26.0 Electromagnetic Wave Theory and Applications

Academic and Research Staff

Prof. J.A. Kong, Prof. I.V. Lindell, Prof. C.H. Chen, Dr. M.C. Lee, Dr. T.M. Habashy, Dr. R.T. Shin, Q. Gu, A. Sihvola, Z. Li, N. Lu

Graduate Students

K. Adler, R. Basch, M. Borgeaud, D. Gaylor, K. Groves, H.C. Han, J.F. Kiang, R. Kim, C.F. Lee, F.C. Lin, S.V. Nghiem, S.Y. Poh, D. Rennie, S. Rogers, A. Schwartz, L. Sichan, M.J. Tsuk, A. Tulintseff, T.E. Yang, N. Yamashita, H.A. Yueh,

26.1 Electromagnetic Waves in Multilayer Media

Joint Services Electronics Program (Contract DAAL03-86-K-0002)

Jin A. Kong, Ann Tulintseff, Ying E. Yang, Herng A. Yueh

We have generalized the transient analysis method for the time-domain bi-directional coupling of a pair of nonuniformly couple dispersionless transmission lines. The transmission line equations are decoupled using the method of characteristics and the equations are solved iteratively. A new set of variables is introduced so that the transformed equations are simpler and both the codirectional and contradirectional coupling can be easily calculated. By virtue of the formulation, causuality is preserved and each higher order term in the perturbational series can be interpreted as a partial reflection along the lines due to nonuniform coupling. Since, in practice, the terminations for interconnecting lines in integrated circuits can be linear or nonlinear, we shall investigate both cases. Solutions accurate to the first order in spatial derivatives of the coupling coefficients, which is analytically managable, are presented. In the cases with linear loads the unit-step response can be obtained in closed-form to the first order, and arbitrary excitations can be handled by convolution. Numerical integration for the cases with nonlinear loads is also shown to be more efficient than integration based on the original coupled partial differential equations.

Vias in multilayered integrated circuits are treated like transmission lines with loadings where they encounter holes in ground planes separating different layers. We have modeled a ground plane with a hole and a circular conductor at the center of the hole as a radial waveguide, which in turn is connected to the via, another section of transmission line. Thus, by computing the characteristic impedance of the former, we have derived the equivalent load impedance of the via hole. The load impedance is one important parameter in calculating the transient propagation along vias.

We have investigated reliable models for many integrated circuits which contain strip lines at different heights that run parallel or perpendicular to each other. First the capacitances associated with the two offset parallel strips at different heights between ground planes are computed using the conformal mapping approach. As an extension, a simplifield circuit of parallel-plate lines with transverse ridges is introduced to model two parallel strips with perpendicularly crossing strips on top. We treated it as a distributed circuit consisting of transmission lines segments with periodical capacitive loading. In order to calculate the coupling between two lines, we reduced this structure to two equivalent single line circuits, viz. the even mode and the odd mode circuits. The Laplace transform approach can be easily applied to find out the transient response. The numerical computation carried out for various environments shows that the crossing strips will cause serious trouble for signals with a rise time of less than 50 ps to propagate along distances of 2 cm or longer.

26.2 Remote Sensing with Electromagnetic Waves

National Science Foundation (Grant ECS 85-04381)

Jin A. Kong, Robert T. Shin, Freeman C. Lin

The study of electromagnetic field intensity propagation in a continuous random medium has been of great interest in the areas of microwave remote sensing of earth terrain media. We have included both multiple scattering and spatial coherence effects in solving the problem of the field intensity propagation in an anistropic random medium layer. The modified radiative transfer (MRT) equations which describe propagation and scattering of the electromagnetic field intensity in a layered anistropic random medium are derived from the Bethe-Salpeter equation with the ladder approximation and the Dyson equations with the nonlinear approximation. The Dyson equation and the Bethe-Salpeter equation are the exact integrodifferential equations that the first and second moments of the field propagating in a continuous random medium must satisfy, respectively. Backscattering enhancement is observed due to the spatial coherence effects between upward and downward propagating waves. It also occurs for the half-space case because of coupling between ordinary and extraordinary waves in an anisotropic random medium layer. The depolarization effect is predicted in the first-order renomalization approximation to the MRT equations.

