Radar Systems and
Remote Sensing Laboratory



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# FINAL REPORT ON GRANT NAG 5-271

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This grant was to study the sources of scattering in vegetation and other surfaces and objects. We built a special radar, SOURCESCAT, that could resolve a cylindrical volume 18 cm in diameter and 11 cm long. This system provided the first really fine-resolution measurements of radar backscatter from vegetation. The original system was at 3-cm wavelength, and later a 6-cm existing system was modified to have the same geometric characteristics. The measurements showed that many of the assumptions used previously in modeling vegetation backscatter were false. They allowed us to specify which parts of different plants contribute the most to both scattering and attenuation of the radar signal.

Vegetation studied included various field crops, prairie grass, and various trees. Major differences were found in the roles of leaves, branches, stems, and trunks for different species. Papers were presented and published detailing the various findings on natural vegetation.

An artificial tree provided by the University of Texas was studied in the laboratory using these systems. The most significant findings were that the average radar volume scattering coefficient is independent of azimuth, and that slanting of the polarization vector can give useful information not available with ordinary vertical and horizontal polarization. A paper describing these results is ready for submittal.

Because the details of all of the measurements have been published in the literature, these details are not listed here.

A model for scattering from a single leaf was part of one of the Ph.D. dissertations resulting from this grant. This model, for the first time, took into account the presence of veins in leaves. The pattern of scatter from a leaf was shown quite different from that for which the veins are ignored.
The project resulted in two Ph.D. dissertations and two masters degree projects.

A list of publications and presentations resulting from this project is attached.

LIST OF PUBLICATIONS

## Refereed Journal Publications


Zoughi, R., R. K. Moore, F. T. Ulaby, L. K. Wu & A. Afifi, "Determination of backscattering sources in surface type targets," International Journal of Remote Sensing, vol. 6, no. 2, pp. 285-297, February 1985.

Wu, L. K., R. K. Moore, R. Zoughi, A. Afifi & F. T. Ulaby, "Preliminary results on the determination of the sources of scattering from vegetation canopies at 10 GHz. I: Corn and milo," International Journal of Remote Sensing, vol. 6, no. 2, pp. 299-313, February 1985.

Wu, L. K., R. K. Moore & R. Zoughi, "Sources of scattering from vegetation canopies at 10 GHz," IEEE Transactions on Geoscience and Remote Sensing, vol. GE-23, no. 5, pp. 737-745, September 1985.

Zoughi, R., L. K. Wu & R. K. Moore, "SOURCESCAT: A very-fine-resolution radar scatterometer," Microwave Journal, vol. 28, no. 11, pp. 183-196, November 1985.

Zoughi, R., L. K. Wu & R. K. Moore, "Identification of major backscattering sources in trees and shrubs at 10 GHz," Remote Sensing of Environment, vol. 19, no. 3, pp. 269-290, June 1986.

Zoughi, R. J. Bredow & R. K. Moore, "Evaluation and comparison of dominant backscattering sources in two treatments of tall grass prairie at 10 GHz," Remote Sensing of Environment, vol. 22, no. 2, pp. 395-412, August 1987.

Zoughi, R., J. Bredow, S. Osman & R. K. Moore, "Fine resolution signature of coniferous and deciduous trees at C-band," accepted for publication in International Journal of Remote Sensing.

Moore, R. K., M. S. Osman & R. Zoughi, "Measurements of radar backscatter from an artificial tree: An indication of azimuthal variations and polarization sensitivity of trees," in preparation.

## Technical Reports and Memoranda

Zoughi, R., L. K. Wu & R. K. Moore, "SOURCESCAT: A very-fine-resolution radar scatterometer," RSL TR 5870-1, December 1984.

Zoughi, R., L. K. Wu & R. K. Moore, "Determination of backscattering sources in tall prairie grass of the Konza Prairie at 10 GHz," RSL TR 5870-2, March 1985.

Wu, L. K., R. K. Moore & F. T. Ulaby, "Focusing the parabolic antenna," RSL TM 5870-1, September 1983.

Boberg, D., "A Hewlett-Packard based system for digital recording of spectrum analyzer traces," RSL TM 5870-2, March 1985.

Zoughi, R., L. K. Wu & R. K. Moore, "Identification of major backscattering sources in pine and pin oak trees at 10 GHz: A preliminary experiment," RSL TM 5870-3, September 1983.

Zoughi, R., J. Bredow & R. K. Moore, "Determination of primary contributors to the backscatter in two treatments of tall prairie grass at X-band," RSL TR 5870-4, August 1986.

## Presentations

Wu, L. K., R. Zoughi, R. K. Moore, A. Afifi & F. T. Ulaby, "Measurements of the sources of scatter from vegetation," presented at the URSI Specialist Symposium on Microwave Signatures in Remote Sensing, Toulouse, France, 16-20 January 1984.

Zoughi, R., L. K. Wu, R. K. Moore, A. Afifi & F. T. Ulaby, "Determination of backscattering sources in surface type targets," presented at the URSI Specialist Symposium on Microwave Signatures in Remote Sensing, Toulouse, France, 16-20 January 1984.

Zoughi, R., L. K. Wu, R. K. Moore, A. Afifi & F. T. Ulaby, "Backscattering sources in vegetation canopies and various other targets," presented at the second annual meeting of the NASA Fundamental Research on Radiation and Atmospheric Effects Characterization, Ft. Collins, Colorado, February 1984.

Zoughi, R., L. K. Wu & R. K. Moore, "Determination of backscattering sources in various targets," presented at the third annual meeting of the NASA Fundamental Research on Radiation and Atmospheric Effects Characterization, Massachusetts Institute of Technology, Boston, Massachusetts, 29-31 January 1985.

Zoughi, R., L. K. Wu & R. K. Moore, "Determination of backscatter sources in tall prairie grass of the Konza Prairie at 10 GHz," presented at the North American Radio Science meeting and International IEEE/AP-S Symposium, Vancouver, Canada, 17-21 June 1985.

Zoughi, R., L. K. Wu & R. K. Moore, "Identification of primary contributors to the backscatter from pine, pin oak, black walnut, American sycamore, sugar maple, and creeping juniper at 10 GHz," presented at IGARSS'85, Amherst, Massachusetts, 7-9 October 1985.

Zoughi, R., L. K. Wu, J. Bredow & R. K. Moore, "Primary contributors to the radar scattering in vegetation canopies and other targets at X-band," presented at the fourth annual meeting of the NASA Remote Sensing Science Research Program (SRAEC), La Jolla, California, 10-13 February 1986.

Zoughi, R., J. Bredow & R. K. Moore, "Fine-resolution 10 GHz radar signature of four components of an urban scene: Lawn grass, concrete walkway, asphalt pavement, and street curb," presented at the International IEEE/AP-S Symposium and National Radio Science Meeting, Philadelphia, Pennsylvania, 9-13 June 1986.

Bredow, J., R. Zoughi & R. K. Moore, "Contributors to the backscatter in potato, milo, and alfalfa at X-band," presented at IGARSS'86, Zurich, Switzerland, 8-12 September 1986.

Zoughi, R., J. Bredow & R. K. Moore, Radar backscatter and attenuation characterisitcs of tall grass at X-band," presented at the URSI International Symposium on Mocrowave Signatures in Remote Sensing, Gothenburg, Sweden, 19-22 January 1987.

Pitts, D. E., G. D. Badhwar, E. Reyna, R. Zoughi, L. K. Wu & R. K. Moore, "Estimation of X-band scattering properties of tree components," presented at IGARSS'87, Ann Arbor, Michigan, 18-21 May 1987.

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