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ТЕМАТИЧЕСКИЙ РЕФЕРАТИВНЫЙ СБОРНИК № 34-1

“Radar Scattering Matrix”
(«РЛ матрица рассеяния»)

Журнальные публикации

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"Coherence, Polarization, and Statistical Independence in Cloude-Pottier's Radar Polarimetry"

The Cloude-Pottier radar polarimetry paradigm, which is understood as the spectral decomposition theorem of the target coherency matrix plus the classification technique based on the triad of parameters given by entropy, alpha angle, and anisotropy, has become a very well-established methodology for treating high-resolution polarimetric radar images, particularly those obtained with synthetic aperture radar (SAR) sensors. This methodology is revisited here from the standpoint of the coherence and polarization theory and their mutual relationship, in the light of the interest aroused once again after Wolf's article on this subject in 2003. Despite its success in terms of acceptance by the SAR community, the Cloude-Pottier paradigm relies on the arguable assumption that different scattering mechanisms can be separated by diagonalizing the aforementioned coherency matrix and then assigning each corresponding eigenvector to one of the independent scattering mechanisms. Our main statement in this paper is that the coherency matrix illustrates the behavior of the target from the point of view of polarization and not of full coherence, which would justify this assumption, even if only partially. Therefore, it is not rigorous to identify each eigenvector of this decomposition with a distinct scattering mechanism. Cloude and Pottier argue that the eigendecomposition of the coherency matrix outperforms other target decomposition theorems due to its uniqueness. It is also suggested that this very uniqueness, together with the orthogonality of the eigenvectors, supports the injective mapping between scattering mechanisms and eigenvectors that was first assumed based on statistical independence. With the aim of providing a comprehensive overview of the problem, we discuss some important concepts with regard to both field and target coherency matrices. In addition, we revise the concepts of entropy, alpha angle, and anisotropy as defined by the aforementioned authors, which are-- also a central part of this paradigm and which have played an important role in SAR image classification since its introduction. Again, some disagreement is found with the meaning of these parameters as they have been discussed so far. [J1]

"Polarimetric Decomposition Over Glacier Ice Using Long-Wavelength Airborne PolSAR"

In recent years, there has been increased interest in using synthetic aperture radar (SAR) to study and monitor glaciers and ice sheets for glaciological and climate change research. However, due to the medium's complexity, SAR backscattering from ice remains poorly understood, including the relative importance of scattering from surface and volume layers and also dependences on frequency and glacier zone. Extreme weather conditions can result in quickly changing surface conditions influencing backscatter signatures while leaving the underlying volume of interest unchanged. Surface and volume components must thus be separated in order to infer information regarding the properties of the ice volume. This paper describes a three-component scattering model to decompose polarimetric SAR (PolSAR) images of glacier ice. Total backscatter is modeled as the incoherent summation of surface, volume, and sastrugi (wind-induced feature) components. The proposed model adapts and extends the Freeman and Durden decomposition for an ice volume scenario in which the volume is a dielectric medium. Forms of the model for both random and oriented volumes are considered, and a new oriented sastrugi component is introduced which is able to explain backscatter behavior between different winter scenes. Validation is performed with airborne PolSAR data at L- and P-band collected using the E-SAR system of the German Aerospace Center over the Austfonna ice cap in Svalbard, Norway, as part of the ICESAR campaign. [J2]

"Modeling PSInSAR Time Series Without Phase Unwrapping"

In this paper, we propose a least-squares-based method for multitemporal synthetic aperture radar interferometry that allows one to estimate deformations without the need of phase unwrapping. The method utilizes a series of multimaster wrapped differential interferograms with short baselines and focuses on arcs at which there are no phase ambiguities. An outlier detector is used to identify and remove the arcs with phase ambiguities, and a pseudoinverse of the variance-covariance matrix is used as the weight matrix of the correlated observations. The deformation rates at coherent points are estimated with a least squares model constrained by reference points. The proposed approach is verified with a set of simulated data. [J3]

"The Effect of Orientation Angle Compensation on Coherency Matrix and Polarimetric Target Decompositions"

The polarization orientation angle (OA) of the scattering media affects the polarimetric radar signatures. This paper investigates the effects of orientation compensation on the coherency matrix and the scattering-model-based decompositions by Freeman-Durden and Yamaguchi et al. The Cloude and Pottier decomposition is excluded, because entropy, anisotropy, and alpha angle are roll invariant. We will show that, after orientation compensation, the volume scattering power is consistently decreased, while the double-bounce power has increased. The surface scattering power is relatively unchanged, and the helicity power is roll invariant. All of these characteristics can be explained by the compensation effect on the nine elements of the coherency matrix. In particular, after compensation, the real part of the (HH-VV) · HV* correlation reduces to zero, the intensity of cross-pol |HV| always reduces, and |HH-VV| always increases. This analysis also reveals that the common perception that OA compensation would make a reflection asymmetrical medium completely reflection symmetric is incorrect and that, contrary to the general perception, the four-component decomposition does not use the complete information of the coherency matrix. Only six quantities are included-one more than the Freeman-Durden decomposition, which explicitly assumes reflection symmetry. [J4]

"Electromagnetic Modeling of Breaking Waves at Low Grazing Angles With Adaptive Higher Order Hierarchical Legendre Basis Functions"

At low grazing angles (LGA), sophisticated electromagnetic scattering of sea surfaces may give rise to complicated surface-current distribution. Therefore, for the multilevel fast multipole algorithm (MLFMA) with the Rao-Wilton-Glisson basis function, the sea scatterer must be meshed fine enough to ensure the precision of the scattering at LGA, which brings huge computational costs. The higher order hierarchical Legendre vector basis functions can bring a great reduction of the unknowns and sparsification of the impedance matrix. The MLFMA with higher order hierarchical Legendre basis functions is applied in the electromagnetic-scattering approach of 3-D breaking water wave crests at LGA for the first time. In addition, an adaptive-order technique is also introduced for the first time in describing the currents which can achieve accurate results and maximally reduce the computational costs from some case analysis. It has been investigated in analyzing the vertically (VV) and horizontally (HH) polarized scattering of profiles of the LONGTANK breaking waves. "Sea-spike" phenomenon has been demonstrated at LGA. [J5]

"Multiscale Compressed Block Decomposition for Fast Direct Solution of Method of Moments Linear System"

The multiscale compressed block decomposition algorithm (MS-CBD) is presented for highly accelerated direct (non iterative) solution of electromagnetic scattering and radiation problems with the method of moments (MoM). The algorithm is demonstrated to exhibit N2computational complexity and storage requirements scaling with N1.5, for electrically large objects. Several numerical examples illustrate the efficiency of the method, in particular for problems with multiple excitation vectors. The largest problem presented in this paper is the monostatic RCS of the NASA almond at 50 GHz, for one thousand incidence angles, discretized using 442,089 RWG basis functions. Being entirely algebraic, MS-CBD is independent of the Greens function of the problem. [J6]

"Adaptive Model-Based Decomposition of Polarimetric SAR Covariance Matrices"

Previous model-based decomposition techniques are applicable to a limited range of vegetation types because of their specific assumptions about the volume scattering component. Furthermore, most of these techniques use the same model, or just a few models, to characterize the volume scattering component in the decomposition for all pixels in an image. In this paper, we extend the model-based decomposition idea by creating an adaptive model-based decomposition technique, allowing us to estimate both the mean orientation angle and a degree of randomness for the canopy scattering for each pixel in an image. No scattering reflection symmetry assumption is required to determine the volume contribution. We examined the usefulness of the proposed decomposition technique by decomposing the covariance matrix using the National Aeronautics and Space Administration/Jet Propulsion Laboratory Airborne Synthetic Aperture Radar data at the C-, L-, and P-bands. The randomness and mean orientation angle maps generated using our adaptive decomposition significantly improve the physical interpretation of the scattering observed at the three different frequencies. [J7]

"Range-Spread Target Detection using Consecutive HRRPs"

In this paper, a heuristic detector is proposed to detect range-spread targets in white Gaussian noise using multiple consecutive high- resolution range profiles (HRRPs) received from a high-resolution radar (HRR). The

detector consists of refiners of HRRPs and a cross-correlation integrator of refined HRRPs. Based on the fact that strong scattering cells are sparse in target HRRPs, nonlinear shrinkage maps are designed to refine received HRRPs before integration, by which most of the noise-only cells in received HRRPs are suppressed while strong scattering cells most probably relevant to target signature are preserved. Since the target's scattering geometry is almost unchanged except for range walking during integration, the refined target HRRPs from consecutive pulses are highly similar while refined noise-only HRRPs are dissimilar due to randomicity. The modified correlation matrix of multiple refined HRRPs is used to measure their similarity. The test statistic, a weighted integration of the entries of the modified correlation matrix, is constructed for target detection. The proposed detector does not depend on a strict target return model and can work in mild conditions. The real target data and simulated noise are used to evaluate the detector, and the experimental results show that it achieves better detection performance than some existing methods. [J8]

"Multiobjective Optimization of OFDM Radar Waveform for Target Detection"

We propose a multiobjective optimization (MOO) technique to design an orthogonal-frequency-division multiplexing (OFDM) radar signal for detecting a moving target in the presence of multipath reflections. We employ an OFDM signal to increase the frequency diversity of the system, as different scattering centers of a target resonate variably at different frequencies. Moreover, the multipath propagation increases the spatial diversity by providing extra "looks" at the target. First, we develop a parametric OFDM radar model by reformulating the target-detection problem as the task of sparse-signal spectrum estimation. At a particular range cell, we exploit the sparsity of multiple paths and the knowledge of the environment to estimate the paths along which the target responses are received. Then, to estimate the sparse vector, we employ a collection of multiple small Dantzig selectors (DS) that utilizes more prior structures of the sparse vector. We use the $\ell 1$-constrained minimal singular value ($\ell 1$-CMSV) of the measurement matrix to analytically evaluate the reconstruction performance and demonstrate that our decomposed DS performs better than the standard DS. In addition, we propose a constrained MOO-based algorithm to optimally design the spectral parameters of the OFDM waveform for the next coherent processing interval by simultaneously optimizing two objective functions: minimizing the upper bound on the estimation error to improve the efficiency of sparse-recovery and maximizing the squared Mahalanobis-distance to increase the performance of the underlying detection problem. We provide a few numerical examples to illustrate the performance characteristics of the sparse recovery and demonstrate the achieved performance improvement due to adaptive OFDM waveform design. [J9]

"Dual-Grid Finite-Difference Frequency-Domain Method for Modeling Chiral Medium"

A dual-grid finite-difference frequency-domain (DG-FDFD) method is introduced to solve for scattering of electromagnetic waves from bianisotropic objects. The formulations are based on a dual-grid scheme in which a traditional Yee grid and a transverse Yee grid are combined to achieve coupling of electric and magnetic fields that is imposed by the bianisotropy. Thus the underlying grid naturally supports the presented formulations. Introduction of a dual-grid scheme doubles the number of electromagnetic field components to be solved, which in turn implies increased time and memory of the computational resources for solution of the resulting matrix equation. As a remedy to this problem, an efficient iterative solution technique is presented that effectively reduces the solution time and memory. The presented formulations can solve problems including bianisotropic objects. The validity of the formulations is verified by calculating bistatic radar cross-sections of three-dimensional chiral objects. The results are compared with those obtained from analytical and other numerical solutions. [J10]

"A Backscatter Modeling for River Ice: Analysis and Numerical Results"

A microwave backscatter model was developed to help provide an understanding of the interaction of a radar signal with the different ice types formed on natural freshwater bodies. This model was based on the radiative transfer theory, which is solved by the doubling matrix method. This numerical method provides an explanation for scattering effects due to volume, boundaries, boundary-volume interactions and interactions between layers. Three ice types were analyzed: columnar ice, frazil ice, and snow ice. Simulations with the model proved that the radar response from river ice cover depends on both ice-cover boundaries. The shape and distribution of air inclusions within the different ice types seem to have a significant impact on their contributions to the total response. The presence of tubular air inclusions within columnar ice causes an increase in the total response as a result of a double-bounce scattering. Small spherical and closed air inclusions within snow ice and frazil ice generate significant backscattering at high frequencies due to volume and surface-volume scattering. A further increase in the ice-cover thickness with air inclusions also causes increased scattering. Superposing two or more of these ice types causes considerable multiple scattering between layers. Finally, radar ice measurements collected over the Athabasca River were employed to further validate the model, and satisfactory results were obtained. [J11]

"Calculation of the Impedance Matrix Inner Integral to Prescribed Precision"

We present a new method for evaluating the inner integral of the impedance matrix element in the traditional Rao-Wilton-Glisson formulation of the method of moments for perfect conductors. In this method we replace the original integrand (modified by a constant phase factor) by its Taylor series and keep enough terms to guarantee a number of significant digits in the integration outcome. We develop criteria that relate the number of Taylor terms to the number of required significant digits. We integrate the leading Taylor terms analytically and the rest through iteration formulas. We show that the iteration formulas converge for all observation points within a sphere with a radius of half-a-wavelength and center the triangle's centroid. We compare results of our method with existing ones and find them in excellent agreement. We also outline a procedure for using cubatures outside the region of convergence. [J12]

"Reconstruction of GPR Signals by Spectral Analysis of the SVD Components of the Data Matrix"

This letter considers the problem of reconstructing total-time responses from noisy data collected by ground-penetrating radar (GPR). The well-known singularity expansion method (SEM)-a theory-for late-time response representation is generalized to establish a matrix model (data matrix)representing total-time responses of radar scattering waveforms. Using singular value decomposition of the data matrix-an intermediate processing technique, we present an approach to model-order determination and successfully reconstruct the total-time responses. The model order is quantitativelyselected by spectral analysis of left singular vectors of the data matrix and of the emitted waveform. The most important discoveries in this letter are as follows: (1) the GPR upper frequency can be used as a criterion for the selection of left singular vectors of the data matrix, and (2) the left singular vectors of the data matrix, which should not be neglected, tend to be predominantly low-pass functions and also provide valuable information for model-order determination. [J13]

"Polarimetric MIMO Radar With Distributed Antennas for Target Detection"

Multiple-input-multiple-output (MIMO) radar systems with widely separated antennas enable viewing the target from different angles, thereby providing spatial diversity gain. Polarimetric design of the transmit waveforms based on the properties of the target scattering matrix provides better performance than transmitting waveforms with only fixed horizontal or vertical polarizations. We propose a radar system that combines the advantages of both systems by transmitting polarized waveforms from multiple distributed antennas, in order to detect a point-like stationary target. The proposed system employs 2-D vector sensors at the receivers, each of which measures the horizontal and vertical components of the received electric field separately. We design the Neyman-Pearson detector for such systems. We derive approximate expressions for the probability of false alarm (PFA) and the probability of detection (PD). Using numerical simulations, we demonstrate that optimal design of the antenna polarizations provides improved performance over MIMO systems that transmit waveforms of fixed polarizations over all the antennas. We also demonstrate that having multiple widely separated antennas gives improved performance over single-input-single-output (SISO) polarimetric radar. We also demonstrate that processing the vector measurements at each receiver separately gives improved performance over systems that linearly combine both the received signals to give scalar measurements. [J14]

"Three-Dimensional Coherent Radar Backscatter Model and Simulations of Scattering Phase Center of Forest Canopies"