In the study of discrimination and classification of earth terrain utilizing polarimetric scattering properties, we use a two-layer anisotropic random medium model to characterize earth terrain media such as vegetation, forest, snow and ice which exhibit stron volume scattering effects and anisotropic behavior. The random medium has a background permittivity and its randomness is characterized by a three-dimensional correlation function with variance and correlation lengths. The polarimetric properties of the backscattering coefficients are found to include depolarization effects in the single-scattering approximation in contrast with the isotropic random medium which does not exhibit cross-polarization terms in the first order backscattering. The Mueller matrix can be transformed to a covariance matrix which is also useful in characterizing the polarimetric scattering properties. Physical interpretations will be given for the properties of the covariance matrix elements.

A general mixing formula is derived 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 quanitity called the apparent permittivity, and with different choices of this quantity the result leads to the generalized Lorenz-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 combined rough surface and volume scattering effects have been studies with the radiative transfer theory. The rough surface scattering effect has been observed to be important for both the active and the passive remote sensing of earth terrain. This is particularly important in the remote sensing of vegetation and soil moisture because most crop fields have uneven surfaces which are quasiperiodic in nature. The scattering of electomagnetic waves from a periodic dielectric interface will be studied by using the extended boundary condition approach and the Rayleigh method. We propose to first solve for the scattering field amplitudes and obtain the emissivity by using the principles of reciprocity and energy conservation. Because of the exact nature of the theory, reciprocity relations and energy conservation will be shown to be satisfied exactly, and the unambiguous emissivity of a periodic dielectric rough surface will be obtained.

Surface-based radiometer data, helicopter-born data, and satellite data taken from either a controlled field, the Arctic region or the Antarctic region have indicated that the sea ice signatures are modified by snow cover due to the volume scattering effects. In order to realistically model the snow-cover sea ice, the three-layer random medium has been developed where the snow layer is modeled by an isotropic random medium and the ice layer by an anisotropic random medium. In snow, the fluctuation of the permittivity and the physical sizes of the granular ice particles are characterized by a variance and two correlation lengths. In ice, the anisotropic effect is attributed to the elongated structures and the preferred alignment of the air bubbles, brine inclusions and other inhomogeneities. Two variances are required to characterize the fluctuations of the permittivities along or perpendicular to the tilted optical axis. The physical sizes of those scattering elements are also described by two correlation lengths. All theoretical results match favorably well with the experimental data for thick first-year and multiyear sea ice with and without the cover of dry and wet snow.

Polarimetric radar backscattering from anisotropic earth terrain such as snow-covered ice fields and vegetation fields with row structures provides a challenging modeling program from the electromagnetic point of view. Snow, ice and vegetation all exhibit volume scattering effects. For snow, the scattering is caused by granular ice particles; for ice, the air bubbles and brine inclusions; and for vegetation, the leaves. the trunks and other inhomogeneities. We model earth terrain covers as random media characterized by brine inclusions and vegetation with row structures, the random medium is assumed to be anisotropic. A three-layer model is used to simulate a vegetation field or a snow-covered ice field with the top layer being ice or trunks, and the bottom layer being sea water or ground.

In order to take into account the polarimetric information, we related the backscattered Stokes vector to the incident Stokes vector by the Mueller matrix, which completely describes the scattering (in amplitude, phase, frequency, and polarization) from the three-layer anisotropic random medium. The Mueller matrix properties, as well as the covariance matrix issues, relevant to the radar backscattering are examined. It is shown that for an isotropic medium, eight of the 16 elements of the Mueller matrix are identically zero. However, the tilted anisotropic permittivity of the middle layer (sea ice or trunks) generates a full non zero Mueller matrix.

