_	MAS	TER COPY			and the second sec	TOW TOW ODED	
. Δ	D-425	6 981	ATION P	AGE		Form Approved OM8 No. 0704-018	Q
			average 1 hour per 1g the collection of to Washington Hea if Management and	response, including the time information - Send comments idquarters Services, Directora Budget, Paperwork Reductio	for reviewing instr regarding this bur ste for information n Project (0704-018)	uctrons, searching existing den estimate or any other Operatrons and Reports, 12 8), Washington, DC 20503	data source ispect of th 15 Jefferso
1. AGENCT	USE UNET (LEAVE DA	EDK) 2. REPURI 8/30/	UATE /92	3. REPORT TYPE	and dates in al	COVERED	
4. TITLE AN Polari	o subtitle metric Measure	ements of Nat	tural Surfa	ces at 95 GHz	S. FUND	ING NUMBERS	
6. AUTHOR	(5)				_DAAL	03-90-6-01	44
Pau Rob	II S. Chang Dert E. McIntos	sh	C	TIC	b		
7.PERFORM Microw Univer Amhers	ung Organization wave Remote Ser sity of Massac st, MA 01003	NAME(S) AND ADD Ising Laborat chusetts	tory	CT 2 2 1992	8. PERFO	ORMING ORGANIZAT RT NUMBER	ION
9. SPONSOF	RING/MONITORING A	GENCY NAME(S) A Office	ND ADDRESS(ES)	10. SPDN AGEN	ISORING/MONITORI	NG R
P. O. Resear	Box 12211 ch Triangle Pa	ark, NC 277	09-2211		ARC	27919.2-6	2
11. SUPPLE The v: author posit: 12a. DISTRIC	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTION/AVAILABILITY	and/or findi d not be con <u>r decision,</u> / STATEMENT	ngs contai strued as unless so	ned in this re an official De designated by	port are partment other doc	those of the of the Army cumentation. TRIBUTION CODE	
11. SUPPLE The v: author posit: 12a. DISTRIC Approv	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTION/AVAILABILITY ved for public	and/or findi d not be con r decision, r STATEMENT release; di	ngs contai strued as unless so stribution	ned in this re an official De designated by unlimited.	port are partment other doc	those of the of the Army cumentation. TRIBUTION CODE	
11. SUPPLE The v: author posit: 12a. DISTRI Approv	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTION/AVAILABILITY ved for public .CT (Maximum 200 wo	and/or findi d not be con <u>r decision,</u> r STATEMENT release; di	ngs contai strued as unless so stribution	ned in this re an official De designated by unlimited.	port are partment other doc	those of the of the Army cumentation. TRIBUTION CODE	
11. SUPPLEI The v: author posit: 12a. DISTRIC Approv	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTHON/AVAILABILITY ved for public CT (Maximum 200 wo igh power 95 Gl used to make p r period of th	and/or findi d not be con <u>r decision,</u> r STATEMENT release; di ros) Hz radar sys polarimetric is grant the	ngs contai strued as unless so stribution tem, develo measuremen following	ned in this re an official De designated by unlimited. oped at the Uni its of natural items were acc	iversity complished	those of the of the Army cumentation. TRIBUTION CODE	cts, vo
11. SUPPLEI The v: autho: posit: 12a. DISTRIC Approv 13 ABSTRA A hi Q. was year	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTION/AVAILABILITY ved for public CT (Maximum 200 wo igh power 95 Gl used to make r period of th 1. The 95 GH taneously 2. The equiv was demon	and/or findi d not be con r decision, r statement release; di ros) Hz radar sys polarimetric is grant the z radar was making cohe alence of th strated.	ngs containstrued as unless so astribution tem, develo measurement following configured rent and in e coherent	ned in this re an official De designated by unlimited. ped at the Uni its of natural items were acc into a unique and noncoherer	iversity constraints system caller matrix	those of the of the Army cumentation. TRIBUTION CODE	:ts, /0 /1- 5. Je
11. SUPPLEI The v: autho: posit: 12a. DISTRIC Approv 13 ABSTRA A hi d. was year	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTION/AVAILABILITY ved for public CT (Maximum 200 wo igh power 95 Gl used to make r period of th 1. The 95 GH taneously 2. The equiv was demon 3. The polar These inc tree spec	and/or findi d not be con r decision, r statement release; di ros) Hz radar sys polarimetric is grant the z radar was making cohe alence of the strated. imetric prop- luded the we ies.	ngs containstrued as unless so astribution tem, develor measurement following configured rent and in e coherent erties of we	ned in this re an official De designated by unlimited. unlimite	iversity of system caller matrix nt measure e targets naple, and	those of the of the Army cumentation. TRIBUTION CODE	il- s. ue erizec ine
11. SUPPLEI The v: autho: posit: 12a. DISTRII Approv 13 ABSTRA A hi Was year	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTION/AVAILABILITY ved for public ved for public igh power 95 G used to make r period of th 1. The 95 GH taneously 2. The equiv was demon 3. The polar These inc tree spec 4. The polar character	and/or findi d not be con r decision, r statement release; di ros) Hz radar sys polarimetric is grant the z radar was making cohe alence of the strated. imetric prop- luded the we ies. imetric prop- ized.	angs containstrued as unless so estribution tem, develor measurement following configured rent and in e coherent erties of we eping willow	ned in this re an official De designated by unlimited.	port are partment other doc liversity of surfaces. complished system ca ler matrix nt measure e targets naple, and ver types	those of the of the Army cumentation. TRIBUTION CODE	ts, vo ul- s. ue erized ine
