27.0 Electromagnetic Wave Theory and Applications

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27.1 Electromagnetic Waves in Multilayer Media

A general method of analyzing the time-domain bi-directional coupling of a pair of nonuniformly coupled dispersionless transmission lines has been devised. 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 most 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.
We have also applied the technique of wave transmission matrices in periodic structures to examine transmission and reflection properties in striplines under the influence of meshed ground planes. Responses at different frequencies are calculated, followed by numerical Fourier inversion to obtain the time-domain response. The resistances of ground planes and strips have been taken into account. The results support the conclusion of the aforementioned research.

Many integrated circuits contain strip lines at different heights that run parallel or perpendicular to each other. We have investigated reliable models for these structures. First the capacitances associated with two offset parallel strips at different heights between ground planes are computed using the conformal mapping approach. As an extension, a simplified 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, i.e., 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 50ps to propagate along a distances of 2cm or longer.

In applying the method of moments to solving the EM scattering problems, it is necessary to solve a large matrix when the dimension of 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 sparse matrix technique to reduce the amount of computation. Some algorithms are compared to solve the sparse matrix. The Gaussian elimination algorithm, Cholesky decomposition algorithm and 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 a continuous line model while considering the coupling between parallel lines in multilayered integrated circuits to be nonuniform. 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 coefficients.

Basically, vias in a 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.

In order to investigate the validity of the quasi-TEM approximation for the time-domain wave propagation, we have developed an iterative approach to perform
quasi-TEM analysis in the time-domain. By assuming first that the longitudinal field components are small, it is shown that the transversal components can be obtained from statics equations analogous to those applied for sinusoidal steady states. They also lead to solutions to the propagation velocities and voltage distributions of different quasi-TEM modes. The convergence criterion is shown to depend upon the time derivative of signals and inhomogeneity of the media.

Theory for quasi-TEM modes propagating in a transversely inhomogeneous (multidielectric) longitudinally uniform transmission line, previously derived for time-harmonic waves, is derived for transient signals. It is seen that, while the starting point for the theory is completely different, the result is similar to the time-harmonic theory, and previously derived properties for propagating modes also apply in the transient case. The range of applicability is discussed with a simple example.

Three methods are given with which bounded electromagnetic sources can be decomposed into two parts radiating, respectively, TE and TM fields with respect to a given constant direction in space. Source equivalence and nonradiating sources are discussed and taken into account in the theory, which leads to a recursive method or two different differential equations for the TE and TM components of the original source. It is seen that for a point source, a decomposition can be made with the aid of a line source, a plane source, or a set of point sources. A combination of these is also possible. The result is discussed and the planar decomposition is seen to match to an earlier result given by Clemmow in 1963. Also, it is demonstrated that the general exact image expression for the Sommerfeld half-space problem can be obtained through the present decomposition method.

The double-deformation technique is a modal technique based on identifying and extracting singularities from the Fourier integrals in the complex frequency and wave number domains. With this method, we have been able to obtain both early and late time response for vertical electric dipole and line source excitations in a two-layer medium very efficiently. We have also discovered a general scheme of breaking up the integrands so that sources with arbitrary time and space dependences can be easily handled without sacrificing convergence.

The analysis of resonance, input impedance and radiation of the elliptic disk, microstrip structure is rigorously formulated in this paper, using the Scalar and Vector Mathieu Transforms. With the help of these transforms, the resonance frequencies of the structure can be derived exactly using Galerkin’s method and approximately using a perturbational approach. Expressions for the input impedance and the radiation pattern are also obtained.

Simple approximation for diffraction surface currents on a conducting half plane, due to an incoming plane wave, is given in terms of a line current (monofile) in complex space. When compared to the approximation by a current located at the edge, the diffraction pattern is seen to improve by an order of magnitude for a minimal increase in computation effort. Thus, the inconvenient Fresnel integral functions can be avoided in quick calculations of diffracted fields and the accuracy is seen to be good in other directions than along the half plane. The method can be generally applied to problems involving planar metal edges.
Exact image method, recently introduced for the solution of electromagnetic field problems involving sources above a planar interface between two homogeneous media, is shown to be valid also for sources located in complex space, which makes its application possible for Gaussian beam analysis. It is demonstrated that the Goos-Hanchen shift and the angular shift of a $TE$ polarized beam are correctly given as asymptotic results by the exact reflection image theory. Also, the apparent image location giving the correct Gaussian beam transmitted through the interface is obtained as another asymptotic check. The present theory makes it possible to calculate the exact coupling from the Gaussian beam to the reflected and refracted beams as well as to the surface wave.