26.3 Remote Sensing of Earth Terrain

National Aeronautics and Space Administration/Goddard Space Flight Center (Contract NAG5-270)

Min C. Lee, Freeman C. Lin

26.4 Remote Sensing of Upper Atmosphere

National Aeronautics and Space Administration Goddard Space Flight Center (Contract NAG5-270)

Min C. Lee, Jin A. Kong, S.V. Nghiem, K.M. Groves, H.C. Han

26.5 Microwave Emission and Scattering

National Aeronautics and Space Administration Goddard Space Flight Center (Contract NAG5-725)

Min C. Lee, Freeman C. Lin

We have developed a fully polarimetric radar model for the purpose of evaluating the radar backscatter from several types of earth terrain such as vegetation, tree canopy and meadow. The Mueller matrix and polarization covariance matrix are described for polarimetric radar systems. The evaluation of full polarimetric backscattering coefficients is useful in the design and analysis of optimal radar detection and classification schemes and in creating randomly generated radar returns for Monte-Carlo simulations. For many types of earth terrain (such as vegetation), the scattering effects due to medium inhomogeneities play an important role in determination of radar backscattering coefficients. The volume scattering properties of a medium can be modeled in two ways: random fluctuation of permittivity (random medium approach), and discrete particles imbedded in a homogeneous medium (discrete scatter approach). We have used the two-layer random medium model to characterize the earth terrain and calculate the Mueller and covariance matrices in the backscattering direction. The earth terrain 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 that accounts for depolarization effects, to find the backscattering elements of the polarimetric matrices. It is found that eight of 16 elements of the Mueller matrix are identically zero, corresponding to a covariance matrix with four zero elements. The Mueller and covariance matrices are illustrated by comparing with experimental data.

The strong fluctuation theory with the distorted Born approximation has been applied to the solution of the radar backscattering coefficients for three-layer configurations such as vegetation canopies and snow-covered ice fields. The top layer is considered to be isotropic (snow or leaves) with a spherical correlation function, the middle layer is assumed to be anisotropic (ice or trunks) with an exponentially decaying correlation function, and the bottom layer is a homogeneous medium (sea water or ground). Furthermore, the permittivity of the middle layer is first described as "discrete", constituted by a background permittivity being either isotropic or anisotropic and a scatterer permittivity being isotropic. Associated with the discrete model, a fractional volume density represents the amount of scatterers. The discrete random medium model is then mapped onto a continuous random medium to obtain a permittivity function depending upon position. In order to take into account the polarimetric information, we related the backscattered Stokes vector to the incident Stokes vector by the Mueller matrix, which completely describes the scattering (in amplitude, phase, frequency and polarization) from the three-layer random medium. The Mueller matrix properties, as well as the covariance matrix issues, relevant to the radar backscattering is examined. It is shown that for an isotropic medium, eight of the 16 elements of the Mueller matrix are identically zero. However, the tilted anisotropic permittivity of the middle layer (sea or trunks) generates a full nonzero Mueller matrix.

Several mechanisms have been investigated to explain the observed spectral broadening of injected VLF waves. They can be generally grouped into two categories: 1) nonlinear scattering of VLF signals by ionospheric density fluctuations; and 2) excitation of electrostatic waves by the injected VLF waves. In the first category, the nonlinear mode conversion of VLF waves into lower hybrid waves occurs when the VLF signals are scattered off the ionospheric density fluctuations. An elliptically polarized wave mode with a large wave number results from this process. The spectral broadening of VLF waves may, therefore, be attributed to the Doppler effect sensed by the airborne detector. The second category involves a different mechanism exciting electrostatic waves (lower hybrid waves, low frequency quasi-modes, etc.) by the injected VLF waves. This process tends to produce a spectrally broadened transmitted pulse with peaks at a discrete set of frequencies on both sides of the nominal carrier frequency.