A 3-D coherent radar backscatter model for forest canopies was developed and used to improve the understanding of synthetic aperture radar (SAR) interferometric data. The model was based on a realistic 3-D spatial structure of a forest stand, in which every scatterer has its deterministic location. A backscattering signal from a scatterer was mapped into a pixel according to its range or signal time delay. The range or the time delay also determines the phase of the scattered field. All scattering matrices within a pixel were coherently added to yield the total backscattering field of the pixel. The coherent radar backscatter model takes into account not only the scattering contribution from the scatterers in the forest canopy but also the direct backscattering of the ground surface. Forest stands with three different spatial structures were simulated using L-system and field measurements. The number and sizes of trees in these forest stands were identical, but the 2-D arrangements of the trees were different. The interferometric SAR (InSAR) signals of these scenes were simulated using the 3-D coherent SAR model, and the heights of scattering phase centers were estimated from the simulated InSAR data. The results reported in this paper show that the spatial structures of vegetation play an important role in the location of the scattering phase center. The height of scattering phase center depends on canopy height, attenuation of canopy, and the gaps within the canopy. This paper shows that the spatial structure needs to be considered when the InSAR data are used for the estimation of forest structural parameters. [J15]

"Applying the Freeman-Durden Decomposition Concept to Polarimetric SAR Interferometry"

In this paper, the Freeman-Durden polarimetric decomposition concept is adapted to polarimetric SAR interferometry (PolInSAR) data. The covariance matrix obtained from PolInSAR observations is decomposed into the three scattering mechanisms matrices proposed by Freeman and Durden for polarimetric SAR (PolSAR) data. The objective is to describe each interferometric cross correlation as the sum of the contributions corresponding to direct, double-bounce, and random volume scattering processes. This procedure enables the retrieval not only of the magnitude associated with each mechanism but also of their location along the vertical dimension of the scene. One of the most important features of this algorithm is the potential to isolate more accurately the direct and volume contributions which usually cannot be correctly separated by means of PolSAR measurements. In addition, it is also possible to distinguish between direct scattering responses originated either at ground or produced by upper layers of vegetation. The proposed algorithm has been tested with simulated data from PolSARProSim software, laboratory data from maize and rice samples, and airborne data from a test site with different scenarios. [J16]

"Scattering Model for a Pine Tree Employing VIE With a Broadband MLFMA and Comparison to ICA"

In this paper, we present accurate calculations of electromagnetic wave scattering from a high-detail pine tree model, which includes also the needles. We have deployed a volume integral equation (VIE) model, which takes into account high-order reflections between all scatterers, even between single needles. The pine tree is modeled as a realistic collection of dielectric cylinders. With the help of our calculations, we assess the importance of multiple scattering inside the pine canopy and the contribution of the needles to the scattering. We compare our calculations with a much simpler model output to determine the validity conditions for simplified approaches. As the simpler model, we use an infinite cylinder approximation (ICA) model which uses a truncated cylinder approximation and takes into account only the first-order reflections from single cylinders. Both models are bistatic, fully coherent, and fully polarimetric models suitable in calculating the scattering from a large and general collection of dielectric cylinders. Our results show that, for the C-band calculations, the VIE model output differs significantly from the simple ICA model output, indicating the importance of the higher order scattering between the needles and branches. However, for the L-band, the accurate VIE model gives similar results as the ICA model, indicating that, in this case, the higher order scattering between the needles can be neglected. [J17]

"Estimation of Forest Structure, Ground, and Canopy Layer Characteristics From Multibaseline Polarimetric Interferometric SAR Data"

This paper concerns forest parameter retrieval from polarimetric interferometric synthetic aperture radar (PolInSAR) data considering two layers, one for the ground under the vegetation and one for the volumetric canopy. A model is designed to combine a physical model-based polarimetric decomposition with the random-volume-over-ground (RVoG) PolInSAR parameter inversion approach. The combination of a polarimetric scattering media model with a PolInSAR RVoG vertical structure model provides the possibility to separate the ground and the volume coherency matrices based on polarimetric signatures and interferometric coherence diversity. The proposed polarimetric decomposition characterizes volumetric media by the degree of polarization orientation randomness and by the particle scattering anisotropy. Using the full model enhances the estimation of the vertical forest structure parameters by enabling us to estimate the ground-to-volume ratio, the temporal decorrelation, and the differential extinction. For forest vegetation observed at L-band, this model accounts for the ground topography, forest and canopy layer heights, wave attenuation in the canopy, tree morphology in the form of the angular distribution and the effective shapes of the branches, and the contributions from the ground level consisting of surface scattering and double-bounce ground-trunk interactions, as well as volumetric understory scattering. The parameter estimation performance is evaluated on real airborne L-band SAR data of the Traunstein test site, acquired by the German Aerospace Center (DLR)'s E-SAR sensor in 2003, in both single- and multibaseline configurations. The retrieved forest height is compared with the ground-truth measurements, revealing, for the given test site, an average root-mean-square error (rmse) of about 5 m in the repeat-pass configuration. This implies an improvement in rmse by over 2 m in comparison to the pure coherence-based RVoG PolInSAR parameter inversion. [J18]

"Polarimetric Scattering Similarity Between a Random Scatterer and a Canonical Scatterer"

In this letter, we propose a novel parameter to measure the scattering similarity between a random scatterer and a canonical scatterer. Compared with the similarity parameter proposed by Yang, the novel parameter not only has some advantages, such as its independence of the spans of a coherence matrix, but also can be applied directly in the case of a random scatterer made up of multiscattering centers. As an example, the novel parameter is adopted to extract some scattering characteristics of a target. With the full polarimetric L-band

airborne synthetic aperture radar data, we illustrate the veracity of the novel parameter in measuring scattering similarity and its application in terrain classification. [J19]

"A Rao Test With Enhanced Selectivity Properties in Homogeneous Scenarios"

This correspondence focuses on the design of a selective receiver for homogeneous scenarios. To this end, at the design stage it is assumed that the cell under test contains a noise-like interferer in addition to thermal noise, clutter, and to the possible signal of interest; a set of secondary data, free of signal components, is available: such data share a common covariance matrix that is equal to that of thermal noise plus clutter in the cell under test. Under the above assumptions, an adaptive detector implementing the RAO test is designed. A preliminary performance assessment, conducted assuming that the cell under test and the secondary data share one and the same covariance matrix of the overall disturbance (including possible noise-like interferers), shows that the newly proposed detector can provide enhanced rejection capabilities with respect to its natural competitor (the W-ABORT). It can also outperform the W-ABORT for matched signals. [J20]

"Fast computation of radar cross-section by fast multipole method in conjunction with lifting wavelet-like transform"

The fast multipole method (FMM) in conjunction with the lifting wavelet-like transform scheme is proposed for the scattering analysis of differently shaped three-dimensional perfectly electrical conducting objects. As a flexible and efficient matrix compression technique, the proposed method can sparsify the aggregation matrix and disaggregation matrix in real time with compression ratio about 30%. The computational complexity and choice of proper wavelet are also discussed. Numerical simulation and complexity analysis have shown that the proposed method can speed up the aggregation and disaggregation steps of the FMM with lower memory requirements. [J21]

"Finding Underground Targets by Means of Change-Detection Methods in Huynen Spaces"

A different and useful approach is presented for detecting new events in a scene, such as the presence or absence of landmines or perhaps the movement of people, vehicles, or structures. The approach rests on the radar examination of an area several times, once, before there are targets present, and the other (or others) after. The change detection algorithm notices if there are any changes after the first view. In the present approach the prospective target is represented, not in terms of three complex elements of a scattering matrix, but in terms of phenomenologically-based Huynen parameters. Each element of the Huynen parameter set conveys a different type of physical and geometrical attribute about the scatterers, thus the potential for significant false-alarm mitigation is increased. We provide results of the application of this approach on fully polarimetric signatures of simulated pairs of buried cylindrical targets. These results indicate the following. 1) Huynen parameters are more effective for change detection than the scattering matrix elements because of their ability to generate higher unambiguous autocorrelation peaks and fewer dominating cross-correlation curves. 2) A large number of symmetries are observed in the plots of the Huynen parameters for both one and two buried cylinders. These symmetries may eventually lead to further classification insights. 3) By using standard Prony methods, relevant resonance frequencies are extracted from the parameter plots, from which the height of either one of the cylinders is estimated. 4) The diameter of either cylinder can also be obtained by a simple procedure based on ray-tracing and time delays. Numerical calculations substantiate all the above assertions. [J22]

"Micro-Doppler Signature Extraction from Ballistic Target with Micro-Motions"

Precession and nutation of the warhead and the wobble of decoys are the typical micro-motions of ballistic targets, and micro-Doppler analysis is a new way to investigate micro-motions. Based on the difference of micro-motions between the warhead and decoys, micro-Doppler signatures might be extracted for radar target identification, which is seen as a good method and a technique of great potential. We build micro-motion models of a ballistic missile target, including precession, nutation, and wobble; develop a novel model of micro-Doppler modulations based on the proposed concept of the micro-motion matrix; derive the formulas of micro-Doppler induced by the three micro-motions; and verify them by simulation studies. In order to further approach the actual case, the effective point scatterer model and the occlusion effect are considered in micro-Doppler, and the simulated results are shown compared with ones under the fixed point scatterer model and without the occlusion effect. In addition the precession experiment is performed in a microwave chamber, and the measured result is in accordance with the simulated result and the computed result. [J23]

"Three-Component Model-Based Decomposition for Polarimetric SAR Data"

An improved three-component decomposition for polarimetric synthetic aperture radar (SAR) data is proposed in

this paper. The reasons for the emergence of negative powers in the Freeman decomposition have been analyzed, and three corresponding improvements are included in the proposed method. First, the deorientation process is applied to the coherency matrix before it is decomposed into three scattering components. Then, the coherency matrix with the maximal polarimetric entropy, i.e., the unit matrix, is used as the new volume-scattering model instead of the original one adopted in the Freeman decomposition. A power constraint is also added to the proposed three-component decomposition. The E-SAR polarimetric data acquired over the Oberpfaffenhofen area in Germany are applied in the experiment. The results show that the pixels with negative powers are totally eliminated by the proposed decomposition, demonstrating the effectiveness of the new model. [J24]

"MIMO Radar Using Compressive Sampling"

A multiple-input multiple-output (MIMO) radar system is proposed for obtaining angle and Doppler information on potential targets. Transmitters and receivers are nodes of a small scale wireless network and are assumed to be randomly scattered on a disk. The transmit nodes transmit uncorrelated waveforms. Each receive node applies compressive sampling to the received signal to obtain a small number of samples, which the node subsequently forwards to a fusion center. Assuming that the targets are sparsely located in the angle-Doppler space, based on the samples forwarded by the receive nodes the fusion center formulates an l1-optimization problem, the solution of which yields target angle and Doppler information. The proposed approach achieves the superior resolution of MIMO radar with far fewer samples than required by other approaches. This implies power savings during the communication phase between the receive nodes and the fusion center. Performance in the presence of a jammer is analyzed for the case of slowly moving targets. Issues related to forming the basis matrix that spans the angle-Doppler space, and for selecting a grid for that space are discussed. Extensive simulation results are provided to demonstrate the performance of the proposed approach at difference jammer and noise levels. [J25]

"Preconditioning Matrix Interpolation Technique for Fast Analysis of Scattering Over Broad Frequency Band"

A hybrid interpolation method is proposed for the fast analysis of the radar cross-section (RCS) over a broad frequency band by use of the matrix interpolation method. In order to efficiently compute electromagnetic scattering, the general minimal residual (GMRES) iterative solver is applied to compute the coefficients of Rao-Wilton-Glisson (RWG) basis functions and the sparse approximate inversion (SAI) preconditioning technique is used to accelerate the iterative solver. Moreover, both the near field impedance and SAI preconditioning matrices are interpolated at intermediate frequencies over a relatively large frequency band with rational function interpolation technique. Therefore, a lot of time can be saved for the calculation of both the near field impedance and preconditioning matrices. Numerical results demonstrate that this hybrid method is efficient for wideband RCS calculation with high accuracy. [J26]

"A General Characterization for Polarimetric Scattering From Vegetation Canopies"

Current polarimetric model-based decomposition techniques are limited to specific types of vegetation because of their assumptions about the volume scattering component. In this paper, we propose a generalized probability density function based on the nth power of a cosine-squared function. This distribution is completely characterized by two parameters; a mean orientation angle and the power of the cosine-squared function. We show that the underlying randomness of the distribution is only a function of the power of the cosine-squared function. We then derive the average covariance matrix for various different elementary scatterers showing that the result has a very simple analytical form suitable for use in model-based decomposition schemes. [J27]

"EM-Wave Scattering by an Axial Slot on a Circular PEC Cylinder With an Eccentrically Layered Inner Coating: A Dual-Series Solution for TE Polarization"

A dual-series approach is used to formulate scattering of a TE-polarized plane wave by a circular, PEC cylinder, having a longitudinal slot and enclosing two, eccentric, cylindrical dielectric layers. The dual-series equations are analytically regularized to a matrix Fredholm equation of the second kind by use of the Abel integral-transform method. The resulting infinite set of linear algebraic equations (i.s.l.a.e.) is truncated and solved numerically. The aforementioned analytical-numerical solution intrinsically takes into consideration the correct edge behavior of the field. Furthermore, the addition theorem of cylindrical wave functions is used to match the field components on any cylindrical interface. The numerical application manifests how the structure of the inner loading of this cylindrical cavity is imprinted on backscattering. Moreover, it is shown how the location of the innermost dielectric cylinder may contribute to the suppression or enhancement of resonances. [J28]

"A Characterization of Shannon Entropy and Bhattacharyya Measure of Contrast in Polarimetric and Interferometric SAR Image"

We analyze the application of Shannon entropy and Bhattacharyya distance for the characterization of polarimetric interferometric synthetic aperture radar (PolInSAR) images. We discuss the relevance of the decomposition of the Shannon entropy of a homogeneous region into the sum of three physically meaningful terms that depend respectively on intensity, polarimetry, and interferometry. We also discuss an analogous decomposition property for the Bhattacharyya distance, which is an efficient measure of the contrast between two regions. We illustrate the application of this approach for analyzing different contributions in the information content of PolInSAR images. [J29]

"Statistics of the Polarimetric Weibull-Distributed Electromagnetic Wave"

The statistical properties of partially polarized light in Gaussian stochastic plane wave fields have been reported in the literature. In this paper, we examine the statistics of the stochastic plane electromagnetic (EM) wave fields that are Weibull distributed. The polarimetric Weibull-distributed wave is characterized by three parameters: the sum of the intensities of the two electric vector components, the orientation angle that the major axis makes with the reference coordinate system, and the ratio of the minor to the major axis. The joint and marginal probability densities of these random variables are determined as a function of the covariance matrix. The main properties of this important distribution are shown. Then, the statistical properties of the normalized Stokes parameters are described in detail in Weibull-distributed stochastic fields. The joint and marginal probability density functions of the three components of the normalized Stokes parameters are presented. Numerical simulations are operated, which coincide with the theoretical derivations. Comparisons between Gaussian and Weibull stochastic fields have been made. The presented statistics of the Weibull polarimetric wave will be useful to random medium scattering and speckle filtering, which can also be extended to deal with the characterization of the scattering matrix elements in radar polarimetry. [J30]

"Estimation of the Equivalent Number of Looks in Polarimetric Synthetic Aperture Radar Imagery"