11. SUPPLEI The v: autho: posit 12a. DISTRIM Approv 13 ABSTRA A h ² Was year	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTION/AVAILABILITY ved for public ved for public igh power 95 Gl used to make r period of th 1. The 95 GH taneously 2. The equiv was demon 3. The polar These inc tree spec 4. The polar character 5. Mueller m	and/or findi d not be con r decision, r statement release; di ros) Hz radar sys polarimetric is grant the z radar was making cohe alence of the strated. imetric prop- luded the we ies. imetric prop- ized. atrix models	ngs containstrued as unless so astribution tem, develor measurement following configured rent and in e coherent erties of we for wet an	ned in this re an official De designated by unlimited. unlimite	port are partment other doc liversity of surfaces. complished system ca ler matrix nt measure e targets naple, and ver types re develop	those of the of the Army <u>sumentation.</u> TRIBUTION CODE	its, wo ll- s. le erized ine
11. SUPPLEI The v: autho: posit: 12a. DISTRIC Approv 13 ABSTRA A h ² Was year 6/6/6/6/6/6/6/6/6/6/6/6/6/6/6/6/6/6/6/	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTHON/AVAILABILITY ved for public cr (Maximum 200 wo igh power 95 Gi used to make p r period of th 1. The 95 GH taneously 2. The equive was demon 3. The polar These inc tree spec 4. The polar character 5. Mueller m	and/or findi d not be con or decision, r statement release; di ros) Hz radar sys polarimetric is grant the z radar was making cohe alence of the strated. imetric prop- luded the we ies. imetric prop- luded the we ies.	angs containstrued as unless so astribution tem, develor measurement following configured rent and int e coherent erties of v eping willor erties of v for wet an	ned in this re an official De designated by unlimited. unlimited. unlimited. und noncoherent des of natural items were acc into a unique coherent Muell and noncoherent various foliage ow, the sugar n various snowcow	port are partment other doc lib. Dist iversity of surfaces. complished system ca ler matrix nt measure e targets naple, and ver types re develop	those of the of the Army cumentation. TRIBUTION CODE	cts, vo ll- s. le erized ine GES
11. SUPPLEI The v: autho: posit: 12a. DISTRII Approv 13 ABSTRA A h ² Was year 6/6 // SUBJEC	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTION/AVAILABILITY ved for public CT (Maximum 200 wo igh power 95 Gl used to make p r period of th 1. The 95 GH taneously 2. The equiv was demon 3. The polar These inc tree spec 4. The polar character 5. Mueller m	and/or findi d not be con or decision, r statement release; di rds) Hz radar sys polarimetric is grant the z radar was making cohe alence of the strated. imetric prop- luded the we ies. imetric prop- ized. atrix models	angs containstrued as unless so estribution tem, develor measurement following configured rent and in ecoherent erties of we for wet an	ned in this re an official De designated by unlimited. unlimited. unlimited. und notural items were acc into a unique coherent Muell and noncoherer various foliage ow, the sugar n various snowcow ed dry snow we	port are partment other doc 12b. Dist iversity of surfaces. complished system ca ler matrix t measure e targets maple, and ver types re develop	those of the of the Army cumentation. TRIBUTION CODE	cts, vo 11- 5. Je erized ine GES
11. SUPPLEI The v: autho: posit: 12a. DISTRIM Approv 13 ABSTRA A h ⁴ Was year UBJEC 17. SECURI DE BEC	MENTARY NOTES iew, opinions r(s) and shoul ion, policy, o BUTION / AVAILABILITY ved for public Ved for public I. The 95 GH taneously 2. The equive was demon 3. The polar These inc tree spec 4. The polar character 5. Mueller m T TERMS	and/or findi d not be con or decision, v STATEMENT release; di ros) Hz radar sys polarimetric is grant the z radar was making cohe alence of the strated. imetric prop- luded the we ies. imetric prop- luded the we ies. imetric prop- luded the we ies. imetric prop- luded the we ies.	angs containstrued as unless so astribution tem, develoc measurement following configured rent and in e coherent erties of we for wet an for wet an	ned in this re an official De designated by unlimited. unlimited. oped at the Unities of natural items were accont into a unique coherent Muell and noncoherent various foliage ow, the sugar no various snowcow and dry snow wen	port are partment other doc liversity of surfaces. complished system ca ler matrix nt measure e targets naple, and ver types re develop	those of the of the Army cumentation. TRIBUTION CODE	derized ine GES

