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ACTIVE AND PASSIVE REMOTE SENSING OF ICE(U)
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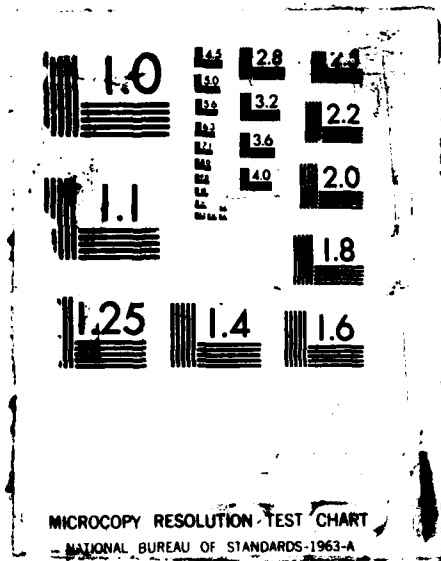
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SEMI-ANNUAL REPORT

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prepared by

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ACTIVE AND PASSIVE REMOTE SENSING OF ICE

Principal Investigator: Jin Au Kong

SEMI-ANNUAL PROGRESS REPORT

Under the sponsorship of the ONR contract N00014-83-K-0258, we have published 2 books, 41 journal and conference papers and 10 student theses.

A systematic approach for the identification of terrain media is developed using the optimum polarimetric classifier. The covariance matrices for various terrain cover are computed from theoretical models of random medium by evaluating the full polarimetric scattering matrix elements. The optimal classification scheme makes use of a quadratic distance measure and is currently applied to classify a vegetation canopy consisting of both trees and grass. Experimentally measured data are used to validate the classification scheme. Theoretical probability of classification error using the full polarimetric matrix is compared with classification based on single features which include the phase difference between the VV and HH polarization returns. It is shown that the full polarimetric results are optimal and provide better classification performance than single feature measurements. The application of this classification scheme to sea ice will be explored.

> We have studied ~~the~~ volume scattering effects of snow-covered sea ice with a three-layer random medium model for microwave remote sensing. ~~The~~ strong fluctuation theory and ~~the~~ bilocal approximation are applied to calculate the effective permittivities for snow and sea ice. ~~The~~ wave scattering theory, in conjunction with the distorted Born approximation, is then used to compute bistatic coefficients and backscattering cross sections. Theoretical results are illustrated by matching experimental data for dry snow-covered thick first-year sea ice at Point Barrow. The radar backscattering cross sections are seen to increase with snow cover for snow-covered sea ice, due to the increased scattering effects in the snow layer. The results derived can also be applied to the passive remote sensing by calculating the emissivity from the bistatic scattering coefficients.



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We have also derived a general mixing formula for discrete scatterers immersed in a host medium. The inclusion particles are assumed to be ellipsoidal. The electric field inside the scatterers is determined by quasistatic analysis, assuming the diameter of the inclusion particles to be much smaller than the wavelength. The results are applicable to general multiphase mixtures, and the scattering ellipsoids of the different phases can have different sizes and arbitrary ellipticity distribution and axis orientation, i.e., the mixture may be isotropic or anisotropic. The resulting mixing formula is nonlinear and implicit for the effective complex dielectric constant, because the approach in calculating the internal field of scatterers is self-consistent. Still, the form is especially suitable for iterative solution. The formula contains a quantity called the apparent permittivity, and with different choices of this quantity, the result leads to the generalized Lorentz - Lorenz formula, the generalized Polder - van Santen formula, and the generalized coherent potential - quasicrystalline approximation formula. Finally, the results are applied to calculating the complex effective permittivity of snow and sea ice.

The Mueller matrix and polarization covariance matrix are described for polarimetric radar systems. The clutter is modelled by a layer of random permittivity, described by a three-dimensional correlation function, with variance, and horizontal and vertical correlation lengths. This model is applied, using the wave theory with Born approximations carried to the second order, to find the backscattering elements of the polarimetric matrices. It is found that 8 out of 16 elements of the Mueller matrix are identically zero, corresponding to a covariance matrix with four zero elements. Theoretical predictions are matched with experimental data for vegetation fields.