This paper addresses estimation of the equivalent number of looks (ENL), an important parameter in statistical modeling of multilook synthetic aperture radar (SAR) images. Two new ENL estimators are discovered by looking at certain moments of the multilook polarimetric covariance matrix, which is commonly used to represent multilook polarimetric SAR (PolSAR) data, and assuming that the covariance matrix is complex Wishart distributed. First, a second-order trace moment provides a polarimetric extension of the ENL definition and also a matrix-variate version of the conventional ENL estimator. The second estimator is obtained from the log-determinant matrix moment and is also shown to be the maximum likelihood estimator under the Wishart model. It proves to have much lower variance than any other known ENL estimator, whether applied to single-polarization or PolSAR data. Moreover, this estimator is less affected by texture and thus provides more accurate results than other estimators should the assumption of Gaussian statistics for the complex scattering coefficients be violated. These are the first known estimators to use the full covariance matrix as input, rather than individual intensity channels, and therefore to utilize all the statistical information available. We finally demonstrate how an ENL estimate can be computed automatically from the empirical density of small sample estimates calculated over a whole scene. We show that this method is more robust than procedures where the estimate is calculated in a manually selected region of interest. [J31]

"Efficient Generation of Method of Moments Matrices Using Equivalent Dipole-Moment Method"

In this letter, the equivalent dipole-moment (EDM) method is applied to compute the matrix elements of the method of moments (MoM) via solving the volume-surface integral equation (VSIE). Besides the advantage of reducing the calculation time significantly, this extended method is unnecessary to treat the boundary condition on the surface of dielectric body and easily constructed by using a simple procedure. The proposed approach can be applied if the distance between the source and the testing basis functions is beyond a threshold distance. Numerical results validate the efficiency and accuracy of the generated matrix elements, and the radar cross-section (RCS) has been verified. [J32]

"Generalized Transition Matrix for Arbitrarily Shaped Scatterers With Composite Structures"

A scatterer is regarded as a one-port device, and an associated generalized transition matrix is defined uniquely to describe the relationships between the rotated tangential scattered field components and the rotated tangential incident field components on a specified reference surface. The reference surface can be moved to proper surfaces with regular shapes, or even be extended to include a group of scatterers with arbitrary shapes and different materials. Furthermore, scatterers connected with perfectly electric conducting (PEC) plates can also be

handled with this one-port device model. Numerical results in two dimensions are provided to show that the generalized transition matrix is effective in analyzing large-scale scattering systems. [J33]

"Polarization Symmetric Scatterer Metric Space"

The coherent polarization scattering matrix decomposition presented in Cameron et al. brought attention to the importance of Symmetric Scatterer Space, the space of scattering matrices corresponding to symmetric scatterers. Each symmetric scatterer scattering matrix can be associated with a complex number z, the scatterer-type parameter, where |z| les 1. A distance measure, d(z1, z2), was defined on Symmetric Scatterer Space providing a means of comparing scattering matrices. It will be demonstrated that Symmetric Scatterer Space is a metric space with metric d(z1, z2). A new mapping of the Unit Disc representation of Symmetric Scatterer Space to a sphere is also presented along with a metric on the sphere, ds(thetas1, phi1; thetas2, phi2), that is equivalent to the metric d(z1, z2) on the Unit Disc. [J34]

"Using Multilook Averaging for Coherently Modeled Scattering From a Pine Tree at L-Band"

In this letter, we study scattering from a scots pine tree by using a realistic cylinder model of the tree and the coherent electric field scattering model. We study the directional variability of bistatic and monostatic scattering at L-band and show that, due to large variations in results, some averaging technique should be used to describe and interpret the model output efficiently. We propose that the needed averaging can be done by multilooking and that multilook data could be easily generated by rotating the tree model randomly around its vertical axis. We show that the resulting scattering data obey generally the multidimensional Gaussian distribution or the more general K-distribution, in a way similar to synthetic aperture radar (SAR) image pixels, and can therefore be represented by a single averaged covariance matrix. The trunk-ground reflection to the backscattering direction adds to the model output non-Gaussian behavior, which can be treated as texture. Covariance matrix formalism allows us to use descriptors which are commonly used to analyze SAR images, like target entropy and alpha angle. The method helps interpretation and comparison between the model output and SAR image. [J35]

"Joint Transmitter and Receiver Polarization Optimization for Scattering Estimation in Clutter"

Controlling the polarization information in transmitted waveforms enables improving the performance of radar systems. We consider the design of optimal polarizations at both the radar transmitter and receiver for the estimation of target scattering embedded in clutter. The goal is to minimize the mean squared error of the scattering estimation subject to an average radar pulse power constraint. Under the condition that the target and clutter scattering covariance matrices are known a priori, we show that such a problem is equivalent to the optimal design of a radar sensing matrix that contains the polarization information. We formulate the optimal design as a nonlinear optimization problem and then recast it in a convex form and is thus efficiently solvable by semi-definite programming (SDP). We compare the sensing performance of the optimally selected polarization over conventional approaches. Our numerical results demonstrate that a significant amount of power gain is achieved in the target scattering estimation through such an optimal design. [J36]

"Electromagnetic Scattering From Arbitrarily Shaped Dielectric Bodies Using Paired Pulse Vector Basis Functions and Method of Moments"

A pair of orthogonal pulse vector basis functions is demonstrated for the calculation of electromagnetic scattering from arbitrarily-shaped material bodies. The basis functions are intended for use with triangular surface patch modeling applied to a method of moments (MoM) solution. For modeling the behavior of dielectric materials, several authors have used the same set of basis functions to represent equivalent electric and magnetic surface currents. This practice can result in zero-valued or very small diagonal terms in the moment matrix and an unstable numerical solution. To provide a more stable solution, we have developed orthogonally placed, pulse basis vectors: one for the electric surface current and one for the magnetic surface current. This combination ensures strongly diagonal moment matrices. The basis functions are suitable for electric field integral equation (EFIE), magnetic field integral equation (HFIE), and combined field formulations. In this work, we describe the implementations for EFIE and HFIE formulations and show example results for canonical figures. [J37]

"Characteristic Polarization States Estimation in an Ultrawideband Context: A Frequency Approach"

The concept of characteristic polarization states (CPSs) is extended to an ultrawideband (UWB) context. This is achieved by a sparse representation of the target UWB scattering spectrum by a set of frequency bands associated with the target natural resonance modes. The polarization description involves using the average power within each resonant frequency band to derive the Kennaugh power matrix and, subsequently, a set of CPSs using the Lagrangian optimization procedure. To validate this, preliminary feature sets are formed by

extracting robust information from each derived CPS and then implementing a correlation measure criterion from which the relationships between these preliminary feature sets as a function of resonance order are established. These relationships are invariant to range and target orientation about the radar-target direction and are robust to noise. [J38]

"Microwave Subsurface Imaging Using Direct Finite-Difference Frequency-Domain-Based Inversion"

We have developed a new algorithm for electromagnetic inverse scattering problems in inhomogeneous media using finite-difference frequency-domain (FDFD) forward modeling, referred to as the FDFD-based inversion method. The key issue of this method is to build a linear expression for the inverse problem from an FDFD forward model by using Born approximation to neglect mutual coupling between scattered pixels and to then solve for the inverse coefficient matrix. An important advantage of this matrix-based method is that there is no need to specify a Green's function. As such, this inverse scattering algorithm is easily implemented and is robust to the heterogeneity in the background. We test the algorithm with a microwave subsurface object detection application using cross-well radar. The new method is compared with conventional inversion using Green's function-based Born approximation. Numerical experiments are presented for a 2-D borehole geometry for buried object detection in uniform soil and in multilayered soil backgrounds. [J39]

"The PALSAR Polarimetric Mode for Sea Oil Slick Observation"

A study on sea oil slick observation by means of L-band polarimetric synthetic aperture radar (SAR) data is accomplished. It is based on different sea surface scattering mechanism expected with and without surface slicks. Polarimetric measurements are processed by means of a simple and very effective filtering technique which is electromagnetically based on the Mueller scattering matrix. Moreover, some polarimetric features, evaluated on both slick-free and slick-covered sea surfaces, are analyzed for confirming the filter output. Experiments are accomplished on the polarimetric SAR data acquired by the Phased Array-type L-band Synthetic Aperture Radar (PALSAR) sensor, mounted on board of the Advanced Land Observing Satellite (ALOS), and are relevant to oil slick, due to a tank accident, and look-alikes. Results demonstrate for the first time that L-band polarimetric SAR measurements are useful for oil slick observation purposes and witness the capability of the ALOS PALSAR data for such application. [J40]

"Phased Array Radar Polarimetry for Weather Sensing: A Theoretical Formulation for Bias Corrections"

It is becoming widely accepted that radar polarimetry provides accurate and informative weather measurements, while phased-array technology can shorten data updating time. In this paper, a theory of phased array radar (PAR) polarimetry is developed to establish the relation between electric fields at the antenna of the PAR and the fields in a resolution volume filled with hydrometeors. It is shown that polarimetric measurements with an electronically steered beam can cause measurement biases that are comparable to or even larger than the intrinsic polarimetric characteristics of hydrometeors. However, these biases are correctable if the transmitted electric fields are known. A correction to the measured scattering matrix that removes biases in meteorological variables is derived. The challenges and opportunities for weather sensing with a polarimetric PAR are discussed. [J41]

"Radar target classification method with reduced aspect dependency and improved noise performance using multiple signal classification algorithm"

This study introduces a novel aspect and polarisation invariant radar target classification method based on the use of multiple signal classification (MUSIC) algorithm for feature extraction. In the suggested method, for each candidate target at each designated reference aspect, feature matrices called `MUSIC spectrum matrices (MSMs)` are constructed using the target`s scattered data at different late-time intervals. An individual MSM corresponds to a map of a target`s natural resonance-related power distribution over the complex frequency plane under the chosen aspect angle`late-time interval conditions. The collection of these feature matrices is used first to determine the best late-time interval for optimal feature extraction. Then, the MSM of a target, which are computed over the optimal time interval at all reference aspects, are superposed to obtain the `fused MUSIC spectrum matrix (FMSM)`. The FMSM of a target is its main classifier feature in the proposed method as the aspect dependency of an FMSM is highly reduced because of its multi-aspect construction process. The suggested method is demonstrated for both simple and complex target geometries such as conducting spheres, dielectric spheres and small-scale aircraft targets with high accuracy rates even for low SNR values using feature fusion at only a few different reference aspects. [J42]

"Analysis of Stepped-Frequency Pulse Train Design"

For uniform frequency stepped pulse trains, there can be undesirable peaks of the autocorrelation function, known as "grating lobes." In this paper we address this issue, using an approach which allows us to suppress grating lobes in the case of appropriately chosen stepped-frequency waveforms, i.e., sequences of narrowband pulses that span the desired bandwidth. We introduce a multiparametric generalization of a stepped-frequency train, and by exploiting a factorization of the autocorrelation function, will be able to effect a useful tradeoff between competing properties of the factors by careful choices of relevant parameters. We provide a detailed description of the method applied to a representative data set. [J43]

"Automatic Target Recognition by Means of Polarimetric ISAR Images and Neural Networks"

Inverse synthetic aperture radar (ISAR) images are often used for classifying and recognizing targets. Moreover, the use of fully polarimetric ISAR (Pol-ISAR) images enhances classification capabilities. In this paper, the authors propose a novel automatic target recognition (ATR) technique based on the use of fully Pol-ISAR images and neural networks (NNs). In order to reduce the amount of data processed by the classifier, the brightest scattering centers are first extracted by means of the Pol-CLEAN technique, and then, their scattering matrices are decomposed using Cameron's decomposition. A classifier based on the use of multilayer perceptron NN that makes use of the features extracted from the Pol-ISAR images is then implemented. A proof-of-concept test is performed on real data acquired during a controlled experiment in an anechoic chamber. [J44]

"An Optimization Procedure of the Lagrange Multiplier Method for Polarimetric Power Optimization"

The Lagrange multiplier method is one of the basic optimization procedures to find the optimum polarizations for the incoherent scattering case. This letter proves for the first time that a fixed relationship exists between the optimum polarization and the Lagrange multiplier. Then, an optimization procedure is proposed to simplify the computational complexity of the Lagrange multiplier method. To speed up the convergence of the proposed procedure, the minimum search intervals are discussed and given theoretically. A numerical example is shown to demonstrate the effectiveness of the proposed procedure. [J45]

"Solution of Electrically Large Problems With Multilevel Characteristic Basis Functions"

We present a multilevel version to the characteristic basis function method (CBFM). This technique extends the range of applicability of the conventional CBFM and allows a direct solution of problems even when they exceed 250,000 degrees of freedom. In this paper, it is shown how we can use the multilevel CBFM, which is a natural extension of the conventional approach and which saves both time and memory, and yet retains excellent accuracy in the computed far fields. Also, the adaptive cross algorithm is used for fast calculation of the interaction between the blocks in the process of generating the reduced matrix. [J46]

"A New Numerical Method for Calculating Extrema of Received Power for Polarimetric SAR"

A numerical method called cross-step iteration is proposed to calculate the maximal/minimal received power for polarized imagery based on a target's Kennaugh matrix. This method is much more efficient than the systematic method, which searches for the extrema of received power by varying the polarization ellipse angles of receiving and transmitting polarizations. It is also more advantageous than the Schuler method, which has been adopted by the PolSARPro package, because the cross-step iteration method requires less computation time and can derive both the maximal and minimal received powers, whereas the Schuler method is designed to work out only the maximal received power. The analytical model of received-power optimization indicates that the first eigenvalue of the Kennaugh matrix is the supremum of the maximal received power. The difference between these two parameters reflects the depolarization effect of the target's backscattering, which might be useful for target discrimination. [J47]

"Algebraic Synthesis of Forest Scenarios From Multibaseline PolInSAR Data"

In this paper, a new methodology is proposed for the analysis of forested areas basing on multipolarimetric multibaseline synthetic aperture radar (SAR) surveys. Such a methodology is based on three hypotheses: 1) statistical uncorrelation of the different scattering mechanisms (SMs), such as ground, volume, and ground-trunk scattering; 2) independence of volumetric and temporal coherence losses of each SM on the choice of the polarimetric channel; and 3) invariance (up to a scale factor) of the average polarimetric signature of each SM with respect to the choice of the track. Under these hypotheses, the data covariance matrix can be expressed as a Sum of Kronecker Products, after which it follows that K SMs are uniquely identified by K (K-1) real numbers. This result provides the basis to perform SM separation by employing not only model-based approaches, generally retained in literature but also model-free and hybrid approaches, while yielding the best Least Square

solution given the hypothesis of K SMs. It will be shown that this approach to SM separation is consistent with the inversion procedures usually exploited in single-baseline polarimetric SAR interferometry. Experimental validation of this methodology is provided on the basis of the P-band data set relative to the forest site of Remningstorp, Sweden, acquired by German Aerospace Center's E-SAR airborne system in the framework of the European Space Agency campaign BioSAR. [J48]

"Knowledge-aided covariance matrix estimation: a MAXDET approach"

The authors consider the problem of knowledge-aided covariance matrix estimation and its application to adaptive radar detection. The authors assume that an a priori (knowledge-based) estimate of the disturbance covariance M, derived from a physical scattering model of the terrain and/or of the environment, is available. Hence, starting from a set of secondary data, the authors evaluate the maximum likelihood (ML) estimate of Massuming that it lies in a suitable neighbourhood of the a priori estimate and formulate this ML estimation in terms of a convex optimisation problem which falls within the class of MAXDET problems. Both the cases of unstructured and structured disturbance covariance are considered. At the analysis stage, the authors assess the performance of the new knowledge-aided covariance estimators both in terms of estimation error and detection probability achievable by a class of adaptive detectors. The results highlight that, if the a priori knowledge is reliable, satisfactory levels of performance can be achieved with considerably less training data than those exploited by conventional algorithms. [J49]