Continued effort has been made on the studies of non linear EM wave interactions with the upper atmosphere. Three problems have been examined: 1) parametric excitation of whistler waves by an HF heater; 2) the resonant ionospheric heating at the electron gyrofrequency; and 3) enhanced ionspheric modifications by the combined operation of HF and VLF heaters. We studied the parametric excitation of whistler waves as the possible mechanism of VLF wave generation by an HF heater. It is found that the threshold of the instability is lower than the peak amplitude of the electric field 3 v/m available with the Tromso heating facility if the effect of swelling on the field amplitude is taken into account. The thermal filimentation instability of heater waves that generates the high frequency sideband modes and the zero-frequency modes (associated with magnetic and density fluctuations) can also occur during the resonant ionospheric heating at the electron gyrofrequency. The instability threshold is mainly imposed by the electron cyclotron damping, while that is determined by the off-resonance (i.e, the detuning) effect if the heater wave frequency is not very close to the electron gyrofrequency.Enhanced ionospheric modifications by the combined operation of HF and VLF heaters have been analyzed. Intense airglow and height distribution of plasma lines can be expected.

Three natural processes occurring in the upper atmosphere have been theorectically analyzed. They are: 1) aura electrojet-induced ionospheric irregularities; 2) geomagnetic field perturbation due to the stimulated scattering of lower hybrid wave modes; and 3) spectral characteristics of geomagnetic VLF pulsations. The modification of the electron-neutral collision frequency due to the electron temperature perturbation in the electrojet can lead to a thermal instability causing the filamentation of auroral electrojet current and giving rise to purely growing magnetic field-aligned density irregularities in the E-region of the high-latitude ionosphere. Our preliminary analysis has shown that geomagnetic fluctuations can be caused by the stimulated scattering instability of lower hybrid waves that can be produced by particle precipitation and whistler waves. The energy spectrum of magnetospheric cavity modes is theoretically calculated showing sharp peaks at discrete frequencies in agreement with observations. Our theoretical model shows that only the discrete set of magnetospheric cavity eigenmodes can efficiently couple the perturbations excited on the boundary of the magnetosphere to the field-line resonant mode excited inside the inner turning point of the cavity eigenmodes.

We are studying a four-wave interaction process exciting ionospheric density fluctuation and geomagnetic fluctuation via the stimulated scattering of whistler wave-induced or particle precipitation-triggered lower hybrid waves. A low-frequency quasi-mode which is about half the wave length of the pump lower hybrid wave. We are currently comparing the theoretical predictions with some in-situ measurements made by orbiting satellites in the topside atmosphere.

The scattering and emission effects of earth terrain media are studied by the multi-layer random medium model for the active and passive microwave remote sensing. The snow-covered ice fields and forest are studied with a three-layer random medium model. The dyadic Green's functions are derived in the far field. With the Born approximation, the backscattering cross sections for copolarization and cross-polarization are calculated for active microwave remote sensing. For passive microwave remote sensing, the bistatic scattering coefficients are computed. Then, the principles of reciprocity and energy conservation are invoked to calculate emissivities.

26.6 Active and Passive Remote Sensing of Ice

U.S. Navy - Office of Naval Research (Contract N00014-83-K-0258)

Jin A. Kong, Robert T. Shin, Freeman C. Lin, Maurice Borgeaud

Geophysical media encountered in nature are generally mixtures of materials that exhibit different dielectric characteristics. In remote sensing applications, it is desirable to treat the microscopically complicated mixture as macroscopically homogeneous and characterize it by an effective permittivity. Many natural heteorgeneous media have been widely studied from this point of view. Examples are snow, lake ice, sea ice, soil, vegetation canopy. rocks and forests. One of the constituents in these mixtures is often water, which makes the dielectric properties sensitive to small variations in fractional component volumes, because the permittivity of water normally greatly differs from that of other components. This fact makes dry and wet snow dielectrically different, and also partly distinguishes the permittivity of one-year and multi-year sea ice to a great extent.

The dielectric mixtures have been analyzed by starting with the study of a two-phase mixture, where dielectric spheres of permittivity are embedded in a host material of permittivity, the analysis is extended to ellipsoids of arbitrary orientation and multiphase mixtures. The materials may be lossy, in which case their dielectric constants are complex numbers. This leads also to a complex effective permittivity for the mixture where the imaginary part stands for the absorption losses of the mixture. However, the scattering losses are not incorporated in the effective permittivity because the analysis is confined within the limits of the quasistatic approach taken. The result is, therefore, a low-frequency solution, its validity range being determined by the size of the constituent particles of the mixture and the wavelength of the operating frequency. Self-consistency is built through the so called "apparent permittivity" and the resulting formula for the effective permittivity is shown to reduce to previously obtained mixing formulas.