The study of the strong fluctuation theory for a bounded layer of random discrete scatterers, are extended to include high-order co-polarized and cross-polarized second moments. The backscattering cross sections per unit area are calculated by including the mutual coherence of the fields due to the coincidental ray paths and that due to the opposite ray paths which are corresponding to the ladder and cross terms in the Feynman diagrammatic representation. It is proved that the contributions from ladder and cross terms for co-polarized backscattering cross sections are the same, while the contributions for the cross-polarized ones are of the same order. The bistatic scattering coefficients in the second-order approximation for both the ladder and cross terms are also obtained. The

enhancement in the backscattering direction can be attributed to the contributions from the cross terms.

we → We have derived the dyadic Green's function for a two-layer anisotropic medium. The Born approximation is used to calculate the scattered fields. With a specified correlation function for the randomness of the dielectric constant, the backscattering cross sections are evaluated. The analytic expressions for backscattering coefficients are shown to include depolarization effects in the single-scattering approximation. It is also shown that the backscattering cross section (per unit area) of horizontal polarization can be greater than that of vertical polarization even in the case of half-space. The bistatic scattering coefficients are first calculated and then integrated over the upper hemisphere to be subtracted from unity, in order to obtain the emissivity. The principle of reciprocity is then invoked to calculate the brightness temperatures. It is shown that both the absorptive and randomly fluctuating properties of the anisotropic medium affect the behavior of the resulting brightness temperatures both in theory and in actual controlled field measurements. The active and passive results are favorably matched with the experimental data obtained from the first-year and the multiyear sea ice as well as from the corn stalks with detailed ground-truth information.

Electromagnetic wave propagation and scattering in an anisotropic random medium *u.s.* has been examined with Dyson equation for the mean field, ^{the} which is solved by bilocal and nonlinear approximations and with Bethe-Salpeter equation for the correlation of field, *4* was derived and solved by ladder approximation. The effective propagation constants are calculated for the four characteristic waves associated with the coherent vector fields propagating in an anisotropic random medium layer, which are the ordinary and extraordinary waves with upward and downward propagating vectors. The z-component of the effective propagation constant of the upward propagating wave is different from the negative of that of the downward propagating wave, not only for the extraordinary wave but also for the ordinary wave. This is due to the tilting of the optic axis which destroys the azimuthal symmetry.

Since both snow and ice exhibit volume scattering effects, we model the snow-covered ice fields by a three-layer random medium model with an isotropic layer to simulate snow, an anisotropic layer to simulate ice, and the bottom one being ground or water. The snow and ice are characterized by different dielectric constants and correlation functions. The theoretical results are illustrated for thick first-year sea ice covered by dry snow at Point Barrow and for artificial thin first-year sea ice covered by wet snow at CRREL. The radar backscattering cross sections are seen to increase with snow cover for snow-covered sea ice, because snow gives more scattering than ice. The results are also used to interpret experimental data obtained from field measurements.

PUBLICATIONS SPONSORED BY THE ONR CONTRACT:

PUBLICATIONS SINCE 1983:

Identification of Terrain Cover Using the Optimum Polarimetric Classifier (J. A. Kong, A. A. Swartz, H. A. Yueh, L. M. Novak, and R. T. Shin). *Journal of Electromagnetic Waves and Applications*, vol.1, no.4, 1987.

Polarimetric microwave remote sensing of anisotropic earth terrain with strong fluctuation theory (M. Borgeaud, J. A. Kong, and R. T. Shin), *IGARSS 87 and URSI Meeting*, University of Michigan, Ann Arbor, MI, May 18-21, 1987.

Theoretical models for active and passive microwave remote sensing of snow-covered sea ice (F. C. Lin, J. A. Kong, and R. T. Shin), *IGARSS 87 and URSI Meeting*, University of Michigan, Ann Arbor, MI, May 18-21, 1987.

Theoretical models for polarimetric radar clutter (M. Borgeaud, R. T. Shin, and J. A. Kong), *Journal of Electromagnetic Waves and Applications*, vol. 1, no. 1, pp. 73-89, 1987.

Electromagnetic Wave Theory (J. A. Kong), Wiley-Interscience, New York, 696 pages, 1986.

Microwave remote sensing of snow-covered sea ice (M. Borgeaud, J. A. Kong, and F. C. Lin), *1986 International Geoscience and Remote Sensing Symposium*, Zürich, Switzerland, 8-11, September, 1986.

Polarimetric radar clutter modeling with a two-layered anisotropic random medium (M. Borgeaud, J. A. Kong, and R. T. Shin), *International Union of Radio Science Commission F Open Symposium*, University of New Hampshire, Durham, New Hampshire, July 28-August 1, 1986.

Remote sensing of snow-covered sea ice (F. C. Lin and J. A. Kong), *International Union of Radio Science Commission F Open Symposium*, University of New Hampshire, Durham, New Hampshire, July 28-August 1, 1986.

Effective permittivity of dielectric mixtures (A. Sihvola and J. A. Kong), *International Union of Radio Science Commission F Open Symposium*, University of New Hampshire, Durham, New Hampshire, July 28-August 1, 1986.

