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Normalized Radar Cross Section of Natural Surfaces at Millimeter Wavelengths

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The scattering of millimeter waves by foliated and snow-covered surfaces is of interest to designers of future radar and communication systems. It is also of interest to the remote sensing community, which is interested in the high-frequency behavior of radar signatures of natural surfaces. The University of Massachusetts Microwave Remote Sensing Laboratory developed a unique high-powered 215 GHz radar system. It used this system to measure the Normalized Radar Cross Section (NRCS) of trees and snow packs. Results of these studies are described in this report.

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FINAL TECHNICAL REPORT

Research Contract DAAG29–85–K–0227

Research Conducted

by

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for the

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1. Forward

The scattering of millimeter waves by foliated and snow-covered surfaces is of interest to designers of future radar and communication systems. It is also of interest to the remote sensing community, which is interested in the high-frequency behavior of radar signatures of natural surfaces. The University of Massachusetts Microwave Remote Sensing Laboratory developed a unique high-powered 215 GHz radar system as part of the research carried out under ARO contract DAAG29-85-K-0227. It used this system to measure the Normalized Radar Cross Section (NRCS) of trees and snow packs. Results of these studies are described below.

2. Table of Contents

3. List of Appendices

Not Applicable

4. Body of Report

A. STATEMENT OF PROBLEM

Very little is known about the transmission and scattering of 215 GHz electromagnetic signals because few systems have been developed that can operate at that frequency. Recent developments of high power sources and receivers, however, suggest that radar systems are feasible at 215 GHz. The research conducted under ARO Grant DAAG29-85-K-0227 was aimed at determining ground clutter effects at 215 GHz.

B. MOST IMPORTANT RESULTS

(1) Development of 215 GHz Radar System

A 215 GHz incoherent radar, originally fabricated by Norden Systems of United Technologies and provided to the U.S. Army-Night Visions Laboratory, was refurbished by the MIRSL. The design and performance of this radar system is described in [1], which is listed in 4C. The electrical characteristics of the 215 GHz system is summarized in Table I below:

Table 1

Characteristics of UMass 215 GHz Radar System

	Transmitter	
Center Frequency	215 GHz Nominal	
Peak Output Power	60W	
Pulsewidth	100 nsec	
PRF	2/10 KHz Internal	
	700 Hz - 20 KHz External	
Tuning Bandwidth	300 MHz	
	Antennas	
	Lens	Horn
3 dB beamwidth	0.64 deg	23 deg
Directivity	49.6 dB	18.5 dB
	Receiver	
Noise Figure	10 dB DSB	
1st IF	1.4 GHz	
2nd IF	160 MHz	
Bandwidth	300 MHz, 1st IF	
	40 MHz, 2nd IF	
Dynamic Range	70 dB	
	System	
Polarization	Linear HH, HV, VH, VV	
Operating Mode	Monostatic or Bistatic	
Positioning	Azimuth and Elevation	

The advent of high-power extended interactions oscillators and low-noise receivers in the 215 GHz frequency window makes it possible to design and operate radar systems at these wavelengths. The UMass high-power 215 GHz pulsed radar system is capable of making calibrated backscatter measurements from terrain targets at ranges of several kilometers under normal atmospheric conditions.

(2) Radar Backscatter Measurements of Trees at 215 GHz

We used the radar described above to make millimeter-wave backscatter measurements of various tree types during the 1987 growing season at Amherst, Massachusetts. These measurements are described in [2], which is listed in 4c below. The normalized radar cross section (NRCS) of a black oak and a white pine tree are shown below. Also measured were ground truth measurements of the normalized leaf area, gravitational leaf water content and the percentage of leaf coverage for all trees in the study.