"Hybrid FEM/Floquet Modes/PO Technique for Multi-Incidence RCS Prediction of Array Antennas"

An original method is proposed which associates rigorous 3D finite element methods (FEM) with Floquet modes through FACTOPO multidomain formalism for computing the radar cross section (RCS) of large array antennas. The most original aspect of the method is the fact that the source unit cell is characterized by a generalized scattering matrix (GSM) which does not depend on the plane wave incidence impinging the structure. Consequently, the factorization step of the FEM matrix, which is the main computational effort, is performed only once. The assembling procedure consists then in expressing the FEM GSM matrix in the Floquet mode basis for each incidence and to solve a linear system giving the complex amplitude of the Floquet modes on the array/cell interface. Associated with this formalism, lateral and back structure effects can be treated using physical optics (PO) combined with the equivalent current method (ECM) to improve the accuracy for far broadside incidence. [J50]

"POLSAR Image Analysis of Wetlands Using a Modified Four-Component Scattering Power Decomposition"

It is important to monitor environmental changes of the Earth's cover by remotely sensed data. This paper analyzes seasonal changes of a wetland by a modified polarimetric four-component scattering power decomposition method. The data sets analyzed here are L- and X-band fully polarimetric synthetic aperture radar (POLSAR) data, which have been acquired by the NICT/JAXA airborne polarimetric and interferometric synthetic aperture radar system in 2004. Since there existed a deficiency in the currently adopted decomposition schemes in that negative powers appear in a few pixels in the image analysis, we modified the approach taking into account physical conditions. It is shown by the modified scheme that the seasonal changes and features of the vegetation near Sakata Lagoon in Niigata, Japan, are observed clearly, demonstrating the utility of POLSAR image analysis for wetland assessments in general. [J51]

"GLRT subspace detection for range and Doppler distributed targets"

A generalized likelihood ratio test (GLRT) is derived for adaptive detection of range and Doppler-distributed targets. The clutter is modeled as a spherically invariant random process (SIRP) and its texture component is range dependent (heterogeneous clutter). We suppose here that the speckle component covariance matrix is known or estimated thanks to a secondary data set. Thus, unknown parameters to be estimated are local texture values, the complex amplitudes and Doppler frequencies of all scattering centers. To do so, we use superresolution methods. The proposed detector assumes a priori knowledge on the spatial distribution of the target and has the precious property of having a constant false alarm rate (CFAR) with the assumption of a known speckle covariance matrix or by the use of frequency agility. [J52]

"Efficient Multilevel Approach for the Generation of Characteristic Basis Functions for Large Scatters"

An efficient approach for deriving the characteristic basis functions (CBFs) for analyzing radiation and scattering problems is proposed. The spectrum of the incident plane waves is partitioned into several angular regions that

are progressively enlarged in a multilevel procedure to generate orthogonal functions. The CBFs are obtained at the final orthogonalization level, so that they cover the entire angular range. This approach to generating the CBFs is better suited for electrically large objects than the conventional approach, which utilizes the entire angular range (visible) of the plane wave spectrum in a single level. [J53]

"An Iteration-Free MoM Approach Based on Excitation Independent Characteristic Basis Functions for Solving Large Multiscale Electromagnetic Scattering Problems"

We describe a numerically efficient strategy for solving a linear system of equations arising in the Method of Moments for solving electromagnetic scattering problems. This novel approach, termed as the characteristic basis function method (CBFM), is based on utilizing characteristic basis functions (CBFs)-special functions defined on macro domains (blocks)-that include a relatively large number of conventional sub-domains discretized by using triangular or rectangular patches. Use of these basis functions leads to a significant reduction in the number of unknowns, and results in a substantial size reduction of the MoM matrix; this, in turn, enables us to handle the reduced matrix by using a direct solver, without the need to iterate. In addition, the paper shows that the CBFs can be generated by using a sparse representation of the impedance matrix-resulting in lower computational cost-and that, in contrast to the iterative techniques, multiple excitations can be handled with only a small overhead. Another important attribute of the CBFM is that it is readily parallelized. Numerical results that demonstrate the accuracy and time efficiency of the CBFM for several representative scattering problems are included in the paper. [J54]

"Equivalence Between Cameron's Unit Disc and PoincarЙ's Sphere for Symmetric Scattering Characterization and Classification"

Scattering type classification represents a significant step toward target classification. Both the surface of Poincare's sphere and Cameron's unit disc have been used separately to represent symmetric scattering matrices and to define classification methods. In this letter, the equivalence of using the surface of Poincare's sphere and Cameron's unit disc in terms of characterization and classification of symmetric scattering types is demonstrated mathematically. [J55]

"Statistical Properties of the Estimated Degree of Polarization"

We derive important and useful new statistical properties of the estimated degree of polarization in the two-dimensional case. We find its distribution function and show how it may be used to construct confidence intervals. We also find an expression for any moment of the distribution, and derive an exact unbiasing formula for the estimator of the squared coefficient. Further we discuss a test for partial polarization. Our statistical analyses enable identification of elliptical polarization for an ultra low frequency wave in the solar magnetic field. [J56]

"Polarimetric Characterization of Bistatic Coherent Mechanisms"

This paper proposes a generalization of the Huynen theory to bistatic radar configurations for which the scattering matrices can no longer be assumed symmetrical. A set of parameters characterizing the physical mechanisms is extracted from the disoriented bistatic Kennaugh matrix. The distribution of amplitude between the parameters of the disoriented Kennaugh matrix is studied. [J57]

"A Bandwidth Estimation Approach for the Asymptotic Waveform Evaluation Technique"

The asymptotic waveform evaluation (AWE) technique has been widely used for handling the fast parameter sweep. However, how to determine the sweep bandwidth is still an open question. This work proposes an efficient and flexible bandwidth estimation approach. This approach also naturally leads to an efficient multipoint AWE technique. The validity of the proposed approach is verified by numerical experiments on the AWE-incorporated hybrid finite element/boundary integral (FE/BI) method for scattering problem. Numerical experiments show that this approach can greatly improve the efficiency and practical capability of the AWE technique. [J58]

"On the Use of the Singular Value Decomposition in the Fast Multipole Method"

The authors present a new matrix compression algorithm to improve the efficiency of the fastmultipolemethod(FMM). The method is based on the application of the singularvaluedecomposition(SVD) to the plane wave FMM aggregationmatrices. These matrices are low-ranked, which is exploited to provide alternative sets of orthonormal singularbasis functions, obtained as linear combinations of the original basis. By choosing only the most relevant singular functions, a much more compact representation is obtained to

accurately handle the interactions between the FMM groups. The new formulation provides a reduction close to one order of magnitude both in computational cost and memory requirements, with a moderate impact on the accuracy of the solution. [J59]

"Wind turbine effects on VOR system performance"

The implementation of wind farms establishment in France is increasing. When wind farms are located close to radionavigation systems, it becomes important to evaluate their electromagnetic effects on existing radionavigation instalations. In this study, the radionavigation system is a VOR (VHF omnidirectional radio) operating at about 110 MHz. Because rotor blades are made of a balsa and dielectric multilayers composition, their electromagnetic behavior differs from that of metal blades at VHF frequences. In this study, we first obtain an electromagnetic CAD model from a real structural design; then we calculate the far field scattering matrix from an integral method (CESC code [1] method of moment) for a (30 m) dielectric blade and compare it with a metal one using RCS (radar cross section) calculation. The impact of (40 m long) dielectric blades is compared with the (65 m high) metal mast effect in terms of scattered field, and then the VOR error (bearing error) is evaluated. These results are analyzed for several geometrical configurations of a three-bladed rotor and compared with the mast. The study is extended on wind farms to discuss geometrical configuration effects with regard to a VOR location. [J60]

"Fast Solution of Scattering From Conducting Structures by Local MLFMA Based on Improved Electric Field Integral Equation"

In this paper, a local multilevel fast multipole algorithm (LMLFMA) based on an improved electric field integral equation (IEFIE) is developed to achieve fast and efficient solution of electromagnetic scattering from 3-D conducting structures. The IEFIE is used to reduce iteration number, and LMLFMA is applied to further accelerate the computation of matrix-vector multiplications in iteration, in which only the local interactions between subscatterers are taken into account. Numerical results show that the present method attains faster iterative convergence than traditional EFIE and less computational cost than MLFMA. The speedup can achieve at least 4-5 times while keeping an rms error of less than 2 dB. [J61]

"Frequency Interpolation of the Electromagnetic Surface Currents Via Singular Value Decomposition. Application to High-Frequency Analysis"

The time-harmonic electromagnetic scattering from conducting surfaces is considered. In this context, a recently published model order reduction for frequency interpolation of the surface current via singular value decomposition (SVD) is analyzed and evaluated: the exact currents computed at Qfrequencies are arranged columnwise in a matrix, the SVD of which provides an orthonormal basis; on account of the observed exponential decrease of the singular values of this matrix, it is assumed that the dimension of the basis required for an accurate interpolation is much smaller than the number of unknowns in the original formulation. We propose in this paper a formal framework that justifies this decrease of the singular values, as well as the corresponding behavior of the interpolation error made on the current. From considerations based on high-frequency electromagnetics, it is shown that this method can be interpreted in terms of sampling criteria for the current, that yield an aprioriestimate for the minimum value of Q. Numerical examples illustrate the capacities of this technique for frequency interpolation and for high-frequency analysis of the currents. [J62]

"Model-Based Polarimetric SAR Speckle Filter"

In this paper, a new framework to filter speckle noise in polarimetric synthetic aperture radar (PolSAR) data is presented. The proposed filter, named the model-based PolSAR (MBPolSAR) filter, is based on exploiting the multiplicative-additive speckle noise model for multidimensional SAR data. The entries of the sample covariance matrix are processed according to this multiplicative-additive speckle noise model as a function of the complex correlation coefficient. Hence, the covariance matrix elements are processed differently. This filtering scheme improves the reduction of speckle noise and ameliorates the estimation of the polarimetric information. The filtering performances of the MBPolSAR approach are first tested quantitatively by means of simulated PolSAR data. In a second stage, they are evaluated by means of experimental SAR data acquired by the Deutsches Zentrum fu umlr Luft-und Raumfahrt. [J63]

"On the Mueller Scattering Matrix for SAR Sea Oil Slick Observation"

In this letter, a fully polarimetric electromagnetic model for sea surface Mueller matrix is exploited to characterize the scattering from oil and biogenic slicks, under low-to-moderate wind conditions. The model predicts a completely different scattering mechanism for oil-covered and oil-free sea surface, while biogenic slicks are

indistinguishable from sea surface in terms of polarimetric scattering. Following this theoretical rationale, a simple and very effective filtering technique is proposed for synthetic aperture radar (SAR) sea oil slick observation. Experiments, accomplished over C-band multilook complex SIR-C/X-SAR data, show the effectiveness of the proposed model and the capabilities of the filter to both observe oil slicks and distinguish them from biogenic look-alikes. [J64]

"Classification With a Non-Gaussian Model for PolSAR Data"

In this paper, we present a generalized Wishart classifier derived from a non-Gaussian model for polarimetric synthetic aperture radar (PolSAR) data. Our starting point is to demonstrate that the scale mixture of Gaussian (SMoG) distribution model is suitable for modeling PolSAR data. We show that the distribution of the sample covariance matrix for the SMoG model is given as a generalization of the Wishart distribution and present this expression in integral form. We then derive the closed-form solution for one particular SMoG distribution, which is known as the multivariate K-distribution. Based on this new distribution for the sample covariance matrix, termed as the K-Wishart distribution, we propose a Bayesian classification scheme, which can be used in both supervised and unsupervised modes. To demonstrate the effect of including non-Gaussianity, we present a detailed comparison with the standard Wishart classifier using airborne EMISAR data. [J65]

"Spectral Elements for the Integral Equations of Time-Harmonic Maxwell Problems"

We present a novel high-order method of moments (MoM) with interpolatory vector functions, on quadrilateral patches. The main advantage of this method is that the Hdiv conforming property is enforced, and at the same time it can be interpreted as a point-based scheme. We apply this method to field integral equations (FIEs) to solve time-harmonic electromagnetic scattering problems. Our approach is applied to the first and second Nedelec families of Hdiv conforming elements. It consists in a specific choice of the degrees of freedom (DOF), made in order to allow a fast integral evaluation. In this paper we describe these two sets of DOF and their corresponding quadrature rules. Sample numerical results on FIE confirm the good properties of our schemes: faster convergence rate and cheap matrix calculation. We also present observations on the choice of the discretization method, depending on the FIE selected. [J66]

"Measurement and Characterization of Entropy and Degree of Polarization of Weather Radar Targets"

To date, few polarimetric weather radars have exhibited the capability to measure full scattering matrices. In contrast, in the synthetic aperture radar (SAR) community, considerable experience has been gained in dealing with complete scattering matrices and their statistical behavior. This paper aims to place weather radar parameters in a wider context in order to exploit more general concepts like target decomposition theorems and polarization basis transformations. Entropy, which is a fully polarimetric variable derived from the Cloude-Pottier decomposition, and the degree of polarization, which is derived from Wolf's coherence matrix, are the subject of this paper. The theoretical analysis carried out in the first part is checked against fully polarimetric data from POLDIRAD, which is the german aerospace center research weather radar. The entropy and the degree of polarization are compared with the copolar correlation coefficient in order to understand whether they can add value to radar meteorological investigations. Because the degree of polarization is available to conventional dual-polarization coherent systems, it is important to assess its potential for operational use. [J67]

"The Compact Polarimetry Alternative for Spaceborne SAR at Low Frequency"

In spaceborne synthetic aperture radar (SAR), a single-polarization on-transmit offers twice the swath width compared to full polarization. This is linked to SAR system design issues, and, without getting into the technical details deserving by themselves a full paper, we can just mention the swath characteristics of ALOS PALSAR (the Advanced Land Observing Satellite, Phased Array L-Band Synthetic Aperture Radar), reducing from 70 km for the dual-pol mode to 30 km for the full polarization mode. The reduced coverage in the full polarization mode has a harmful impact on the revisit time, which is always a major drive for the Earth-observing community. The options chosen up to now for dual-pol system designs (or single-polarization on-transmit) rely on a linear polarization on-transmit [either horizontal (H) or vertical (V)], with two orthogonal polarizations on-receive. Souyris and Raney in earlier papers proposed more pertinent alternatives for the selection of the transmit polarization leading to a better characterization of the scattering mechanisms. In this paper, the analysis is pursued in more depth by including the effect of the ionosphere on the wave propagation and extending the applications to polarimetric interferometry SAR (PolInSAR). A compact mode is developed where the transmit polarization is circular, whereas the only constraint on the two receiving polarizations is independence. Indeed, the choice of the polarizations of the two receive channels does not matter, as any polarization on-receive can be synthesized from these two measurements. This is, however, not the case for the unique transmit

polarization. At a low frequency, where the ionosphere has a significant effect, the circular transmit polarization is the only sensible option, as it provides an effective constant polarization as seen by the scattering surface. This is an essential condition for a meaningful multitemporal analysis. Both the polarimetric SAR applications and the PolInSAR appl--ications in the context of this compact polarimetry (CP) mode are explored. A pseudocovariance matrix can be reconstructed following Souyris' proposed approach for distributed targets and is shown to be very similar to the full polarimetric (FP) covariance matrix. The reconstruction of the cross-polarized Sigma0 is shown to be reliable and to have very low sensitivity to Faraday rotation. A PolInSAR vegetation height inversion for P-band is presented and applied to the CP data with a level of performance that is similar to the one derived from FP (a 1.2-m root-mean-square height error on the ONERA Airborne radar (RAMSES) data over the Landes Forest). A procedure is developed to correct for the ionospheric effects for the PolInSAR acquisition in the FP or CP mode and is assessed on the data simulated from an airborne acquisition. The results demonstrate that the technique is efficient and robust. The calibration of CP data is identified as an important challenge to be solved, and some clues are provided to address the problem. [J68]