The transient electromagnetic radiation by a vertical electric dipole on a two-layer medium is analysed using the double deformation technique, which is a modal technique based on identification of singularities in the complex frequency and wavenumber planes. Previous application of the double deformation technique to the solution of this problem is incomplete in the the early time response. In this paper we show 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 will be compared with those obtained via explicit inversion, and a single deformation method.

The transient response of fundamental sources, such as dipole and line current, was carefully analyzed. With the double-deformation technique, which is a modal technique based on identification of singularities in the complex frequency and wave number planes, we are able to obtain both early and late time response very efficiently. Some results for vertical electric dipole excitation on a two-layer medium have been published. Recently, we have discovered a general scheme of breaking up the integrands so that sources with arbitrary time and space dependence can be incorporated into our formulation without sacrificing convergence.

Publications


### 27.2 Remote Sensing of Earth Terrain

*National Aeronautics and Space Administration (Contract NAG 5-270)*
*National Science Foundation (Contract ECS 85-04381)*

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

A systematic approach for the identification of terrain media such as vegetation canopy, forest, and snow-covered fields is developed using the optimum polarimetric classifier. The covariance matrices for the 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 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 are compared with classification based on single features including 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.

We modeled earth terrain covers as random media characterized by different dielectric constants and correlation functions. In order to model sea ice with brine inclusions and vegetation with row structures, the random medium is assumed to be anisotropic. A three-layer model will be used to simulate a vegetation field or a snow-covered ice field with the top layer being snow or leaves, the middle layer being ice or trunks, and the bottom layer being sea water or ground.

The strong fluctuation theory with the distorted Born approximation is applied to the solution of the radar backscattering coefficients. In order to take into account the polarimetric information, we relate 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 will be 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 nonzero Mueller matrix.
The Mueller matrix and polarization covariance matrix are studied for polarimetric radar systems. The clutter is modeled 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 eight 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.

We have used the strong fluctuation theory to derive the backscattering cross sections. The study of the strong fluctuation theory for a bounded layer of random discrete scatterers is further extended to include higher 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.

A two-layer anisotropic random medium model is developed for the active and passive microwave remote sensing of ice fields. The dyadic Green's function for this two-layer anisotropic medium is derived. With a specified correlation function for the randomness of the dielectric constant, the backscattering cross sections are calculated with the Born approximation. It is shown that the depolarization effects exist in the single-scattering process. Treating sea ice as a tilted uniaxial medium, the observed strong cross-polarized return in the bistatic scattering coefficients is successfully predicted from the theoretical model. It is also shown that the backscattering cross section of horizontal polarization can be greater than that of vertical polarization even in the half-space case. The principle of reciprocity and the principle of energy conservation are invoked to calculate the brightness temperatures. 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 for the random medium layer. 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 match favorably well 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.

The Feynman diagrammatic technique is used to derive the Dyson equation for the mean field and the Bethe-Salpeter equation for the correlation or the covariance of the field for electromagnetic wave propagation and scattering in an anisotropic random medium. With the random permittivity expressed in a general form, the bilocal and the nonlinear approximations are employed to solve the Dyson equation and the ladder approximation to the Bethe-Salpeter equation. The mean dyadic Green's function for a two-layer anisotropic random medium with arbitrary three-dimensional correlation functions has been investigated with the zeroth-order solutions to the Dyson equation under the nonlinear 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.

A three-layer random medium model is adopted to study the volume scattering effects for the active and passive microwave remote sensing of snow-covered ice fields. We simulate the snow layer 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 the variance and two correlation lengths. In ice, the anisotropic effect is attributed to the elongated structures and the specific orientations of the air bubbles, the brine inclusions, and other inhomogeneities. Two variances are required to characterize the fluctuations of the permittivities along or perpendicular to the tilted optic axis. The physical sizes of those scattering elements are also described by two correlation lengths.

The vegetation canopy and snow-covered ice field have been studied with a three-layer model, an isotropic random medium layer overlying an anisotropic random medium. We have calculated the dyadic Green’s functions of the three-layer medium and the scattered electromagnetic intensities with Born approximation. The backscattering cross sections are evaluated for active microwave remote sensing. The theoretical approach can be extended to derive the bistatic scattering coefficients. After integrating the bistatic scattering coefficients over the upper hemisphere and subtracting from unity, we can also compute the radiometric brightness temperatures for passive microwave remote sensing by invoking the principle of reciprocity.