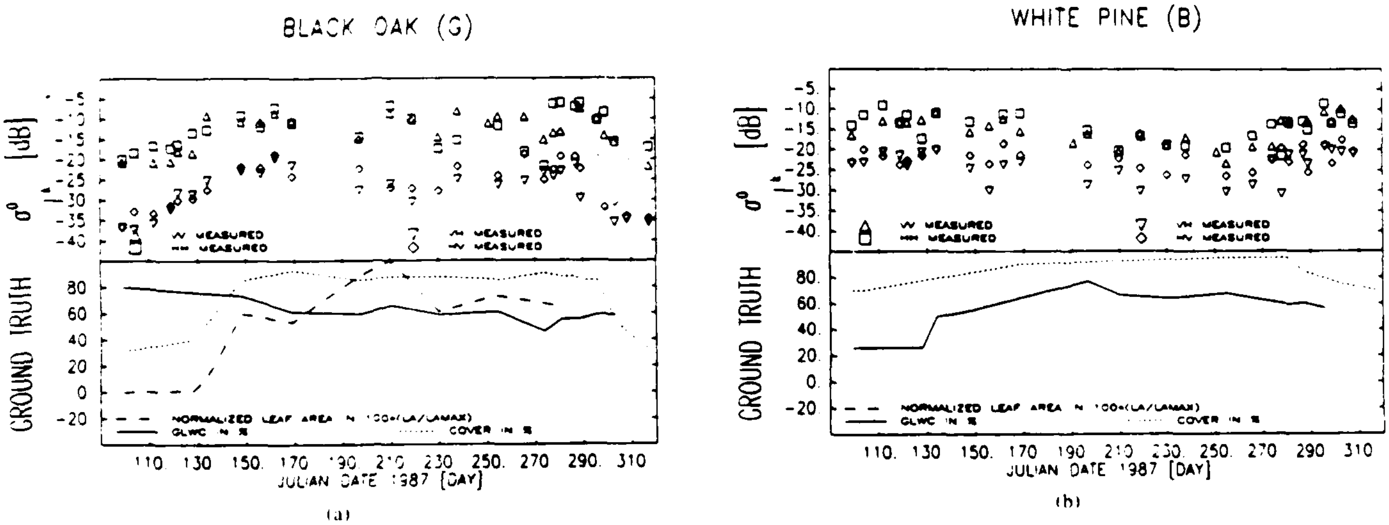

Fig. 1 **NRCS measurements of black oak and white pine trees during 1987 foliation season.**

The NRCS was obtained for VV, HH, HV and VH polarization for 17 different trees and tree groups. A summary of like-pol NRCS values averaged over the entire growing season is shown in Table II.

Table II.
Comparison of NRCS of Planophil versus Erectophil Trees Near Horizontal Incidence

Tree	Code*	Tree Type	$<\sigma^o_{VV}>$ $dB(m^2 \cdot m^{-2})$	$<\sigma^o_{HH}>$ $dB(m^2 \cdot m^{-2})$	Difference Between VV and HH Measurements $<\sigma^o_{VV}> - <\sigma^o_{HH}>$ dB	Average of VV and HH Measurements $dB(m^2 \cdot m^{-2})$
1. Red Maple *(Acer Rubrum)*	N	Planophil	−17.1	−16.3	+.8	16.7
2. Silver Maple *(Acer Saccharinum)*	H	Planophil	−12.6	−12.1	+.5	-12.4
3. Sugar Maple *(Acer Saccharum)*	D	Planophil	−12.9	−10.3	+2.6	-11.6
4. Black Oak *(Quercus Velutina)*	G	Planophil	−10.7	−11.7	−1.0	-11.2
Average of all Planophil Trees			**−13.3**	**−12.6**	**.7**	**-13.0**
Standard Deviation of All Planophil Trees			**2.7**	**2.6**	**1.5**	**2.5**
5. Pin Oak *(Quercus Palustris)*	M	Erectophil	-8.1	−7.5	−1.6	7.8
6. Eastern Cottonwood *(Populus Deltoides)*	E	Erectophil	-6.5	-8.6	−2.1	-7.6
7. Pin Oak *(Quercus Palustris)*	F	Erectophil	-6.7	-8.2	−1.5	-7.5
8. Weeping Willow *(Salix Babylonica)*	I	Erectophil	-3.9	-5.1	−1.2	4.5
Average of all Erectophil Trees			**-6.3**	**−7.4**	**−1.1**	**6.9**
Standard Deviation of All Erectophil Trees			**1.8**	**1.6**	**1.2**	**1.6**

* From [9].

(3) Millimeter Backscattering from Snow

MIRSL has also measured the 215 GHz NRCS of snow packs during the 1987-88 winter season at VV, HH, HV and VH polarizations. Concurrent ground truth measurements of snow surface roughness, moisture content, density, hardness, particle size and grain types were also made. The results of this study are summarized in [3], which is listed in 4C.

The NRCS of 16 different snow packs were measured between 18 December 1987 and 15 February 1988. Typical data are shown in Fig. 2 for measurements made on 6 February, 1988. In general, the like-pol NRCS decreases as a function of incidence angle from a maximum of +5 dB ($m^2 \cdot m^{-2}$) for dry snow at 20° incidence angle to -28 dB ($m^2 \cdot m^{-2}$) for wet snow at 83° incidence angle. The mean depolarization ratio varies from -10 dB to -5 dB, depending on snow conditions.

Of all the snow surface truth parameters measured, snow wetness appears to have the most important effect on the measured results. For example, the NRCS of like-pol measurements drops 5 to 7 dB when the volumetric moisture of the top layer of a snow pack increases from .15% on day 11 to 1.3% on day 12. This agrees with backscatter measurements made by others at lower millimeter frequencies.