"Analysis of the Effects of Faraday Rotation on Spaceborne Polarimetric SAR Observations at -Band"

Spaceborne microwave observation of subcanopy and subsurface requires the polarimetric synthetic aperture radar (SAR) technology at lower microwave frequencies, such as P-band. However, SAR observation at P-band is remarkably influenced by the Faraday rotation (FR) effect through the ionosphere. An example in this paper illustrates why the measured polarimetric data with FR at P-band cannot be directly applied to terrain surface classification. We further present that the parameters u, nu, H, alpha, A for terrain surface classification derived from the polarimetric data without FR, which are recovered from the data with FR, can be applied to the surface classification, there is a plusmnpi/2 ambiguity error unresolved. Based on gradual change of the FR degree along a geographical location, a method to eliminate the plusmnpi/2 ambiguity error is designed. Thus, the polarimetric scattering vector and Mueller matrix without FR and plusmnpi/2 ambiguity can be fully inverted from the measured polarimetric data with FR [J69]

"Active Learning Applied to RCS Computations With Nonuniform Sampling Using Different Objective Functions"

An active learning framework is introduced to reduce the number of frequencies and angles one must consider for wideband monostatic scattering computations or measurements. This method is used to optimally select those frequencies and angles that would be most informative, resulting in nonuniform sampling and often a reduced number of points (vis-agrave-vis uniform sampling). In this paper we focus on jointly two-dimensional optimal sampling in frequency and incident angle thetas for monostatic scattering. The method consists of two basic steps. One step involves estimation of model parameters using a least-square (LS) algorithm. The next step is to optimally choose the next point (frequency and thetas) for analysis by the computational model or experiment. This new point is selected with the goal of reducing uncertainty in the parametric model (quantified via the Fisher information matrix). Iterating these two steps, a sequence of numerical computations or measurements are performed, each at the most informative point for learning the parameters of the associated simpler parametric model. This idea is demonstrated here in the context of reducing the number of points (frequencies and orientations) at which a computational model must be employed. And in order to avoid repeatedly gathering samplings at the edge of the input space, an alternative objective function is applied which makes the actively selected points closer to a region of interest [J70]

"MIMO radar waveform design based on mutual information and minimum mean-square error estimation"

This paper addresses the problem of radar waveform design for target identification and classification. Both the ordinary radar with a single transmitter and receiver and the recently proposed multiple-input multiple-output (MIMO) radar are considered. A random target impulse response is used to model the scattering characteristics of the extended (nonpoint) target, and two radar waveform design problems with constraints on waveform power have been investigated. The first one is to design waveforms that maximize the conditional mutual information (MI) between the random target impulse response and the reflected waveforms given the knowledge of transmitted waveforms. The second one is to find transmitted waveforms that minimize the mean-square error (MSE) in estimating the target impulse response. Our analysis indicates that under the same total power constraint, these two criteria lead to the same solution for a matrix which specifies the essential part of the optimum waveform design. The solution employs water-filling to allocate the limited power appropriately. We also present an asymptotic formulation which requires less knowledge of the statistical model of the target [J71]

"Groundwave Modeling and Simulation Strategies and Path Loss Prediction Virtual Tools"

Reliable and accurate groundwave propagation path loss prediction between a pair of transmitter/receiver necessitates a good understanding of electromagnetic wave scattering in the presence of non-flat terrain and inhomogeneous atmosphere, and this is one of the major issues in radio communication and radar systems design. A propagation engineer desires to have a numerical propagator that calculates the radiowave path loss, without going into details and/or having a deep knowledge of the propagation phenomena, between any two points specified on a digital map of the area of interest. Since a generally applicable, all-purpose propagation prediction method has not developed yet one has to understand validity and accuracy ranges, and the limitations of available prediction models and tools; this certainly requires, to some extent, the physical insight of the propagation problem at hand. This article aims to summarize groundwave propagation modeling and numerical simulation strategies, and to review some of the virtual tools, introduced recently. [J72]

"Re-examination of analytical models for microwave scattering from deciduous leaves"

This paper presents an examination of classical scattering models for radar cross sections of deciduous leaves, such as the generalised Rayleigh-Gans (GRG) model and the physical optics (PO) model. The PO model employs the resistive sheet approximation in this study. The validity regions of the analytical models for microwave scattering from deciduous leaves are investigated by comparison with the precise numerical results of the method of moment. It was found that the GRG and PO models extend their validity regions for estimating the scattering amplitudes as the thickness of a lossy dielectric disk decreases. The GRG and PO models can be used alternatively for computing the scattering matrices of natural deciduous leaves at microwave frequencies regardless of the size of the leaves, because of the very small thickness of the leaves (0.2-0.4 mm) [J73]

"Dual-Baseline Coherence Tomography"

In this letter, we consider a dual-baseline formulation of coherence tomography and show how practical application of the method is limited by numerical stability. To help reduce this, we propose a regularization technique based on a matrix singular value decomposition to stabilize the inversion. We then apply the new dual-baseline algorithm to ground-based radar data from the European Microwave Signature Laboratory. We consider a sample of maize plants and employ dual-baseline interferometric data to reconstruct vertical tomograms through the vegetation as a function of frequency. We use these reconstructions to interpret the primary scattering mechanisms and their polarization dependence [J74]

"Target Scattering Decomposition in Terms of Roll-Invariant Target Parameters"

The Kennaugh-Huynen scattering matrix con-diagonalization is projected into the Pauli basis to derive a new scattering vector model for the representation of coherent target scattering. This model permits a polarization basis invariant representation of coherent target scattering in terms of five independent target parameters, the magnitude and phase of the symmetric scattering type introduced in this paper, and the maximum polarization parameters (orientation, helicity, and maximum return). The new scattering vector model served for the assessment of the Cloude-Pottier incoherent target decomposition. Whereas the Cloude-Pottier scattering type alpha and entropy H are roll invariant, beta and the so-called target-phase parameters do depend on the target orientation angle for asymmetric scattering. The scattering vector model is then used as the basis for the development of new coherent and incoherent target decompositions in terms of unique and roll-invariant target parameters. It is shown that both the phase and magnitude of the symmetric scattering type should be used for an unambiguous description of symmetric target scattering. Target helicity is required for the assessment of the symmetry-asymmetry nature of target scattering. The symmetric scattering type phase is shown to be very promising for wetland classification in particular, using polarimetric Convair-580 synthetic aperture radar data collected over the Ramsar Mer Bleue wetland site to the east of Ottawa, Ontario, Canada [J75]

"Multiple-Scattering Formulation of Pulsed Beam Waves in Hydrometeors and Its Application to Millimeter-Wave Weather Radar"

This letter deals with the backscattering of millimeter pulsed beam waves from hydrometeors. A new approach is presented for a solution of time-dependent three-dimensional vector radiative transfer equation for the Stokes vectors to study the multiple-scattering effects of beam waves on radar echoes. General solutions for beam waves are derived in an integral form without any approximation. They are given in numerically tractable forms representing the scattering process in the space and time domain. Time-dependent second-order solutions for radar echoes of pulsed beam waves are straightforwardly obtained to predict multiple-scattering effects depending on the variation of an incident beam size. It is shown that the inhomogeneity of the radial direction of beam waves causes the mode coupling of waves between the azimuth directions in the scattering matrix, and that the mode coupling depends on the ratio of the incident beam size to the total mean free path length of the

medium [J76]

"On the Extension of Multidimensional Speckle Noise Model From Single-Look to Multilook SAR Imagery"

Speckle noise represents one of the major problems when synthetic aperture radar (SAR) data are considered. Despite the fact that speckle is caused by the scattering process itself, it must be considered as a noise source due to the complexity of the scattering process. The presence of speckle makes data interpretation difficult, but it also affects the quantitative retrieval of physical parameters. In the case of one-dimensional SAR systems, speckle is completely determined by a multiplicative noise component. Nevertheless, for multidimensional SAR systems, speckle results from the combination of multiplicative and additive noise components. This model has been first developed for single-look data. The objective of this paper is to extend the single-look data model to define a multilook multidimensional speckle noise model. The asymptotic analysis of this extension, for a large number of averaged samples, is also considered to assess the model properties. Details and validation of the multilook multidimensional speckle noise model are provided both theoretically and by means of experimental SAR data acquired by the experimental synthetic aperture radar system, operated by the German Aerospace Center [J77]

"Electromagnetic Scattering From Multilayer Rough Surfaces With Arbitrary Dielectric Profiles for Remote Sensing of Subsurface Soil Moisture"

Radar remote sensing of soil moisture content at low frequencies requires an accurate scattering model of realistic soils, which often involves multilayer rough surfaces and dielectric profiles. In this paper, a hybrid analytical/numerical solution to two-dimensional scattering from multilayer rough surfaces separated by arbitrary dielectric profiles based on the extended boundary condition method (EBCM) and scattering matrix technique is presented. The reflection and transmission matrices of rough interfaces are constructed using EBCM. The dielectric profiles are modeled as stacks of piecewise homogeneous dielectric thin layers, whose scattering matrices are computed by recursively cascading reflection and transmission matrices of individual dielectric interfaces. The interactions between the rough interfaces and stratified dielectric profiles are taken into account by applying the generalized scattering matrix technique. The scattering coefficients are obtained by combining the powers computed from the resulting Floquet modes of the overall system. The bistatic scattering coefficients are validated against existing analytical and numerical solutions. Field-collected soil moisture data are then used for numerical simulations to investigate the penetration capability at different frequencies and to address the potential of low-frequency radar systems in estimating deep soil moisture. In particular, soil moisture profiles during dry ground, wet ground, and wet subsurface layer conditions are examined. The results show that both backscattering coefficients and copolarized phase difference at low frequencies are sensitive to the roughness of subsurface interfaces and deep soil moisture. Also, much larger depth sensitivity can be achieved using copolarized phase difference than scattering coefficients [J78]

"An Efficient Volume Integral Equation Solution to EM Scattering by Complex Bodies With Inhomogeneous Bi-Isotropy"

A generalized volume integral equation method is formulated for electromagnetic scattering by arbitrarily shaped complex bodies with inhomogeneous bi-isotropy. Based on the volume equivalence principle, the integral equations are represented in terms of a pair of coupled bi-isotropic polarized volume electric and magnetic flux densities. Reduction of the integral equations into the corresponding matrix equations is obtained using the method of moments (MoM) combined with the tetrahedral mesh. In the MoM solution, the three-dimensional solenoidal function is incorporated as the basis function defined over each tetrahedral element and the details of implementation, particularly the treatment of integral singularities, will be elucidated. The efficiency and accuracy of the proposed method are validated by illustratively supported examples. [J79]

"Electromagnetic Scattering From a Rough Layer: Propagation-Inside-Layer Expansion Method Combined to an Updated BMIA/CAG Approach"

An efficient method is developed to calculate the bistatic scattering coefficient (BSC) from a stack of two one-dimensional rough interfaces separating homogeneous media. The propagation-inside-layer expansion (PILE) method recently published by Dechamps was efficient with a complexity O(N2) (N being the number of samples per interface). To reduce this complexity, a fast method valid for a single rough surface, the banded matrix iterative approach/canonical grid (BMIA/CAG) is combined to the PILE method. Furthermore, the calculation of the coupling interactions between both interfaces are also accelerated using a new method similar to the BMIA/CAG. The PILE method reaches then a complexity of only O(NlogN). A study of the convergence of the PILE is done and compared to another efficient method, the forward-backward. [J80]

"A Spectral Multigrid Method Combined With MLFMM for Solving Electromagnetic Wave Scattering Problems"

A new spectral multigrid method (SMG) combined with the multilevel fast multipole method (MLFMM) is proposed for solving electromagnetic wave scattering problems. The MLFMM is used to speed up the matrix-vector product operations and the SMG is employed to accelerate the convergence rate of the Krylov iteration. Unlike traditional algebraic multigrid methods (AMG), the spectral multigrid method is an algebraic two-grid cycle built on a preconditioned Krylov iterative method that is used as the smoother, and the grid transfer operators are defined using the spectral information of the preconditioned matrix. Numerical experiments indicate that this class of multigrid method is very effective with the MLFMM and can reduce both the iteration number and the overall simulation time significantly. [J81]

"Power Optimization for Polarimetric Bistatic Random Mechanisms"

The aim of this paper is to investigate the optimal polarizations (i.e., emitted and received polarizations for which the received power is maximum or minimum) in the general case of random mechanisms observed by a bistatic full-polarimetric radar. We are particularly interested in the methods leading to analytical solution as far as this is possible. It is the reason why the Kennaugh matrix is taken as the starting point of the optimizations. The optimal polarizations corresponding to the monostatic and bistatic deterministic cases are found again as particular cases. [J82]

"Variational Low Frequency Scattering by a Rectangular Trough in a Hard Ground Plane"

A set of analytical expressions are presented for the diffraction from a rectangular trough when excited by a transverse-electric polarized plane-wave. The final explicit forms are appropriate for applications requiring efficient computation, making minimal use of special functions and requiring no matrix inversions. The solution is arrived at via a quasi-static variational technique wherein the aperture field is represented by a linear combination of three simple functions suggested by the solution to Laplace's equation in the channel geometry. Comparison with an independent moment method indicates that the variational solution to the dynamic problem is highly accurate for troughs of general depth. The upper limit on the frequency corresponds to a total aperture width of one-half of a free-space wavelength. [J83]

"Design Principles of MIMO Radar Detectors"

This paper considers the problem of multiple-input multiple-output (MIMO) radars employing space-time coding (STC) to achieve diversity. To this end, after briefly outlining the model of the received echo, a suitable detection structure is derived, and its performance is expressed in closed form as a function of the clutter statistical properties and of the space-time code matrix. Interestingly, this receiver requires prior knowledge of the clutter covariance, but the detection threshold is functionally independent thereof. At the transmitter design stage, we give two criteria for code construction: the first is based on the classical Chernoff bound, the second is an information-theoretic criterion. Interestingly, the two criteria lead to the same condition for code optimality, which in turn specializes, under the assumption of uncorrelated clutter and square code matrix, in some well-known full-rate space-time codes. A thorough performance assessment is also given, so as to establish the optimum achievable performance for MIMO radar systems. [J84]

"Analytic performance bounds on estimates of scattering center parameters"

Cramer-Rao bounds (CRBs) on the estimates of the main scattering center parameters, i.e., the position, intensity and geometry type, are presented in analytic forms. The resolution limit for wideband radar and the SNR threshold for the correct identification of the geometry type parameter of scattering centers are further deduced. Though the results are obtained from the CRB matrix for damped exponentials (DE) after many approximations and simplifications, their validity and adaptability for geometric theory of diffraction (GTD) based scattering center model have been verified both numerically and experimentally. [J85]

"MoM Analysis of Dipole Antennas in Crosshole Borehole Radar and Field Experiments"