Standard Form 298 (Rev. 2-89) Prescribed by ANSr Std. 239-18 298-102

POLARIMETRIC MEASUREMENTS OF NATURAL SURFACES AT 95 GHZ

Final Report

Paul S. Chang Robert E. McIntosh

August 17, 1992

U.S. Army Research Office

DAAL03-90-G-0144

University of Massachusetts

Approved for Public Release; Distribution Unlimited

THE VIEW, OPINION, AND/OR FINDINGS CONTAINED IN THIS REPORT ARE THOSE OF THE AUTHOR(S) AND SHOULD NOT BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION, POLICY, OR DECISION, UN-LESS SO DESIGNATED BY OTHER DOCUMENTATION. Polarimetric measurements of natural surfaces were made at 95 GHz over the twoyear span of this proposal. This data was collected with a high power 95 GHz polarimetric radar system developed hy the Microwave Remote Sensing Lahoratory, MIRSL [1]. Figure 1 contains a system block diagram and some system specifications. Several remote sensing applications were studied and a comparison of the coherent and noncoherent techniques for determining the Mueller matrix of a target was conducted. Polarimetric observations of foliage and various types of fallen snow were also made.

The current configuration of the 95 GHz radar system permits polarimetric measurements to he made simultaneously using coherent and noncoherent techniques. The following three features make this possible: (1) a low phase noise source, (2) a ferrite polarization switch, and (3) an adjustable quarter-wave plate.

Coherent measurement of the Mueller matrix requires a system capable of measuring the complex scattering matrix of a scene. The Mueller matrix is a square matrix comprised of 16 real numbers that completely characterize the transformation between the incident and scattered fields hy the target. The measurement of the scattering matrix requires rapid switching of the two orthogonal transmitted polarizations to prevent the scene from decorrelating. A signal source with low phase noise is also required for coherent operation to prevent corruption of the scattering matrix measurement due to phase fluctuations hy the transmit source.

Noncoherent measurement of the Mueller matrix requires the transmission of four polarizations, hut we usually use six polarizations to reduce measurement errors. There are no time requirements in the switching hetween transmit polarizations if the scene heing observed remains stationary in the mean for the duration of the measurement. The combination of the ferrite polarization and a quarter-wave plate is used to achieve vertical, horizontal, +45 linear, -45 linear, right hand circular, and left hand circular polarizations. During the Summer and the Fall of 1991 simultaneous coherent and noncoherent polarimetric measurements were made on several species of trees. Figure 2 contains polarization signatures of a specimen of the Weeping Willow species. Figure 2a was calculated using the noncoherent measurement technique. Figures 2b-d utilized the coherent technique. These measurements demonstrate experimentally that the proper use of both measurement techniques leads to equivalent results[2].

The Winter of 1991-92 marked the start of a measurement campaign on fallen snow with the 95 GHz radar. The radar was mounted on a gantry on the roof top of a 30 meter high building on the University of Massachusetts campus. This vantage point provided an unobstructed view of a flat field. Incidence angles between the radar pointing direction and the flat surface ranged from 60 to 80 degrees, and 25 degrees as shown in Figure 3. In-situ measurements of the percent water content were taken coincidentally with the radar measurements.

Several snow types were encountered during this measurement campaign. The snowcover types studied can be grouped into two broad categories. The first snow type consisted of nearly spherical crystals which led to the assumption that the snowcover can be considered an isotropic volume scatterer. The scattering behavior of this class of snowcover was observed to be a function of incidence angle such that σ_{vv} became greater than σ_{hh} as incidence angle increases. To account for this behavior a model for the Mueller Matrix was developed which assumes that the snow contains scatterers that are insensitive to the orientation of the incident polarization. A simplified model of the Mueller matrix consisting of only two parameters was developed which allows the determination of the Mueller matrix using only co- and cross-polarized power measurements [3]. Figure 4 shows the polarization signatures for this isotropic snowcover for different incidence angles.