Modified radiative transfer theory for a two-layer anisotropic random medium (J. K. Lee and J. A. Kong), *National Radio Science Meeting*, Philadelphia, Pennsylvania, June 9-13, 1986.

Theoretical modeling of polarimetric radar clutter (M. Borgeaud, R. T. Shin, and J. A. Kong), *National Radio Science Meeting*, Philadelphia, Pennsylvania, June 9-13, 1986.

Radar cross section prediction using a hybrid method (C. Lee and R. T. Shin), *National Radio Science Meeting*, Philadelphia, Pennsylvania, June 9-13, 1986.

Radar cross section prediction for coated perfect conductors with arbitrary geometries (S. W. Rogers and R. T. Shin), *National Radio Science Meeting*, Philadelphia, Pennsylvania, June 9-13, 1986.

Backscattering and propagation of radar pulses in earth terrain media (F. C. Lin, J. A. Kong, R. T. Shin, and Y. E. Yang), *IEEE IMTC/86 Meeting*, Boulder, Colorado, March 24-27, 1986.

Electromagnetic wave scattering in a two-layer anisotropic random medium (J. K. Lee and J. A. Kong), *J. Optical Society of America*, vol.2, no.12, 2171-2186, December 1985.

Theory of Microwave Remote Sensing (L. Tsang, J. A. Kong, and R. T. Shin), Wiley-Interscience, New York, 613 pages, 1985.

Thermal filamentation instability of millimeter waves in laboratory plasmas (M. C. Lee, J. A. Kong, and S. P. Kuo), *Conference Digest of the 10th International Conference on Infrared and Millimeter Waves*, Florida, December 9-13, 1985.

Saturation of cyclotron maser instability driven by an electron loss-cone distribution (S. P. Kuo and M. C. Lee), *Conference Digest of the 10th International Conference on Infrared and Millimeter Waves*, Florida, December 9-13, 1985.

Analysis of the harmonic gyrotron travelling wave amplifier (S. P. Kuo, S. C. Kuo, B. R. Cheo, and M. C. Lee), *Conference Digest of the 10th International Conference on Infrared and Millimeter Waves*, Florida, December 9-13, 1985.

Passive microwave remote sensing of an anisotropic random medium layer (J. K. Lee and J. A. Kong), *IEEE Trans on Geoscience and Remote Sensing*, vol. GE-23, no.6, 924-932, November 1985.

Active microwave remote sensing of an anisotropic random medium layer (J. K. Lee and J. A. Kong), *IEEE Trans on Geoscience and Remote Sensing*, vol. GE-23, no. 6, 910-923, November 1985

A model for the discrete spectrum of the resonant VLF waves (S. P. Kuo, M. C. Lee, and A. Wolfe), *Proceedings of the workshop on Hydromagnetic Waves in the earth's magnetosphere*, Columbia University, New York, Oct. 17-18, 1985.

Electromagnetic wave scattering by a two-layer anisotropic random medium, (J. K. Lee and J. A. Kong), *IGARSS 85 and URSI Meeting*, University of Massachusetts, Amherst, MA, October 7-9, 1985.

Strong fluctuation theory for scattering, attenuation, and transmission of microwave through snowfall (Y. Q. Jin and J. A. Kong), *IEEE Transactions on Geoscience and Remote Sensing*, vol. GE-23, No. 5, 754-760, September 1985.

Electromagnetic characterization of snow and ice for active and passive remote sensing (J. A. Kong), *AGU meeting*, San Francisco, CA, September 1985.

Strong fluctuation theory of random medium and applications in remote sensing (Y. Q. Jin and J. A. Kong), *International Symposium on Antennas and EM Theory (ISAE)*, Beijing, China, August 26-28, 1985.

Mean dyadic Green's function for a two-layer anisotropic random medium: nonlinear approximation to the Dyson equation (J. K. Lee and J. A. Kong), *International Symposium on Antennas and Propagation*, Kyoto, Japan, August 20-22, 1985.

Radar backscattering from snow-covered ice (F. C. Lin, J. K. Lee, J. A. Kong, and R. T. Shin), *Proceedings Snow Symposium V*, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, August 13-15, 1985.

Electromagnetic characterization of inhomogeneous media exhibiting volume scattering effects (J. A. Kong), *Workshop on Waves in Inhomogeneous Media*, Schlumberger Doll Research, Ridgefield, Connecticut, August 8-9, 1985.

Polar ionospheric irregularities and possible source mechanisms (M. C. Lee, J. Buchau, H. C. Carlson, Jr., J. A. Klobuchar, and E. J. Weber), *North American Radio Science Meeting and International IEEE/AP-S Symposium*, Vancouver, Canada, June 17-21, 1985.