The correlation function for sea ice with brine inclusions is extracted from the photograph of the sea ice sample. The effective permittivity is derived by the strong fluctuation theory and bilocal approximation. The backscattering coefficients for active remote sensing and the brightness temperatures for passive remote sensing are calculated. The strong fluctuation theory will be further developed to arrive at the modified radiative transfer equations and to take into account the anisotropic effects. The strong fluctuation random medium theory will then be applied to the modelling of various earth media such as snow-ice and vegetation canopy.

The polarimetric radar model has been applied to study the ice fields. We have used the two-layer random medium model to characterize the ice fields and calculate the Mueller and covariance matrices in the backscattering direction. The ice layer has a background permittivity and its randomness is characterized by a three-dimensional correlation function with variance and correlation lengths. The radar backscattering coefficients are obtained by applying the first order Born approximation, which accounts for single scattering effects. The analytic expressions for backscattering coefficients are found to include depolarization effects in the single-scattering approximation, in contrast with the isotropic random medium which does not exhibit cross-polarization terms in the first order backscattering. We have transformed the Mueller matrix to a covariance matrix which is also useful in characterizing the polarimetric scattering properties. The Mueller and covariance matrices are illustrated by comparing with experimental data.

Experimental data taken from either a controlled field, the Arctic region, or the Antarctic region have indicated that the sea ice signatures are modified by snow cover due to the volume scattering effects. In the active and passive microwave remote sensing of snow-covered ice fields, the volume scattering effects are studied with a three-layer model as derived in the far field. With the Born approximation, the backscattering cross sections for copolarization and cross-polarization are calculated for active microwave remote sensing. The autocorrelation and cross-correlation functions are assumed to have a Gaussian and exponential form in the lateral and vertical direction, respectively. For passive microwave remote sensing, the bistatic scattering coefficients are computed. Then, the principles of reciprocity and energy conservation are invoked to calculate emissivities. Theoretical results are illustrated by matching the experimental data taken from dry and wet snow-covered sea ice.

The snow-covered sea ice is studied with a three-layer random medium model. The snow layer is modeled by an isotropic random medium to account for the volume scattering effect which is due to randomly distributed granular ice particles. The ice layer is modeled by an anisotropic random medium to account for the volume scattering which is due to brine inclusions, air bubbles, and other inhomogeneities. The dyadic Green's function for this three-layer model is derived in the far field. With the Born approximation the backscattering cross sections for copolarization with cross-polariztion are calculated for active microwave remote sensing. The autocorrelation with cross-correlation functions are assumed to have Gaussian and exponential form in the lateral and vertical directions, respectively. For passive microwave remote sensing, the bistatic scattering coefficients are computed. Then the principles of reciprocity and energy conservation are invoked to calculate emissivities. Theoretical results are illustrated by matching the experimental data taken from dry and wet snow-covered ice.

The three-layer random medium model for the snow-covered sea ice has been studied under the assumption of week fluctuations of the permitivities. However, there is a large contrast between the permittivities of air, ice, brine and water. Therefore, we have generalized the three-layer random medium model with the strong fluctuation theory to account for the large permittivity fluctuations in the snow-covered sea ice. The random permittivity fluctuation in the sea ice caused by the brine inclusions are characterized by a correlation function which can be extracted from the digitized photographs of a sea ice sample. The strong fluctuation theory and the bilocal approximation are used to derive the effective permittivities for snow and sea ice. The singularity of the dyadic Green's function is properly considered. The distorted Born approximation is then used to calculate the bistatic scattering coefficients.Theorectical results are illustrated by comparing with the experimental data for thick first-year sea ice covered by dry snow.

26.7 Time Domain Wave Propoagation in Circuits

U.S. Navy - Office of Naval Research (Contract N00014-86-K-0533)

Jin A. Kong, Ann Tulintseff, Michael J. Tsuk, Soon Y. Poh

26.8 Time Domain Electromagnetic Waves

U.S. Army - Research Office Durham (Contract DAAG29-85-K-0079)

Jin A. Kong, Ying E. Yang, Ann Tulintseff, Michael J. Tsuk

26.9 Wave Transmission and Coupling in Multilayered Media

International Business Machines, Inc.