Publications


### 27.3 Remote Sensing of Upper Atmosphere

*National Aeronautics and Space Administration (Contracts NAG 5-270, NAG 5-725, and NAG 5-889)*

*University of Dayton Research Institute*

Jin A. Kong, Robert T. Shin, Min C. Lee, Freeman C. Lin, Son V. Nghiem, Keith M. Groves, H.C. Han

Radio measurements of Total Electron Content (TEC) and optical detection of airglow variations show that large scale plasma patches appearing in the high latitude ionosphere have irregular structures, evidenced by the satellite phase and amplitude scintillations. Whistler waves, intense quasi-DC electric fields, atmospheric gravity waves, and electrojets are potential sources of various plasma instabilities. The role of thermal effects in generating ionospheric irregularities by these sources have been investigated. A model has been developed to explain the discrete spectrum of the resonant ULF waves that have been commonly observed in the magnetosphere. The resonant electron diffusion is suggested to be an effective saturation process of the auroral kilometric radiation. The calculated intensity of the saturated radiation has a significantly lower value in comparison with that caused by the quasi-linear diffusion process as an alternative saturation process.

Faraday Polarization Fluctuations (FPF) of transionospheric radio waves in the presence of random density irregularities have been studied. The irregularities are anisotropic and modeled by a correlation function containing different correlation lengths in the directions parallel and perpendicular to the Earth’s magnetic field. Expression for the FPF variance is obtained under the underdense ionospheric plasma condition. The results show that the FPF variance depends on the ratio of the perpen-
dicular to the parallel correlation lengths and the anisotropic irregularity effect becomes more appreciable for the longitudinally propagating modes.

The ionospheric modification caused by an HF or MF heater wave can be enhanced with the subsequent illumination of the ionosphere by a powerful VLF wave. Let the HF or MF heater be operated in a pulse-wave mode to assure the excitation of short-rather than large-scale ionospheric density irregularities. These excited ionospheric density striations can effectively scatter the VLF wave into a lower hybrid wave via the nonlinear mode conversion provided that the scale lengths of ionospheric irregularities are much less than the wavelength of the VLF wave. For example, the wavelength of a VLF wave at the frequency of 10 kHz is of the order of 500 meters in the ionospheric F region. The preferential excitation of meter-scale ionospheric irregularities by the HF or MF heater wave can provide the subsequently injected VLF wave with a favorable condition for the nonlinear mode conversion. These density striations, in fact, can also be intensified by the powerful VLF wave via a plasma instability that can concomitantly generate lower hybrid waves. The ionosphere modified by the two heater waves is expected to have intense lower hybrid waves and short-scale ionospheric density striations. These VLF wave-produced electrostatic waves can effectively heat the ionospheric plasma. Enhanced modification effects in, for instance, airglow and height distribution of plasma lines are expected. The proposed experiment can provide the controlled study of the spectral broadening effect of propagating VLF waves.

Nearly monochromatic signals at 13.6 kHz ± Hz injected from a ground-based VLF transmitter can experience a broadband expansion as high as 10% (~ 100 Hz) of the incident wave frequency as they traverse the ionosphere and reach satellite altitudes in the range of 600-3800 kilometers. We investigate two different source mechanisms that can potentially result in the observed spectral broadening of injected monochromatic VLF waves. One is the nonlinear scattering of VLF signals by induced ionospheric density fluctuations that renders the nonlinear mode conversion of VLF waves into lower hybrid waves. These quasi-electrostatic modes result when the injected VLF waves are scattered by ionospheric density fluctuations with scale lengths less than \(0.7(c/f_p)(f_e/f_o)^{1/2}\) where \(c\), \(f_p\), \(f_e\), and \(f_o\) are the speed of light in vacuum, the plasma frequency, the electron cyclotron frequency, and the VLF wave frequency, respectively. A second mechanism involves the excitation of electrostatic waves (lower hybrid waves, low frequency quasi-modes) 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.

Publications


27.4 Remote Sensing of Sea Ice

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

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

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.

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.

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.

