such as the fft and windowing, as well as advanced techniques developed at our lab, to provide the scattering coefficient at all frequency, polarization and incidence angle combinations.

Once the scattering coefficient values have been determined, they will be compared with modeling results using conventional vegetation canopy models. Next, we will utilize a inversion algorithm based on a feed forward artficial neural network (FANN) to create a scattering model that will invert important parameters such as biomass, leaf-area index (LAI) and soil moisture from the scattering coefficients. These two approaches will be compared and contrasted and a methodology for using our results for better SAR data interpretation will be presented.

5.0 Conclusions

We have completed the radar design and implementation satisfactorily at both C and X band and measurements were performed using this system during IFC-2. The L-band RF section has been redesigned and will be operational for IFC-3 helicopter missions.

In addition to the helicopter-based measurements, we also took ground-based measurements over a large bandwidth (2 to 18 GHz) at the OJP and YJP sites during IFC-2. We plan to perform a similar experiment during IFC-3 using a plane wave antenna that will allow us to determine more accurately the contributions to the total backscatter from various layers of the forest floor.

After IFC-3 is completed we will perform antenna radiation pattern measurements at all three frequencies using the antenna range facility at NASA GSFC. Also, we will reduce the helicopter data to scattering coefficients and begin the model development phase of our research.

Finally, the modeling results will be interpreted and their usefulness in terms of interpreting SAR data over the boreal forest regions will be evaluated.

Appendix I - IFC-2 Ground-Based Radar Measurements

Figure A1-1 shows the backscatter as a function of frequency from a typical spot on the ground at the OJP site. At the lower end of the spectrum the backscatter from the soil seems to dominate and there is a general decrease in the backscatter until a frequency of about 11 GHz. For frequencies greater than 11 GHz the scatter from the lichen begins to dominate and the backscatter increases with frequency.

Figure A1-2 shows the backscatter as a function of frequency from the same spot as in figure A1-1 with the lichen layer removed. Under these conditions, the backscatter remains relatively constant throughout the entire spectrum.