Jin A. Kong, Soon Y. Poh, Qizheng Gu, Jean-Fu Kiang, Ying-Ching E. Yang

On the analysis of transient behavior of pulse propagation along conducting strips in multilayer dielectric media, we have: 1) modeled and calulated the impedance parameters and propagation characteristics for simple structures; 2) analyzed the transient response of signal transmission on strip lines with perpendicularly crossing strips geometry; 3) with periodical meshed ground plane; 4) generalized the method of characteristics for signal propagation on nonuniformly coupled transmission lines; and 5) studied the transient response of point and line sources excitation on two-layer media. We have also applied the technique of wave transmission matrices in periodic structures to examine transmission and reflection properties in striplines with meshed ground planes. A numerical Fourier inversion can then be done to obtain the time-domain response. Preliminary results support the previous conclusion.

In applying the method of moments to solving the EM scattering problems, it is necessary to solve a large matrix when the dimension for the scatterer is larger than several wavelengths. Tremendous amount of computer CPU time will be spent on solving the matrix equation. When only the far field properties such as scattering cross section is of interest, we can use the sparce matrix technique to reduce the amount of computation. Some algorithms are compared to solve the sparce matrix. The Gaussian elimination algorithm, Cholesky decomposition algorithm, several versions of conjugate gradient methods are used. the number of multiplications and divisions (flops) are counted for comparing the efficiency of these algorithms. The effect of the nonzero element positions to the efficiency is also studied by defining the clustering index.

Another way of incorporating the effect of complicated geometry is to use continuous line model while considering the coupling between parallel lines in multilayered integrated circuits to be uniform. In addition to the scheme that combines the method of characteristics and perturbational series to simplify the computation of the transient response from the coupled transmission line equations, new transformation for decoupling enables us to generalize this formulation to calculate the near-end and far-end crosstalks to very high accuracy, given arbitrary positional dependence for both capacitive and inductive coupling coeefficients.

A general method of analyzing the time-domain bi-directional coupling of a pair of nonuniformly coupled dispersionless transmission lines has been derived. The transmission line equations are decoupled using the method of characteristics and the equations are solved iteratively. In the cases with linear loads, the unit-step response can be obtained in closed-form to the first order approximation, and arbitrary excitations can be handled by convolution. General approximate solutions to the transient response on two identical, nonuniformly coupled transmission lines terminated with linear or nonlinear loads have been obtained through an iterative scheme. The iterative method is very useful when the coupling coefficients are slowly varying with position since the zeroth order or first order approximation would be sufficiently accurate yet much easier to calculate. Furthermore, with the help of newly devised special transformations, we have shown that both the codirectional coupling and contradirectional coupling of the problem with unit-step excitation and linear loads have closed form expressions up to the first order approximation. Arbitrary excitation can then be taken into account by convolution. This method is hence more efficient.As for nonlinear terminations, numerical integrations are performed along the characteristics. Examples have been given for both cases to illustrate the use of this method. Extension to problems in which the phase velocities of coupled lines are not equal, or where more than two coupled lines are involved is also under consideration.

26.10 Radar Scene Generation for Tactical Decision Aids

National Aeronautics and Space Administration/Goddard Space Flight Center (Contract NAG5-269)

Jin A. Kong, A. Swartz, Freeman C. Lin, Robert T. Shin

26.11 MMW Clutter Simulation Baseline Model

Simulation Technologies

Jin A. Kong, A. Swartz, Freeman C. Lin, Robert T. Shin

For millimeter wave (MMW) clutter simulation we have developed a multi-layer random medium model to study the volume scattering effects. The vegetation fields such as corn, alfalfa, soybeans, meadow, etc., are modeled by the two-layer isotropic random medium. The vegetation fields with row structures are modeled by the two-layer anisotropic random medium. The snow-covered ice fields and forests are modeled by a three-layer random medium in which an isotropic random medium is used to simulated the snow layer and the leaves and an anisotropic random medium to simulate the ice layer and the trunks. The dyadic Green's functions for these multi-layer models are derived in the far field. With the Born or distorted Born approximations, the backscattering cross sections for copolarization and cross-polarization are calculated for active microwave remote sensing.