In this paper, we propose a method-of-moments (MoM) analysis that includes the borehole effects on crosshole borehole radar, and we verify that the MoM represents the crosshole borehole radar data correctly. We derive the far-field approximation of an electric field radiated by an electric point source. In this derivation, we assume that the point source is in a cylindrically layered medium, while the observed electric field is in another cylindrically layered medium. The equations that are derived are used as a transfer function to connect the two impedance matrices-one for the transmitting antenna and the other one for the receiving one. In these matrices,

the influence of the scattered field by the borehole is included completely. We conducted field experiments in granite with a controlled borehole medium in order to investigate the influence of the borehole. In this paper, we estimated the relative amplitude and the group delay of the received signals between the water-filled borehole case and the air-filled borehole case. This paper showed that the estimated amplitude and delay depend on the frequency and that the proposed MoM could predict these frequency dependencies. [J86]

"Spectral Two-Step Preconditioning of Multilevel Fast Multipole Algorithm for the Fast Monostatic RCS Calculation"

A new spectral two-step preconditioning of multilevel fast multipole algorithm (MLFMA) is proposed to solve large dense linear systems with multiple right-hand sides arising in monostatic radar cross section (RCS) calculations. The first system is solved with a deflated generalized minimal residual (GMRES) method and the eigenvector information is generated at the same time. Based on this eigenvector information, a spectral preconditioner is defined and combined with a previously constructed sparse approximate inverse (SAI) preconditioner in a two-step manner, resulting in the proposed spectral two-step preconditioner. Restarted GMRES with the newly constructed spectral two-step preconditioner is considered as the iterative method for solving subsequent systems and the MLFMA is used to speed up the matrix-vector product operations. Numerical experiments indicate that the new preconditioner is very effective with the MLFMA and can reduce both the iteration number and the computational time significantly. [J87]

"Polarimetric Analysis of Bistatic SAR Images From Polar Decomposition: A Quaternion Approach"

This paper focuses on polar decomposition, which is based on the quaternion formalism, in single-look and multilook synthetic aperture radar polarimetry. Polar decomposition is used to decompose a bistatic or monostatic polarimetric scattering matrix into a product of a Hermitian matrix (boost) and a unitary matrix (rotation). After an overview of polar decomposition principle and quaternion properties, coherent (single-look complex) and incoherent (multilook) polar decompositions are discussed. In single-look polar decomposition, we introduce the boost parameter and the rotation parameter with the purpose of classifying scattering mechanisms of different natures. New relationships between these geometrical parameters and the scattering matrix elements are obtained. We also briefly reexamine the standard coherent polarimetric target decomposition algorithms in the light of quaternions. Next, an original use of polar decomposition for incoherent polarimetric imaging is proposed, which leads to the definition of the multilook boost parameter and of the degree of polarization dispersion. Subsequently, a new approach is presented, which consists in decomposing the scattering matrix into boost and rotation components before vectorization, then in averaging to generate boost and rotation coherency matrices separately. This leads to new inferred parameters: the boost and rotation entropies, and the concurrent dominant scattering mechanisms. The link between these new parameters and standard polarimetric invariants from the Cloude and Pottier decomposition is discussed. Eventually, the multilook extension of polar decomposition may allow this to be applied to the classification of remote sensing data. In this framework, a set of five parameters reducing to four in the monostatic case can be considered. [J88]

"Paddy Fields as Electrically Dense Media: Theoretical Modeling and Measurement Comparisons"

Early models for paddy fields consist of a single-layered medium in which coherent effects within clusters of leaves are considered but multiple volume scattering is not. In this paper, the paddy canopy is modeled as a multilayered dense discrete random medium consisting of cylindrical and needle-shaped scatterers. Consideration is given to the coherent and near-field effects of the closely spaced scatterers through the Dense Medium Phase and Amplitude Correction Theory and Fresnel corrections, respectively, in the phase matrix. Then, this dense medium phase matrix is applied in the radiative transfer equations and solved up to the second order to consider double-volume scattering. Ground truth measurements of paddy fields were acquired at Sungai Burung, Selangor, Malaysia, for an entire season from the early vegetative stage of the plants to their reproductive stage. Measured parameters are used in the theoretical model to calculate the backscattering coefficients of paddy fields. Theoretical analysis of the simulation results shows in particular that second-order effects are important for cross-polarized backscatter data and that coherent effects need to be considered at lower frequencies. However, the use of needles to represent paddy leaves tends to underestimate the HH-polarized backscattering coefficients especially at the latter stages of plant growth, i.e., when the leaves are broader. The results are also used for comparisons with the backscattering coefficients obtained from RADARSAT images as well as that of earlier models to test the validity of the dense medium model with promising results. [J89]

"Robust Voltage Fitting Techniques for Meteor Doppler Speed Determination"

The nonlinear least square fitting techniques that the authors have employed until recently for measuring the

Doppler velocities of head-echo meteor returns have proven to be limited in their effectiveness under certain circumstances where significant incoherent scattering from the ionosphere is present. Two alternative methods developed to independently but jointly determine the Doppler speeds are presented. The first method uses the Moore-Penrose matrix inverse to obtain the relevant meteor parameters. The second method is the steepest descent searching technique. These techniques have been applied to simulated meteor returns as well as meteor data set from February 2001. The Doppler velocities obtained using the new algorithms are presented. The implications of the improved Doppler resolution as well as robustness of the new approach are also discussed [J90]

"Conservative Polarimetric Scatterers and Their Role in Incorrect Extensions of the Cameron Decomposition"

The properties of conservative symmetric polarimetric scatterer scattering matrices are examined. It is shown that the unambiguous rotation angle for "conservative" symmetric polarimetric scatterers is the interval (-pi/4,+pi/4] as compared with (-pi/2,+pi/2] for nonconservative symmetric scatterers. Errors relating to the Cameron decomposition, which are recently introduced into the literature, are discussed. It is demonstrated that these errors arise from a faulty symmetric scatterer scattering matrix distance measure. This, in turn, leads to an improper mapping of the symmetric scatterer unit disk to a hemisphere. The correct mapping of the symmetric scatterer unit disk to the symmetric scatterer unit sphere is described [J91]

"Analysis of the electromagnetic scattering by perfectly conducting convex polygonal cylinders"

An effective method for the analysis of the scattering by a perfectly conducting convex polygonal cross-section cylinder is presented. The effectiveness stems from the generalization of the Neumann series, factorising the right edge behavior of the electromagnetic field, thus leading to a quickly convergent method. The induced currents, the radar cross section (RCS) and the induced field ratio have been evaluated. [J92]

"Insect ventral radar cross-section polarisation dependence measurements for radar entomology"

Radar entomology has developed such that routine long-term monitoring of insect flight through the atmospheric boundary layer is now practical. Typical entomological radars use X-band (9.4 GHz) marine transceivers with a vertical pencil beam and rotate the plane of polarisation about the beam axis. Ideally, insect species and other parameters (mass etc.) should be estimated from the measured radar cross-section variation with polarisation angle. For this, a library of known insect cross-section polarisation signatures is required. Two models are currently used to parameterise the polarisation signature: the harmonic model and a model using the scattering matrix for symmetric targets (SM3). Data from the literature and a doctoral research project are presented and analysed to obtain parameters for both the harmonic and SM3 models. Knowledge of the measurement errors allows SM3 parameter uncertainties to be quantified in most cases using a maximum likelihood approach. Results for 68 insects representing 24 species are presented. These include several economically significant species (e.g. bees and locusts), with individual insect masses ranging from 9 mg to 3 g [J93]

"Scattering-model-based speckle filtering of polarimetric SAR data"

A new concept in polarimetric synthetic aperture radar (POLSAR) speckle filtering that preserves the dominant scattering mechanism of each pixel is proposed in this paper. The basic principle is to select pixels of the same scattering characteristics to be included in the filtering process. To achieve this, the algorithm first applies the Freeman and Durden decomposition to separate pixels into three dominant scattering categories: surface, double bounce, and volume, and then unsupervised classification is applied. Speckle filtering is performed using the classification map as a mask. A single-look or multilook pixel centered in a 9 Ч 9 window is filtered by including only pixels in the same and two neighboring classes from the same scattering category. This filter is effective in speckle reduction, while perfectly preserving strong point target signatures, and retains edges, linear, and curved features in the POLSAR data. The effect of speckle filtering on scattering characteristics, such as entropy, anisotropy, and alpha angle, will be discussed. [J94]

"A CAD-oriented method to analyze and design radiating structures based on bodies of revolution by using finite elements and generalized scattering matrix"

In this work, an efficient analysis of radiating structures based on bodies of revolution is dealt with. The procedure is a hybrid method based on a segmentation of the structure into two-dimensional regions, finite elements and a spherical computation domain surrounding the antenna, defining a boundary or port where a spherical mode expansion of the fields is used. A reduced order model is computed for a fast frequency sweep. To validate this method, some structures based on bodies of revolution as a rod dielectric antenna, conical

dielectric-loaded horns, profiled horns and a monopole-dielectric resonator antenna are studied and results are compared with those demonstrated by other authors. The design of a smooth-walled horn by means of the optimization of the profile is also carried out [J95]

"Spectral-domain covariance estimation with a priori knowledge"

A knowledge-aided spectral-domain approach to estimating the interference covariance matrix used in space-time adaptive processing (STAP) is proposed. Prior knowledge of the range-Doppler clutter scene is used to identify geographic regions with homogeneous scattering statistics. Then, minimum-variance spectral estimation is used to arrive at a spectral-domain clutter estimate. Finally, space-time steering vectors are used to transform the spectral-domain estimate into a data-domain estimate of the clutter covariance matrix. The proposed technique is compared with ideal performance and to the fast maximum likelihood technique using simulated results. An investigation of the performance degradation that can occur due to various inaccurate knowledge assumptions is also presented [J96]

"Extraction of Ocean Wave Spectra From Simulated Noisy Bistatic High-Frequency Radar Data"

An algorithm is developed for the inversion of bistatic high-frequency (HF) radar sea echo to give the nondirectional wave spectrum. The bistatic HF radar second-order cross section of patch scattering, consisting of a combination of four Fredholm-type integral equations, contains a nonlinear product of ocean wave directional spectrum factors. The energy inside the first-order cross section is used to normalize this integrand. The unknown ocean wave spectrum is represented by a truncated Fourier series. The integral equation is then converted to a matrix equation and a singular value decomposition (SVD) method is invoked to pseudoinvert the kernel matrix. The new algorithm is verified with simulated radar Doppler spectrum for varying water depths, wind velocities, and radar operating frequencies. To make the simulation more realistic, zero-mean Gaussian noise from external sources is also taken into account [J97]

"CFAR detection of extended and multiple point-like targets without assignment of secondary data"

We design and assess adaptive schemes to detect extended and multiple point-like targets embedded in correlated Gaussian noise. Proposed algorithms rely on either the generalized likelihood ratio test (GLRT) or ad hoc procedures. Such detectors make it possible to get rid of distinct secondary data and guarantee the constant false alarm rate (CFAR) property with respect to the covariance matrix of the disturbance. A preliminary performance assessment, conducted by resorting to simulated data, also in comparison to the so-called modified GLRT (MGLRT) proposed in, has shown that newly introduced CFAR detectors may represent a viable means to deal with uncertain scenarios. [J98]

"Application of matrix pencil to obtain the current modes on electrically large bodies"

The matrix pencil method, in combination with an interpolation using nonuniform rational bi-spline surfaces, is applied for the expansion of the induced currents on complex bodies in terms of current-modes. The approach is useful for solving electrically large problems of radiation or scattering using physical optics with one or more bounces. The techniques presented in this paper can be also useful to improve some rigorous methods [J99]

"RF radiation properties of printed-circuits boards in a GTEM cell"

The behavior of reradiated fields from printed-circuits boards (PCBs), with the radar cross section being the main parameter of interest, is investigated in this paper. A rigorous approach to predict radiation from PCBs in a gigahertz transverse electromagnetic cell is presented. The analysis is based upon the use of the reciprocity theorem in combination with the method of moment applied to the scattered field, thus yielding a generalized impedance matrix, whose determinant represents the characteristic polynomial of the scattering system. The effectiveness of the method is demonstrated by investigating some canonical circuit configurations and structures illustrating sources of fundamental electromagnetic interference mechanism. The validity and the accuracy of the analysis becomes obvious in view of the one-to-one correlation with measurements [J100]

"A four-component decomposition of POLSAR images based on the coherency matrix"

A four-component decomposition scheme of the coherency matrix is presented here for the analysis of polarimetric synthetic aperture radar (SAR) images. The coherency matrix is used to deal with nonreflection symmetric scattering case, which is an extension of covariance matrix approach. The same decomposition results have been obtained. The advantage of this approach is explicit expressions of four scattering powers in terms of scattering matrix elements, which serve the interpretation of polarimetric SAR data quantitatively [J101]

"On Huynen's decomposition of a Kennaugh matrix"

For some special case, Huynen's decomposition cannot be used to extract a desired target from an average Kennaugh matrix. In this paper, the authors modify Huynen's method for overcoming its disadvantage, based on a simple transform of a Kennaugh matrix. Using an example, the effectiveness of the modified method is validated [J102]

"Orientation angle preserving a posteriori polarimetric SAR calibration"

Fully polarimetric synthetic aperture radar (SAR) data analysis has found wide application for terrain classification, land-use, soil moisture, and ground cover classification. Critical to all analyses and applications is accurate calibration of the relative amplitudes of and phases between the various polarimetric channels. Here we propose an a posteriori method imposing only the weakest of constraints, scattering reciprocity, on the polarimetric data. Calibration parameters are self-consistently estimated from full 4Ч4 polarimetric covariance matrices. Whilst the complete set of calibration parameters is underdetermined, we give several reasonable heuristic methods to provide a complete calibration. Stronger constraints reduce the number of independent parameters and provide an overdetermined set of equations but at a cost-the loss of polarimetric fidelity when the underlying assumptions are violated. Without recourse to in situ calibration targets, the extent of the polarimetric distortion that results from polarimetric calibration remains unknown. We apply our new method to simulated data, anechoic chamber data and polarimetric SAR imagery. We also present comparisons with alternate calibration methods and different approximate solutions of the new technique. [J103]

"A combined method to model microwave scattering from a forest medium"

A novel method, which employs both a matrix doubling algorithm and the first-order solution of a radiative transfer (RT) equation for modeling microwave backscattering from forest, is presented in the paper. The method is based on the assumption that a forest canopy can be divided into a number of distinct horizontal vegetation layers over a dielectric half-space rough surface. The scattering phase matrix of each layer is calculated by either matrix doubling to account for the multiple-scattering effect or first-order solution of an RT equation, depending on the scattering characteristics of the layer. The first-order solution of the RT equation is used for the trunk layer while the matrix doubling technique is applied to both the crown layer and understory. The advanced integral equation model and reflectivity matrix are used to calculate the noncoherent and coherent surface boundary conditions. Comparisons between model predictions and field measurements on radar backscattering coefficients for a walnut orchard showed a good agreement at both L-band and X-band and for all three polarizations. Comparative analyses of model predictions for backscattering from a forest medium calculated using the combined model, first-order RT model, and the standard matrix doubling model were also presented. Understory effects, that can significantly change the weight of each scattering mechanism, were also evaluated by using the combined method. [J104]

"A Spectral Domain Integral Equation Method Utilizing Analytically Derived Characteristic Basis Functions for the Scattering From Large Faceted Objects"