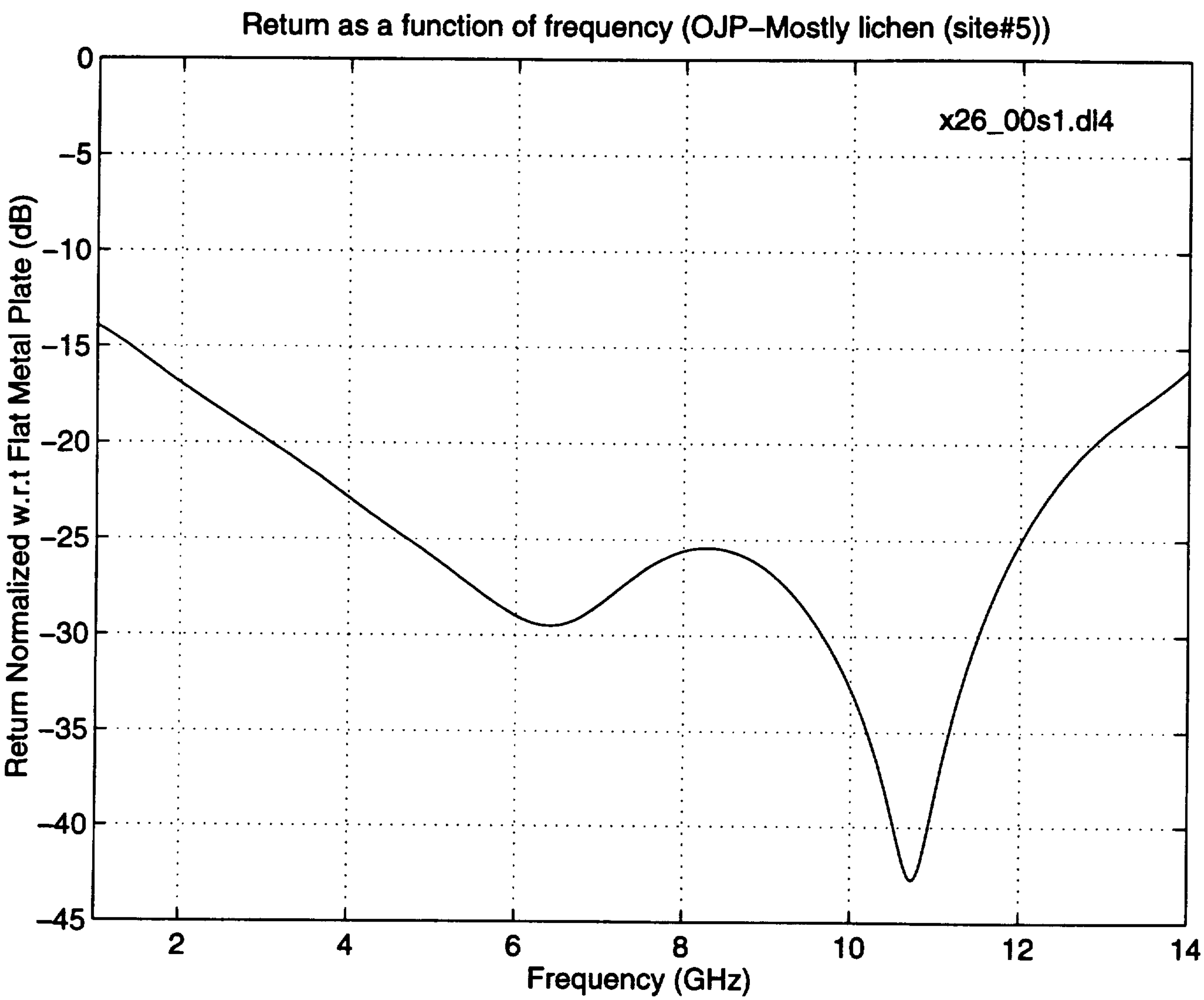

Figure A1-1. Backscatter as a Function of Frequency at OJP with a Lichen-Covered Ground

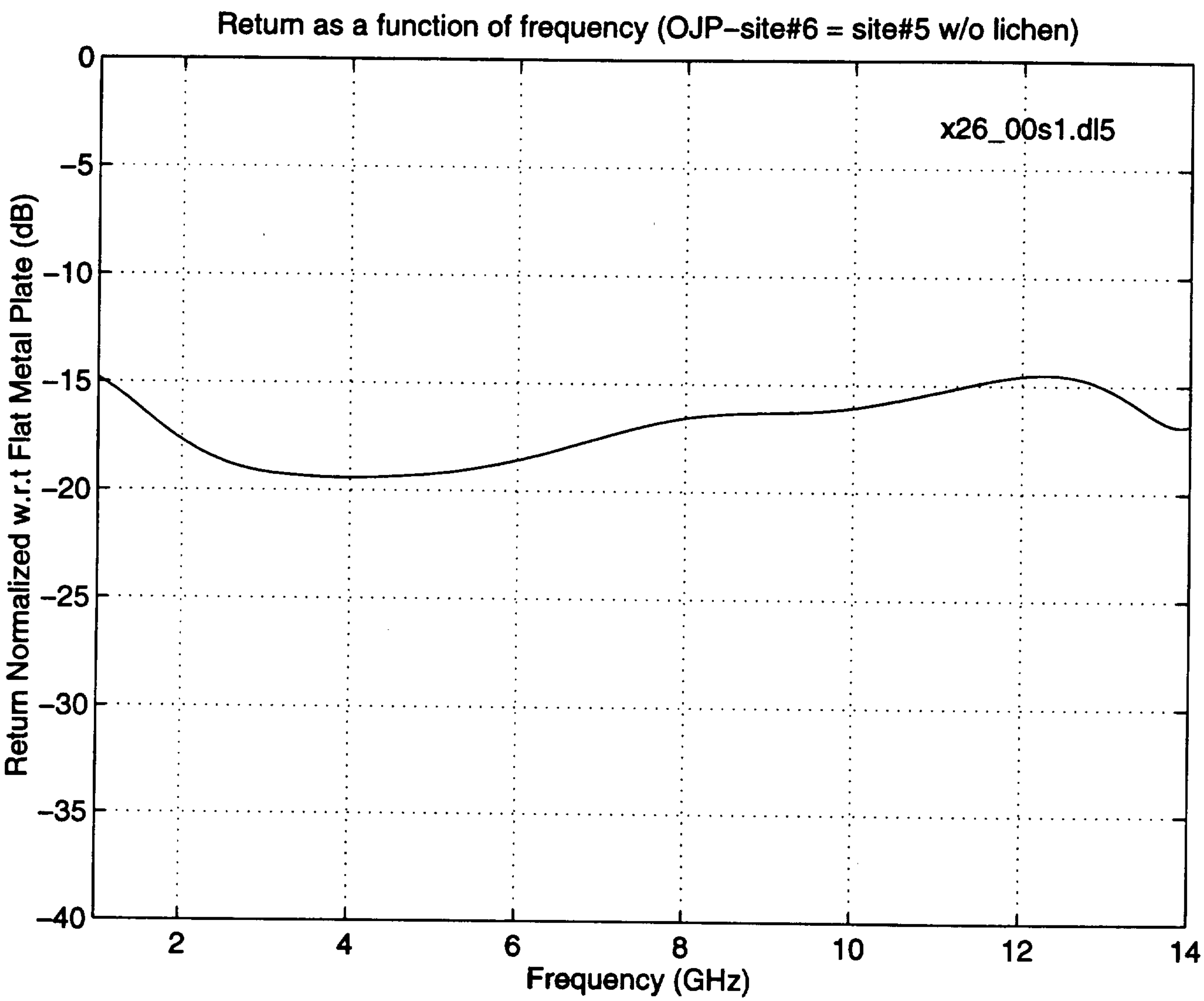

Figure A1-2. Backscatter as a Function of Frequency at OJP with Lichen Layer Removed

References

1. C. A. Balanis, *Antenna Theory*, Harper and Row, New York, 1982.

2. A. W. Love (ed.), *Electromagnetic Horn Antenna*, pp. 88-89, IEEE Press, New York, 1976.