For radar image simulation, a set of "efficient" and "user-friendly" FORTRAN programs has been generated to calculate the normalized, co-polarized and cross-polarized backscattering cross sections for the scattering geometry. The numerical results of these FORTRAN codes cover all polarizations within the freqency range of 1 GHz to 100 GHz for all angles of incidence and all angles of scattering.

The radiative transfer (RT) equations for a general layered structure have been implemented in our VAX 11/750 computers. Both the random medium model and the discrete scattering model have been used in the radiative transfer theoretical developments. Due to the wide applications of the radiative transfer theory, it is important to determine the limitation of such a theory, and, moreover, to determine the conditions under which the RT equations might follow from a general wave formalism. Under the assumption of far field interaction and incoherence among waves in different directions, RT equations have been derived from wave theory for an unbounded medium. The MRT theory that incorporates partial coherent effects has been developed by applying the nonlinear approximation to Dyson's equation together with the ladder approximation to the Bethe-Salpeter equation.

We have used the two-layer anisotropic medium model to characterize the clutter and calculate the Mueller and covariance matrices in the backscattering direction. The random medium has a background permittivity and its randomness is characterized by a three-dimensional correlation function with variance and correlation lengths. The polarimetric properties of the backscattering coefficients are studied by calculating the full Mueller matrix. The radar backscattering coefficients of a two-layer anisotropic random medium are obtained by applying the first order Borm approximation, which accounts for single scattering effects. The analytical expressions for backscattering coefficients are found to include depolarization effects in the single scattering approximation, in contrast with the isotropic random medium which does not exhibit cross-polarization terms in the first order backscattering. We have transformed the Mueller matrix to a covariance matrix which is also useful in characterizing the polarimetric scattering properties. Physical interpretations will be given for the properties of the covariance matrix elements.

Along with the development of theoretical models tailored for the active and passive remote sensing of earth terrain, we have made use of the theoretical results to match the available data collected with radars and radiometers from satellites, aircraft and truck-mounted platforms. The distinctive characteristics as identified by the theoretical results are useful in explaining trends in data curves. Consistent measurement features as displayed in experimental data sets will prompt the development of more complete and useful theories, and the refinement of the theoretical models along with the improvement of interpretation will prompt the suggestion of new experiments. This effort will be continued throughout our research program. The most sensitive parameters for each model will be identified in their order of importance to facilitate the application of the theoretical models to data interpretation, which will lead to a reliable scheme for radar scene generation in its application to the Tactical Decision Aids (TDA) for the Air Land Battlefield Environment (ALBE) Thrust Program.

26.12 Acoustic and Electromagnetic Wave Studies.

Schlumberger-Doll Research

Jin A. Kong, Tarek M. Habashy, Soon Y. Poh

A scalar and a vector Mathieu transform pair are developed, which facilitate the analysis of mixed boundary-value problems that are governed by the scalar and vector Helmholtz wave equations in the elliptic cylinder coordinate system. The properties of the transform kernels have been studied and their orthogonality relationships have been derived both in the spatial and spectral domains. Also the corresponding Parseval's theorems have been deduced. These transforms are very useful in formulating the scattering of electromagnetic waves from elliptical disks which has applications in modeling microstrip antennas. Also, these transforms can be used in formulating the reflection and transmission from open-ended elliptical waveguides.

The transient electromagnetic radiation by a vertical electric dipole on a two-layer medium is analyzed using the double deformation technique, which is a model technique based on identification of singularities in the complex frequency and wavenumber planes. We have shown that the existence of a pole locus on the negative imaginary frequency axis, which dominates the early time response, proves crucial in obtaining the solution for all times. A variety of combinations of parameters are used to illustrate the double deformation technique, and results are compared with those obtained via explicit inversion, and a single deformation method.

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