A novel technique, based on a spectral domain integral equation method with analytically derived characteristic basis functions, is introduced in this paper. It enables us to treat scattering problems from electrically large faceted bodies in a numerically rigorous and computationally efficient manner, in terms of both time and memory. The analytically derived characteristic basis functions include certain desirable features of the asymptotic schemes and are defined on subdomains that can be electrically large, not being bound to the typical discretization size of the conventional method of moments. By properly weighting through a Galerkin procedure the resulting electric field integral equation, the problem is reduced to a matrix equation having dimensions that do not depend on the size of the scatterer but only on its shape. Electrically large problems can be handled in a computationally efficient manner by using the proposed method since the associated matrix size is relatively small; moreover, all the reduced matrix elements are calculated in the spectral domain without evaluating any convolution products [J105]

"Radar Cross Section Modeling and Measurements of Inlets and Cylinders With Skew Blades"

Ray based methods give useful scattered field predictions from the skin of the aircraft illuminated by an incident plane wave. They can also be used to predict the returns from simple inlets and cavities but fail when complex terminations such as skewed blades are encountered. As a possible enhancement to the ray-tracing procedure, an auxiliary program based on the modal method was developed to predict the scattering of electrically large and complex jet inlets with engines. For the present development, it is assumed here that these structures can be approximated by a series of rectangular, circular, coaxial and sectoral waveguide sections. The field matching

technique is used to give the generalized scattering matrices of the junctions between these waveguide sections. By combining the scattering matrices of the waveguide sections representing the inlet and engine, an overall S-matrix is obtained. Knowing the modes induced at the inlet aperture by the incident plane wave, the scattered fields from the inlet and engine can be readily predicted in all directions. Monostatic RCS measurements of a 0.706 m diameter test cylinder containing 30 skewed blades mounted on a center shaft with a conical hub have been performed at X-band. The dimensions of the structure, the number and orientation of the blades are consistent with those of existing jet engines. Fair to good agreement between predictions and measurements verify the developed software and analytical method used [J106]

"Forward-backward iterative physical optics algorithm for computing the RCS of open-ended cavities"

The forward-backward methodology is combined with the iterative physical optics (IPO) algorithm to improve convergence for cavity scattering problems. Wave propagation inside elongated cavities, such as jet engine inlet ducts, follows a predominant down-and-back path. The forward-backward method allows the IPO currents on the cavity walls to be updated sequentially (forward) and reverse-sequentially (backward) along the waveguide axis. A relaxation parameter is introduced to help control the convergence characteristics, making the new algorithm mathematically equivalent to the classical iterative method of symmetric successive over-relaxation. The fast far-field approximation (FaFFA) accelerates the matrix-vector products in the IPO formulation, and an equivalent surface impedance is used to characterize thin material linings in the cavity. [J107]

"Diffraction of obliquely incident waves by a strip in a bianisotropic medium"

Diffraction of obliquely incident waves by a perfectly conducting strip of infinite length immersed in either 1) an unbounded bianisotropic medium or 2) a bianisotropic cylinder is investigated. Systems of singular integral-integrodifferential equations having the induced surface current densities as the unknowns are derived by following several independent formulation techniques. Discretization is carried out using moment-method-oriented techniques applied to singular integral equations. The matrix elements are given either in closed form or by exponentially convergent series which require no numerical integration. Moreover, the algorithms are found to converge exponentially versus matrix size. Numerical results are presented which show the effect of changing either the degree of bianisotropy or the strip width and orientation on the scattering characteristics. [J108]

"Numerical Simulation of the Doppler spectrum of a flying target above dynamic oceanic surface by using the FEM-DDM method"

To study the Doppler (DP) spectrum of a flying target above dynamic oceanic surface, a two-level quasi-stationary algorithm (TLQSA) of the finite element method (FEM) with domain decomposition (DDM) is developed. The DP spectrum of a fast-moving target requires small time-sampling rate. At most time steps, scattering from the flying target is solved by the FEM solution in only one subdomain. Meanwhile, the interactions between the target and rough sea surface in other subdomains are obtained by solving the global DDM coupling matrices. The slowly moving sea surface is evolved at a larger time step and the DP of oceanic clutter is obtained through all-subdomain FEM calculation. Numerical simulations of the DP spectrum from a target flying above dynamic oceanic surface with and without the presence of a ship-like object are obtained. The functional dependence of the DP spectrum in both the time and frequency domains upon sea surface wind speed, target altitude, observation angle, etc., are demonstrated and discussed. [J109]

"Integration of optical and radar classifications for mapping pasture type in Western Australia"

In this study, independent classifications of Landsat Thematic Mapper imagery and Jet Propulsion Laboratory AirSAR were combined to create an integrated classification of pasture and other vegetation types for a study area in the agricultural zone of Western Australia. The resulting classification combines greenness and brightness information from optical data with structure and water content information from synthetic aperture radar (SAR). Field observations of vegetation type, botanical composition, ground cover percentage, wet and dry biomass, canopy height, and soil water content were collected at 34 sites representing a range of pastures, browse shrubs, and crops. An unsupervised version of the Complex Wishart classification procedure, based on preserving scattering characteristics from the Freeman and Durden backscatter decomposition, was applied to the C-, L-, and P-band polarimetric SAR data. The optical classification was carried out using a principle component analysis on the green, red, and near-infrared bands and clustering on the basis of a class centroid distance measure and knowledge of ground targets. These two classification results were then fused together. Assessment of a confusion matrix using the individual sites showed that identification of more uniform, dense, and structurally distinct canopies was better than that of more diverse, sparse, and structurally ambiguous canopies, as the former were better represented by the canopy height attribute used in the SAR classification

component. The optical classification enabled correction of SAR misclassification of vegetation due to surface roughness and soil moisture effects, or similar backscatter responses from herbaceous or arboreal canopies. The results show that simplification of vegetation into groups based upon properties with sensitive responses in both the optical and SAR domains, and combination of separate SAR and optical classifications, has potential for improving classification of diverse and heterogeneous herbaceous and browse cover in grazing lands. However, collection of ground calibration data must be at an appropriate spatial scale and include canopy and surface measurements directly related to backscatter mechanisms and spectral sensitivity. [J110]

"Four-component scattering model for polarimetric SAR image decomposition"

A four-component scattering model is proposed to decompose polarimetric synthetic aperture radar (SAR) images. The covariance matrix approach is used to deal with the nonreflection symmetric scattering case. This scheme includes and extends the three-component decomposition method introduced by Freeman and Durden dealing with the reflection symmetry condition that the co-pol and the cross-pol correlations are close to zero. Helix scattering power is added as the fourth component to the three-component scattering model which describes surface, double bounce, and volume scattering. This helix scattering term is added to take account of the co-pol and the cross-pol correlations which generally appear in complex urban area scattering and disappear for a natural distributed scatterer. This term is relevant for describing man-made targets in urban area scattering. In addition, asymmetric volume scattering covariance matrices are introduced in dependence of the relative backscattering magnitude between HH and VV. A modification of probability density function for a cloud of dipole scatterers yields asymmetric covariance matrices. An appropriate choice among the symmetric or asymmetric volume scattering covariance matrices allows us to make a best fit to the measured data. A four-component decomposition algorithm is developed to deal with a general scattering case. The result of this decomposition is demonstrated with L-band Pi-SAR images taken over the city of Niigata, Japan. [J111]

"Ultrawideband microwave breast cancer detection: a detection-theoretic approach using the generalized likelihood ratio test"

Microwave imaging has been suggested as a promising modality for early-stage breast cancer detection. In this paper, we propose a statistical microwave imaging technique wherein a set of generalized likelihood ratio tests (GLRT) is applied to microwave backscatter data to determine the presence and location of strong scatterers such as malignant tumors in the breast. The GLRT is formulated assuming that the backscatter data is Gaussian distributed with known covariance matrix. We describe the method for estimating this covariance matrix offline and formulating a GLRT for several heterogeneous two-dimensional (2-D) numerical breast phantoms, several three-dimensional (3-D) experimental breast phantoms, and a 3-D numerical breast phantom with a realistic half-ellipsoid shape. Using the GLRT with the estimated covariance matrix and a threshold chosen to constrain the false discovery rate (FDR) of the image, we show the capability to detect and localize small ([J112]

"Computation of longwave electromagnetic response of nonhomogeneous media"

A method for the numeric estimation of the effective permittivity of any nonhomogeneous medium that admits the effective medium approximation under the longwave approximation is presented. Media are modeled as inclusions embedded in a continuous matrix. We show how the potentials at the inclusion boundaries are sufficient information for the estimation of the effective permittivity. We also show efficient implementation techniques to estimate them computationally, either by Monte Carlo random walk or by relaxation. We provide numerical results for several regular two- and three-dimensional structures and show the dependence of the effective response on the shape of the inclusions and their spatial arrangement, and the influence of the percolation threshold. [J113]

"Radiative transfer model for microwave bistatic scattering from forest canopies"

A bistatic forest scattering model is developed to simulate scattering coefficients from forest canopies. The model is based on the Michigan Microwave Canopy Scattering (MIMICS) model (hence called Bi-MIMICS) and uses radiative transfer theory, where the first-order fully polarimetric transformation matrix is used. Bistatic radar systems offer advantages over monostatic radar systems because of the additional information provided by the diversity of the geometry. By simulating the forest canopy scattering from multiple viewpoints, we can better understand how the forest scatterers' shape, orientation, density, and permittivity affect the canopy scattering. Bi-MIMICS is parametrized using selected forest stands with different canopy compositions and structure. The simulation results show that bistatic scattering is more sensitive to forest biomass changes than backscattering. Analyzing scattering contributions from different parts of the canopy gives us a better understanding of the microwave's interaction with the tree components. The ground effects can also be studied. Knowledge of the canopy's bistatic scattering behavior combined with additional synthetic aperture radar measurements can be

used to improve forest parameter retrievals. The simulation results of the model provide the required information for the design of future bistatic radar systems for forest sensing applications. [J114]

"A discrete-time uniform geometrical theory of diffraction for the fast transient analysis of scattering from curved wedges"

In this paper a discrete time (DT) representation of Maxwell's equations is employed to describe the time domain (TD) Maxwell's equations in terms of matrix equations analogous to time harmonic Maxwell's equations, which allows one to conveniently develop many TD solutions based on their frequency domain (FD) formulations. It was then employed to develop a TD version of the uniform geometrical theory of diffraction (UTD) (referred as DT-UTD) for the efficient electromagnetic transient analysis of scattering from perfectly conducting curved wedges. This DT-UTD retains the advantages of its corresponding FD UTD solution in several aspects including the form, ray physical picture and definitions of ray parameters. Furthermore, the transformation of the FD-UTD to the DT-UTD formulation can be easily achieved via a simple interpretation of notation. Numerical examples are presented to validate and illustrate the utilizations of this DT-UTD. [J115]

"A new well-conditioned Integral formulation for Maxwell equations in three dimensions"

We present a new boundary integral equation dedicated to the solution of the boundary problem of a perfectly electrically conducting surface for the harmonic Maxwell equations in unbounded domains. Any solution of the harmonic Maxwell equations is represented as the electromagnetic field generated by a combination of electric and magnetic potentials. These potentials are those appearing in the classical combined field integral equation (CFIE), but their coupling is realized by an operator Y˜+instead of a coefficient. Therefore, the integral equation obtained can be viewed as a generalization of the CFIE. In this paper, we propose an explicit construction of the coupling operator Y˜+which is designed to approximate the exterior admittance operator of the scattering obstacle. A local approximation by the admittance operator of the tangential plane seems to be relevant thanks to the localization effects related to high-frequency phenomena. The provided numerical simulations show that this formulation leads to linear systems that are better conditioned compared to more classical integral equations, which speeds up the resolution when solved with iterative techniques. [J116]

"Efficient solution of EFIE via low-rank compression of multilevel predetermined interactions"

This paper describes the predetermined interaction list oct-tree (PILOT) algorithm and its application in expediting the solution of full-wave electric field integral equation (EFIE)-based scattering problems for three-dimensional arbitrarily shaped conductors. PILOT combines features of the fast multipole method (FMM) and QR decomposition-based matrix compression techniques to optimize setup times, solve times, and memory requirements. The method is kernel independent and stable for electrically small structures unlike traditional FMM. The novel features of the algorithm, namely the mixed potential compression scheme and the hierarchical multilevel predetermined matrix structure are explained in detail. A complexity estimate is presented to demonstrate the scaling in time and memory requirements. Examples exhibiting the accuracy and the time and memory performances are also presented. Finally, a quantitative study is included to address the expected but gradual degradation of QR-based compression techniques for electrically large structures. [J117]

"Total- and scattered-field decomposition technique for the finite-element time-domain modeling of buried scatterers"

The total- and scattered-field decomposition (TSFD) technique, developed earlier for scattering in free space, is extended for the finite-element time-domain (FETD) modeling of scattering by an object either residing above, partially embedded, or completely buried in a lossy dielectric half-space. The formulation leads to both a volumetric and a Huygens' surface method to excite an incident field in the total-field region. Numerical examples demonstrate the accuracy and the flexibility of the method. [J118]

"Mode-expansion method for calculating electromagnetic waves scattered by objects on rough ocean surfaces"

A mode-expansion method that needs less than 6% the number of unknowns required by conventional method of moments is introduced in calculating two-dimensional electromagnetic wave scattering from perfectly conducting objects on rough ocean surfaces. Modes are selected for dominant propagation waves so that the number of unknowns in the matrix equation are minimized. In the numerical examples, ocean surfaces are modeled as perfectly conducting rough surfaces described by the Pierson-Moskowitz power spectrum. Bistatic radar cross-sections (RCS) of various objects, such as ship-like and low-observable targets, are calculated for a 1-GHz incident plane wave and are validated for accuracy against an iterative MoM solution. [J119]

"Bounds on maximum likelihood ratio-Part II: application to antenna array detection-estimation with imperfect wavefront coherence"

The maximum likelihood ratio (LR) lower bound analysis introduced in our previous papers is applied to support the detection-estimation of multiple Gaussian spread (distributed, scattered) sources. Since angular spreading eliminates any "noise eigensubspace" from the spatial covariance matrix, traditional detection techniques based on the equality of noise-subspace eigenvalues are not applicable here. Brute-force "focusing", which is based on the Schur-Hadamard inverse, is shown to be inefficient. Our technique is based on generalized likelihood-ratio test (GLRT) principles and involves LR maximization over the set of admissible covariance matrix models. The introduced technique yields results that statistically exceed the LR generated by the exact covariance matrix, which is used as the lower bound. High optimization efficiency drives high detection-estimation performance that, nevertheless, breaks down under certain threshold conditions. It is demonstrated that this breakdown phenomenon is not curable within the maximum likelihood (ML) paradigm since these highly erroneous solutions are still "better" than the true covariance matrix (as measured by the LR). [J120]

"Sparse inverse preconditioning of multilevel fast multipole algorithm for hybrid Integral equations in electromagnetics"

In computational electromagnetics, the multilevel fast multipole algorithm (MLFMA) is used to reduce the computational complexity of the matrix vector product operations. In iteratively solving the dense linear systems arising from discretized hybrid integral equations, the sparse approximate inverse (SAI) preconditioning technique is employed to accelerate the convergence rate of the Krylov iterations. We show that a good quality SAI preconditioner can be constructed by using the near part matrix numerically generated in the MLFMA. The main purpose of this study is to show that this class of the SAI preconditioners are effective with the MLFMA and can reduce the number of Krylov iterations substantially. Our experimental results indicate that the SAI preconditioned MLFMA maintains the computational complexity of the MLFMA, but converges a lot faster, thus effectively reduces the overall simulation time. [J121]

"Speckle filtering in polarimetric SAR data based on the subspace decomposition"