Electromagnetic wave propagation and scattering in an anisotropic random medium has been examined with Dyson equation for the mean field which is solved by bilocal and nonlinear approximations and with Bethe-Salpeter equation for the correlation of field 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


### 27.5 SAR Image Interpretation and Simulation

*National Aeronautics and Space Administration (Contract NAG 5-769)*

*U.S. Army Corps of Engineers/Waterways Experimental Station (Contract DADA39-87-K-0022)*

*Simulation Technologies*


Using the random medium model, synthetic aperture radar (SAR) simulations can now be generated based on ground truth data from a given terrain site. We first match the various elements within the data to the physical parameters previously discussed, which are compiled in a database generated from correlation function studies. Based on these physical terrain parameters, we next use the random medium model to predict the radar backscatter from the various terrain elements in order to generate a range cross-range terrain profile. We have taken into account the change of incident angle...
along the ground swath as well as the terrain local incident angle, when the terrain backscatter is computed. Finally the effects of fading (i.e., speckle) are incorporated into the simulated imagery. Utilizing this procedure, we are able to simulate the radar measurements which would have been actually recorded had this terrain been imaged by an airborne SAR. There simulations are fully polarimetric. The advantage to terrain simulation using the random medium model is that, in general, most airborne radars operate at either a single frequency, of over some relatively small bandwidth. However, the random medium model allows us to generate simulations of the same terrain for a variety of operating frequencies. In light of this fact, we see that terrain simulation based on the random medium model is an extremely useful tool.

Development of high resolution and autocorrelation range profile algorithms, which are a special case of the above mentioned terrain simulation, has continued. Modification to the algorithms, discussed in previous reports, were detailed at SIMTECH. The primary modification altered the way in which the terrain was sectioned into high resolution range bins. Formerly these bins were evenly spaced on a flat terrain, however, spacing was not uniform when terrain elevation information was added. The new methodology takes this effect into account. Now the terrain scattering elements, located in each range bin are evenly separated both in the case of a flat terrain and for regions in which ground elevation occurs. Since most terrain regions are not uniformly flat, this new algorithm for partitioning the terrain represents an improvement over the previous model.

We have developed a data processing algorithm which produces maximum contrast between two scattering classes, each represented by its respective covariance matrix. We will derive an optimal linear decision vector or decision functional which maximizes the contrast or expected power return ratio between the two scattering classes. The suboptimal case of a fixed transmit polarization will also be considered. The maximization procedure involves solving an eigenvalue problem in which the eigenvector yielding this maxima will correspond to the decision functional we seek. To demonstrate the physical significance of the linear weighting decision vector, we transform it into its associated transmit and receive polarization state, in terms of horizontal and vertical vector components. This technique is then applied to radar imagery to enhancement contrast between different classes within a given database.

The scattering of electromagnetic waves from a randomly perturbed periodic surface is solved using the Extended Boundary Condition (EBC) method. The scattering from periodic surface is solved exactly using the EBC method and this solution is used in the small perturbation method to solve for the scattered field from a randomly perturbed periodic surface. The random perturbation is modeled as a Gaussian random process and the surface currents and the scattered fields are expanded and solved up to the second order. The theoretical results are illustrated by calculating the bistatic and backscattering coefficients. It is shown that as the correlation length of the random roughness increases, the bistatic scattering pattern of the scattered fields show several beams associated with each Bragg diffraction direction of the periodic surface. When the correlation length becomes smaller, then the shape of the beams become broader. The results obtained using the EBC method is also compared with the results obtained using the Kirchhoff approximation. It is shown that the Kirchhoff approximation results show quite a good agreement with EBC method results for the VV and HH polarized backscattering coefficients for small angles of incidences. However, the Kirchhoff approximation does not give depolarized returns in the backscattering direction whereas
the results obtained using the EBC method give significant depolarized returns when the incident direction is not perpendicular to the row direction of the periodic surface.

Polarimetric radar backscatter data have been used extensively to classify terrain cover. Since it is difficult to calibrate out the effects of amplitude and phase errors induced by atmospheric effects, path loss, etc., absolute amplitude and phase of radar returns are not reliable features for terrain classification purposes. The use of normalized polarimetric data is proposed so that only the relative magnitudes and phases will be utilized to discriminate different terrain elements. It is shown that the Bayes classification error does not depend on the form of the normalization function if the unknown radar system calibration factor is modeled as a multiplicative term in the received signal. This holds true for arbitrary probabilistic distributed polarizations. Assuming a multivariate Gaussian distribution for the un-normalized polarimetric data, the probability density function (PDF) of the normalized data and the corresponding Bayes classifier distance measure for the normalized data are derived. Furthermore, by assuming a specific form of the covariance matrix for the polarimetric data, exact PDFs are given for HH, HV, VV and span type normalization schemes. Corresponding classification errors are evaluated to verify their independence from all normalization functions.

We have studied the Mueller matrix and polarization covariance matrix for polarimetric radar systems. The clutter is modeled 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 eight 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.

Publications