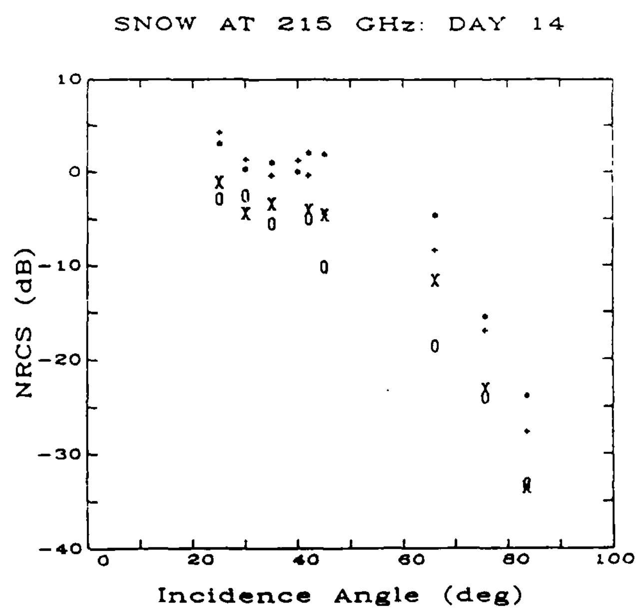

Fig. 2 NRCS of snow vs. incidence angle for VV(+), HH(*), VH(x) and HV(o) polarizations measured on 6 February 1988, Amherst, MA. (from [3])

(4) Modelling of Natural Surfaces for NRCS

The MIRSL has also developed simple models that, to a first order, agree with the measurements described in 4B(2) and 4B(3), above. A phenomenological model based on geometrical optics is given in [2], which predicts the NRCS of deciduous trees as a function of leaf coverage, and time during the foliation period. A more complex computer simulation, made of deciduous trees has also been developed [4], which correctly predicts the effects that leaf orientation has on the normalized backscatter cross section of trees. We observe that the NRCS of Phanophil and Erectophil trees differs substantially with the incidence angle that the millimeter wave impinges on the tree.

C. PUBLICATIONS AND REPORTS RESULTING FROM RESEARCH

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2. Narayanan, R.M., Borel, C.C. and McIntosh, R.E., "Radar Backscatter Characteristics of Trees at 215 GHz," IEEE Transactions on Geoscience and Remote Sensing, Vol. GE-26, No. 3, pp. 217-228, May 1988.
3. Narayanan, R.M. and McIntosh, R.E., "Millimeter-wave Backscatter Characteristics of Multi-layered Snow Surfaces," submitted to the IEEE Transactions on Antennas and Propagation, August 1988, 25 pp + 8 figures, (copy forwarded to ARO September 1988).
4. Borel, C.C. and McIntosh, R.E., "A Simulation of Millimeter Wave Backscattering from Trees," submitted to the IEEE Transactions on Antennas and Propagation, September 1988, 25 pp + 15 figures, (copy forwarded to ARO, September 1988).
5. Mead, J.B., McIntosh, R.E., Vandemark, D. and Swift, C.T., "Remote Sensing of Clouds and Fog with a 1.4 mm Radar," submitted to the Journal of Atmospheric

on Oceanic Technology, October 1988, 7 pp. + 9 figures, (copy forwarded to ARO, October 1988).

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7. Narayanan, R.M., "Measurement and Analysis of Electromagnetic Scattering from Vegetation and Fallen Snow at 215 GHz," Ph.D. Dissertation, Univeristy of Massachusetts, September 1988, 146 pp.
8. Vandemark, D., "Measurements of Atmospheric Liquid Water at 215 GHz," Master's Thesis, September 1988, 89 pp.
9. Chao, Y.F., "RACDA - A Radar Control and Data Acquisition Subsystem for Remote Sensing Applications," Master's Thesis, May 1988, 153 pp.

D. PARTICIPATING SCIENTIFIC PERSONNEL

1. Robert E. McIntosh, Professor and Principal Investigator
2. Calvin T. Swift, Professor and Co–principal Investigator
3. Ram Narayanan, Graduate Student, received Ph.D. degree August 1988, (now a faculty member at the University of Nebraska).
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5. James Mead, Ph.D. Graduate Student, expected graduation date, September 1989.
6. Douglas Vandemark, Graduate Student, received M.S. degree, September 1988.
7. Yen–Fang Chao, Graduate Student, received M.S. degree, May 1988.
8. Philip Langlois, Graduate Student, M.S. Candidate.
9. William Teso, Visiting Professor, (regularly employed at the University of Hartford).
10. Chris Ruf, Research Engineer, (now employed at JPL).

5. Bibliography

Not Applicable

6. Appendices

Not Applicable