A second catagory of snowcover consisted of stellar dendrites, needles, columns, or plates. These crystal types are nonspherical and are likely to exhibit some anisotropic behavior due to their preferred fall orientation[4]. This type of snowcover does not exhibit any significant preference for σ_{vv} over σ_{hh} as incidence angle increases. The preferred fall orientation of the snow crystals gives rise to a large imaginary part in the covariance of the co-polarized scattering coefficients, S_{vv} and S_{hh} . This indicates a significant phase shift

2

2

ا ز

between S_{vv} and S_{hh} and is due to either differential scattering or transmission through the snowpack. The anisotropic scattering behavior occurs for incidence angles greater than 50 degrees. Figure 5 shows the polarization signatures for incidence angles of 25 and 80 degrees. The data in figure 5a and 5b was collected the morning following a snowfall event the previous night. The snow pack consisted of 7.5 cm of dry, low-density snow comprised of nonspherical crystals. The phase shift between S_{vv} and S_{hh} introduces a twist in the polarization signature that can be seen in the 80 degree data. There is no significant phase shift seen in the 25 degree data. Figure 5c shows 80 degree data for the same snowfall event measured later in the day. The snowpack had melted from the bottom to a depth of 3.5 cm with the top layer consisting of the dry low density snow. The anistropic scattering behavior is still visible but to a lesser degree. This suggests that the magnitude of the imaginary part of the covariance of S_{vv} and S_{hh} is a function of the snowpack depth for this snow type.

The following items were accomplished during the two year period of this proposal.

- 1. The 95 GHz radar was configured into a unique system capable of simultaneously making coherent and incoherent Mueller matrix measurements.
- 2. The equivalency of the coherent and incoherent measurement technique was demonstrated. The advantages and disadvantages of both methods were explored.
- 3. The polarimetric properties of various foliage targets were characterized. These included the Weeping Willow, the Sugar Maple, and the White Pine trees species.
- 4. The polarimetric properties of various snowcover types were characterized.
- 5. Mueller matrix models for wet and dry snow were developed.

References

- [1] P.M. Langlois, "Design and Calibration of a 95GHz Coherent Polarimeter," M.S. Thesis, University of Massachusetts, Amherst, MA, 1991.
- [2] P.S. Chang, J.B. Mead, R.E. McIntosh, "A Comparison of Coherent and Noncoherent Polarimetric Measurement Techniques at Millimeter Wavelengths", in preparation.
- [3] J. Mead, P. Chang, S. Lohmeier, P. Langlois, and R. McIntosh, "Polarimetric Observation and Theory of Millimeter-wave Backscatter from Snowcover", accepted for publication in IEEE Trans. on Ant. Prop.
- [4] H.R. Proppacher, J. D. Klett, "Microphysics of Clouds and Precipitation", D. Reidel Co., Boston, 1980, pp. 334-344.
- [5] J. Mead and R. McIntosh, "Pulsed Polarimetric Millimeter-wave Radars that Utilize Extended Interaction Amplifier and Oscillator Tubes", presented at the National Telesystems Conference at Atlanta, Georgia in March 1991.
- [6] J. Mead and R. McIntosh, "Polarimetric Techniques and Measurements at 95 and 225 GHz", presented at the AGARD Conference on Target and Clutter Scattering at Ottawa, Canada in May 1991.
- [7] J. Mead, P. Langlois, P. Chang, and R. McIntosh, "Polarimetric Scattering from National Surfaces at 225 GHz", IEEE Trans. Ant. Prop., vol. 39, Sept. 1991, pp.1405-1411.



Transmitter

Source Frequenc Extended Interaction Amplifier

Modulation Pulse

Peak Power 1.5 kW

Maximum PRF 20 KHz

Pulsewidth 50-2000 nS

Receiver

Dynamic Range	75 dB
Noise Figure	9 dB Single Sideband
Noise Floor	–101 dBm @ 20 MHz

Antennas

.7° Beamwidth

12" lens

Figure 1:

(a) 95 GHz radar block diagram(b) 95 GHz radar system specifications

6POL_TIBIB CO-POLARIZED NORMHLIZED J .5 .5 -90 -90 -45 0 ¢ +45 +45 +90 +90 -45 0 T +45 (a)

V/H_TIBIB CO-POLARIZED



(b)

45/-45_T1B1B CO-POLARIZED

NORMALIZED O



(c)





Figure 2:

Polarization signatures of a willow tree

- (a) noncoherent processing
- (b)-(d) coherent processing
 - (b) vertical/horizontal polarizations
 - (c) +45 linear/-45 linear polarizations
 - (d) right hand circular/left hand circular polarizations



1

Figure 3: Geometry of snow measurement site





Co - Polarized Signature



Co - Polarized Signature

Scientific Personnel Supported by This Project and Degrees Awarded During This Reporting Period

. · . · .

Robert E. McIntosh, Professor James B. Mead, Senior Research Fellow Philip M. Langlois, awarded M.S. degree, May, 1991 Paul S. Chang, Ph.D. Candidate Stephen Fraiser, Ph.D. Candidate Stephen P. Lohmeier, awarded M.S. degree, February, 1992 Geoffrey Hopcraft, Ph.D. Candidate