Generation of E region density irregularities by thermal plasma instabilities (M. C. Lee and S. P. Kuo), *North American Radio Science Meeting and International IEEE/AP-S Symposium*, Vancouver, Canada, June 17-21, 1985.

Ionospheric modifications by HF heaters (M. C. Lee, J. A. Kong, H. C. Carlson, Jr., and S. P. Kuo), *Proceedings of the NATO AGARD Spring 1985 Electromagnetic Wave Propagation Panel Symposium on Propagation effects on military systems in the high latitude region*, Fairbanks, Alaska, June 3-7, 1985.

Ladder and cross terms in second-order distorted Born approximation (Y. Q. Jin and J. A. Kong), *J. Mathematical Physics*, vol. 26(5), 994-1011, May 1985.

Wave approach to brightness temperature from a bounded layer of random discrete scatterers (Y. Q. Jin), *Electromagnetics*, vol. 4, 323-341, 1984.

Scattering of electromagnetic waves from a randomly perturbed quasiperiodic surface (R. T. Shin and J. A. Kong), *Journal of Applied Physics*, vol. 56, 10-21, July 1984.

Microwave thermal emission of periodic surface (J. A. Kong, S. L. Lin, and S. L. Chuang), *IEEE Transactions on Geoscience and Remote Sensing*, vol. GE-22, 377-382, July 1984.

Active and passive microwave remote sensing of layered anisotropic random medium (J. K. Lee and J. A. Kong), *National Radio Science Meeting*, Boston, Massachusetts, June 25-28, 1984.

Modified radiative transfer equation in strong fluctuation approach (Y. Q. Jin and J. A. Kong), *National Radio Science Meeting*, Boston, Massachusetts, June 25-28, 1984.

Scattering of electromagnetic waves by a randomly perturbed quasi-periodic surface (R. T. Shin and J. A. Kong), *National Radio Science Meeting*, Boston, Massachusetts, June 25-28, 1984.

Wave scattering by a bounded layer of random discrete scatterers (Y. Q. Jin and J. A. Kong), *National Radio Science Meeting*, Boulder, Colorado, January 11-13, 1984.

Applied Electromagnetism (L. C. Shen and J. A. Kong), Brooks/Cole, California, 507 pages, 1983.

Dyadic Green's functions for layered anisotropic medium (J. K. Lee and J. A. Kong), *Electromagnetics*, vol.3, 111-130, 1983.

Theory of microwave remote sensing of dense medium (L. Tsang and J. A. Kong), *URSI Symposium*, San Francisco, 1983.

Scattering of electromagnetic waves from a half-space of densely distributed dielectric scatterers (L. Tsang and J. A. Kong), *IEEE/APS Symposium and URSI Meeting*, Houston, Texas, May 23-26, 1983.

Mie scattering of electromagnetic waves by precipitation (Y. Q. Jin and J. A. Kong), *Optical Society of America Topical Meeting on Optical Techniques for Remote Probing of the Atmosphere*, Lake Tahoe, Nevada, January 10-12, 1983.

Thermal microwave emission from a scattering medium with rough surfaces (R. Shin and J. A. Kong), *URSI Symposium*, Boulder, Colorado, January 5-7, 1983.

Remote sensing of soil moisture and vegetation (J. A. Kong, S. L. Lin, S. L. Chuang, and R. T. Shin), *URSI Symposium*, Boulder, Colorado, January 5-7, 1983.

RECENT TECHNICAL REPORTS:

Theoretical Models for Microwave Remote Sensing of Snow-Covered Sea Ice (F. C. Lin, J. A. Kong, and R. T. Shin), Technical Report No. EWT-RS-102-8705, MIT, 1987.

TE/TM decomposition of electromagnetic sources (I. V. Lindell), Technical Report No. EWT-RS-101-8610, MIT, 1986.

Radar backscattering from snow-covered ice (F. C. Lin, J. K. Lee, J. A. Kong, and R. T. Shin), Technical Report No. EWT-RS-80-8508, MIT, 1985.

Polarimetric radar clutter modeling with a two-layer anisotropic random medium (M. Borgeaud, J. A. Kong and R. T. Shin), Technical Report No. EWT-RS-94-8608, MIT, 1986.

Dielectric properties of geophysical media (A. Sihvola and J. A. Kong), Technical Report No. EWT-RS-96-8608, MIT, 1986.

Effective permittivity of dielectric mixtures (A. Sihvola and J. A. Kong), Technical Report No. EWT-RS-97-8608, MIT, 1986.

Theoretical Models for Polarimetric Radar Clutter (M. Borgeaud, R. T. Shin and J. A. Kong), Technical Report No. EWT-RS-99-8608, MIT, 1986.

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