In this paper, a new approach to speckle filtering of synthetic aperture radar (SAR) data is presented. We define a parameter space consisting of two orthogonal subspaces-the signal subspace and the noise subspace. Then, the full polarimetric information from the signal subspace is obtained after speckle filtering. In this way, edges of different kinds of targets are preserved. The effectiveness of this method is demonstrated using the National Aeronautics and Space Administration Jet Propulsion Laboratory airborne L-band polarimetric SAR data. [J122]

"Error analysis of the moment method"

Because of the widespread use of the Method of Moments for simulation of radiation and scattering problems, analysis and control of solution error is a significant concern in computational electromagnetics. The physical problem to be solved, its mesh representation, and the numerical method all impact accuracy. Although empirical approaches such as benchmarking are used almost exclusively in practice for code validation and accuracy assessment, a number of significant theoretical results have been obtained in recent years, including proofs of convergence and solution-error estimates. This work reviews fundamental concepts such as types of error measures, properties of the problem and numerical method that affect error, the optimality principle, and basic approximation error estimates. Analyses are given for surface-current and scattering-amplitude errors for several scatterers, including the effects of edge and corner singularities and quadrature error. We also review results on ill-conditioning due to resonance effects and the convergence rates of iterative linear-system solutions. [J123]

"Efficient generation of method of moments matrices using the characteristic function method"

We present a new, fast, and efficient technique for computing the MoM matrix elements from Rao-Wilton-Glisson (RWG) bases, one that does not require evaluating the usual surface integrals involving the expansion and testing functions. The matrix elements are represented in terms of characteristic functions (CFs), which can be expressed in a closed canonical form. These universal CFs make matrix generation more efficient and faster than the conventional triangular facet interaction scheme. The proposed technique can be applied for any subsectional basis functions other the RWG if the size of the basis function is small enough compared to the wavelength and the distance between the source and the testing basis functions is beyond a nominal distance. The proposed approach is validated for several canonical geometries, and the accuracy of the generated matrix elements, as well as the radar cross-section (RCS) has been verified. [J124]

"On the use of permanent symmetric scatterers for ship characterization"

The symmetric scattering characterization method (SSCM) has been recently introduced for high-resolution characterization of certain targets under coherent conditions. SSCM is based on the Poincarer' sphere representation, which supports a high-resolution decomposition of symmetric target scattering, as well as assessment and validation of the backscatter coherence. In this paper, the SSCM is investigated for ship characterization using Convair-580 polarimetric synthetic aperture radar (SAR) data. It is shown that the target Poincarer' parameters permit identification of dominant scatterers with a significant symmetric scattering component. The polarization orientation angle of these quasi-symmetric scatterers is used to derive an estimate of the ship's pitch angle, under certain conditions. The effect of SAR system focus setting errors and Doppler centroid mistracking on the SSCM performance is investigated. It is shown that the SSCM is sensitive to the system focus setting and Doppler centroid shift. The first-order effects of these errors can be removed prior to the application of the SSCM method. [J125]

"Ambiguity resolution for permanent scatterer interferometry"

In the permanent scatterer technique of synthetic aperture radar interferometry, there is a need for an efficient and reliable nonlinear parameter inversion algorithm that includes estimation of the phase cycle ambiguities. Present techniques make use of a direct search of the solution space, treating the observations as deterministic and equally weighted, and which do not yield an exact solution. Moreover, they do not describe the quality of the estimated parameters. Here, we use the integer least squares estimator, which has the highest probability of correct integer estimation for problems with a multivariate normal distribution. With this estimator, the propagated variance-covariance matrix of the estimated parameters can be obtained. We have adapted the LAMBDA method, part of an integer least squares estimator developed for the ambiguity resolution of carrier phase observations in global positioning systems, to the problem of permanent scatterers. Key elements of the proposed method are the introduction of pseudo-observations to regularize the system of equations, decorrelation of the ambiguities for an efficient estimation, and the combination of a bootstrap estimator with an integer least squares search to obtain the final integer estimates. The performance of the proposed algorithm is demonstrated using simulated and real data. [J126]

"A symmetric FEM-IE formulation with a single-level IE-QR algorithm for solving electromagnetic radiation and scattering problems"

This paper presents, for the first time in the engineering community, a symmetric coupling between the finite element and integral equation methods (FEM-IE) for solving three-dimensional unbounded radiation and scattering problems. The proposed FEM-IE is based on the E-field vector Helmholtz equation. Curl-conforming vector finite elements are used to discretize the interior region, whereas the divergence-conforming surface elements are utilized in the IE truncation surface. The symmetry in the IE part is restored through the application of the Calderon-projector. Moreover, the IE computations are accelerated using a single level QR algorithm. This reduces both memory and computational time. Furthermore it allows the use of different Green's functions for the exterior problem, with only minor modifications on the algorithm. The resulted system of equations is solved with a very efficient preconditioned conjugate gradient (PCCG) with a p-Multiplicative Schwarz preconditioner. [J127]

"A hybrid BEM/WTM/DFT technique for analysis of the EM scattering from open-ended circular cavities with cylindrically periodic terminations"

The cavity problem, formulated using a magnetic field integral equation (MFIE), can be solved by the iterative physical optics (IPO) method, the progressive physical optics (PPO) method or the hybrid boundary element method/wavelet transform method (BEM/WTM). In this paper, we focus on open-ended circular cavities with cylindrically periodic terminations. The cavity problem is formulated using an electric field integral equation (EFIE), based on the dyadic Green function technique, instead of an MFIE. The discrete Fourier transform (DFT) technique is applied by exploiting the periodicity of the termination to reduce the original computational size by a factor of Nswith corresponding computational savings of a factor of Ns2, where Nsdenotes the number of blades in the cylindrically periodic termination. Two kinds of dyadic Green functions are derived to reduce the integral range in the EFIE, thus accelerating the scattering solutions for different cavity applications. The BEM/WTM method is combined with the DFT to obtain sparse impedance matrices that can be efficiently solved using sparse solvers. The proposed hybrid BEM/WTM/DFT technique provides an alternative means of effectively analyzing the electromagnetic (EM) scattering from large-size circular cavities with cylindrically periodic terminations. Numerical results are presented to demonstrate the merits of the method. [J128]

"A memory-reduction scheme for the FFT T-matrix method [JEM wave scattering applications]"

We present a memory-reduction technique for the fast Fourier transformation (FFT) T-matrix method. The technique exploits the configuration- and Fourier-space symmetry relations of the transverse spherical multipole

translation coefficients whose storage drives the memory requirement. The technique is capable of reducing the memory requirement by a factor of 6/spl sim/16 depending on the number of modes used and the spatial distribution of scatterers and is simple to implement in an existing FFT T-matrix code. We establish its accuracy and effectiveness by applying the technique to compute the RCS of aggregates of dielectric spheres. [J129]

"Volume decorrelation effects in polarimetric SAR interferometry"

Volume decorrelation is an aspect of synthetic aperture radar interferometry that is currently at stake. It stems from the distribution in height of the backscattering cross section in a imaged scene, and it widely affects interferometric coherence images, e.g., in the presence of forests or buildings. The interest in its reduction lies on the fact that "resolving" volume decorrelation and fixing the exact position of the scattering centers in a resolution cell may lead to an estimation of the height of the observed distributed scatterers. Indeed, the determination of the volume scattering contribution is determinant in digital elevation model generation as well as in biomass estimation. However, volume decorrelation itself may be a source of information on the mechanisms that originate it. In this paper, a distinction is made between the behavior of volume decorrelation due to random volumes and stationary distributed targets. The two cases are then studied by means of polarimetry: the response of such targets to different polarizations is considered by applying a series of decompositions of the scattering matrix, and a systematic analysis of the interferometric coherence characteristics is reported. [J130]

"Algorithms for estimating the complete group of polarization invariants of the scattering matrix (SM) based on measuring all SM elements"

The procedure for estimating polarization invariants of the backscattering matrix in horizontal-vertical basis is considered for radar observation of arbitrary nonreciprocal objects. Two polarization invariants are added to the well-known six Huynen-Euler invariants. These new invariants (nonreciprocity angle and difference in absolute phases of the symmetric and antisymmetric parts of the scattering matrix) describe the nonreciprocal properties of the object itself. With the simultaneous measurement of all eight quadratures of the scattering matrix elements, the closed-form expressions for calculating the eight polarization invariants are given. The derived expressions are the starting point for complete estimation of the polarization properties of arbitrary radar objects with a nonsymmetric scattering matrix. The given approach can be used to study various polarization effects in remote radar sensing of artificial and natural objects, and also to simulate polarization measurement processes and estimation errors caused by the measurements of scattering matrix elements at different instants. [J131]

"A generalized capon estimator for localization of multiple spread sources"

In this correspondence, we develop a generalized Capon spatial spectrum estimator for localization of multiple incoherently distributed (spread) sources in sensor arrays. The proposed generalized Capon technique estimates the source central angles and angular spreads by means of a two-dimensional (2-D) parameter search. Simulation results show that the proposed method has a substantially improved performance compared with several popular spread source localization methods. [J132]

"The hybridization of fast multipole method with asymptotic waveform evaluation for the fast monostatic RCS computation"

The fast multipole method hybridized with the asymptotic waveform evaluation is presented in this paper to efficiently calculate the scattering from electrically large objects. A novel interpolation method for the hybridization is proposed, which provides a more accurate result for the scattering pattern calculation than the original extrapolation method. The accuracy and efficiency of this proposed hybrid method are examined through numerical examples. [J133]

"Electromagnetic scattering by a mixture of conducting and dielectric objects: analysis using method of moments"

In this paper, the method of moments is employed to solve the combined field integral equation for characterizing electromagnetic scattering by large three-dimensional structures of arbitrary shape. Unlike those discussed in the literature, these structures consist of mixed conducting and homogeneous dielectric objects. To improve the matrix conditioning number, the basis functions used to represent magnetic currents are also chosen as the popular Rao-Wilton-Glisson functions, but are multiplied by a constant number. A Galerkin's procedure is implemented, i.e., the testing functions are chosen to be the same as the basis functions. [J134]

"Polarimetric scattering from two-layered two-dimensional random rough surfaces with and without buried objects"

A three-dimensional polarimetric analysis of the two-layered rough ground with and without buried objects is investigated here. A rigorous electromagnetic surface integral-equation-based model is used in this analysis. The statistical average of the polarimetric scattering matrix elements is computed based on the Monte Carlo simulations for both the vertically and horizontally polarized incident waves. The results show a significant impact on the scattered intensities due to the two-layer nature of the ground. However, these intensities show almost no difference between the ground signature with or without the object. On the other hand, the statistical average of the covariance matrix elements shows a distinct difference between these two signatures despite the small size of the buried object. [J135]

"Direction finding for an extended target with possibly non-symmetric spatial spectrum"

We consider the problem of estimating the direction of arrival (DOA) of an extended target in radar array processing. Two algorithms are proposed that do not assume that the power azimuthal distribution of the scatterers is symmetric with respect to the mass center of the target. The first one is based on spectral moments which are easily related to the target's DOA. The second method stems from a previous paper by the present authors and consists of a least-squares fit on the elements of the covariance matrix. Both methods are simple and are shown to provide accurate estimates. Furthermore, they extend the range of unambiguous DOAs that can be estimated, compared with the same previous paper. [J136]

"A covariance fitting approach to parametric localization of multiple incoherently distributed sources"

In this paper, a new algorithm for parametric localization of multiple incoherently distributed sources is presented. This algorithm is based on an approximation of the array covariance matrix using central and noncentral moments of the source angular power densities. Based on this approximation, a new computationally simple covariance fitting-based technique is proposed to estimate these moments. Then, the source parameters are obtained from the moment estimates. Compared with earlier algorithms, our technique has lower computational cost and obtains the parameter estimates in a closed form. In addition, it can be applied to scenarios with multiple sources that may have different angular power densities, while other known methods are not applicable to such scenarios. [J137]

"Retrievals of underlying surface roughness and moisture from polarimetric pulse echoes in the specular direction through stratified vegetation canopy"

The time-dependent Mueller matrix solution of vector radiative transfer for stratified random media of nonspherical scatterers is presented. Copolarized and cross-polarized bistatic scattering for a polarized pulse incidence are numerically simulated. Numerical results well demonstrate volumetric and surface scattering mechanism and depict the fraction distribution of random scatterers of stratified random media. The peak tails in polarized echoes due to wave reflections from the underlying surface can be identified. Its copolarized peaks in the specular direction are employed for simultaneous retrievals of the underlying surface roughness and moisture with the presence of stratified vegetation canopy. [J138]

"Generalized optimization of polarimetric contrast enhancement"

A generalized optimization of polarimetric contrast enhancement (GOPCE) is proposed in this letter. For this problem, it is not only necessary to find the optimal polarization states such that the received power ratio of a desired target and clutter is maximal, but also necessary to find three optimal coefficients such that the ratio of two factors associated with the desired target and clutter is maximal, where both the factors consist of three parameters, i.e., the Cloude entropy and two special similarity parameters. The optimal coefficients of the GOPCE are obtained by solving an eigenvalue problem. Using an example, we demonstrate that the GOPCE can be employed for detecting roads in a forest area by using polarimetric synthetic aperture radar data. [J139]

"Polarization diversity detection of distributed targets in compound-Gaussian clutter"

We deal with the problem of polarimetric detection of compound-Gaussian clutter with unknown distributed targets in covariance matrix. Since no uniformly most powerful (UMP) detector exists for the problem at hand, we devise and assess two classes of suboptimum receivers. The former contains two detectors, designed according to the Wald and the generalized likelihood ratio tests, which resort to secondary data, free of signal components and with the same covariance structure of the cells under test, for estimating the clutter spectral properties. The latter contains a detector which achieves adaptivity without exploiting the training set All the decision rules ensure the constant false alarm rate (CFAR) property with respect to the texture statistics but they are not theoretically CFAR with respect to the disturbance covariance matrix. Finally, we present simulation results,

based also on real clutter data, showing that the Wald test receiver achieves in general a better detection performance and a stronger robustness than its counterparts. [J140]

"Plane-wave characterization of antennas close to a planar interface"

The plane-wave scattering matrix is used to characterize antennas that are located just above a planar interface that separates two media. The plane-wave transmitting spectrum for the field radiated downward into the lower medium is expressed directly in terms of the current distribution of the transmitting antenna. The transmitting spectrum for a reciprocal antenna determines the plane-wave receiving spectrum for the field that propagates upward in the lower medium. A measurement procedure is discussed for determining the plane-wave transmitting and receiving spectra from measurements with a probe that is located in the lower medium. [J141]

"A procedure for modeling material junctions in 3-D surface integral equation approaches"

Surface integral equations become cumbersome to solve when arbitrary combinations of materials, and complicated arrangements of junctions between those materials, are considered. This paper describes a straightforward approach for generalizing integral equation techniques to handle any combinations of materials with junctions. Particular attention is focused on a unique, easily implemented junction resolution algorithm that maps each basis function coefficient to one or more unknowns. Three examples are presented for validation purposes. [J142]

"Calibration of linearly polarized polarimetric SAR data subject to Faraday rotation"

A model for linearly polarized fully polarimetric backscatter measurements is used, incorporating the effects of system noise, channel amplitude, phase imbalance, crosstalk, and Faraday rotation. A step-by-step procedure is outlined for correction (or calibration) of fully polarimetric data subject to Faraday rotation, to recover the true scattering matrix. The procedure identifies steps for crosstalk removal and correction of channel imbalances that are robust in the presence of Faraday rotation. The final steps in the procedure involve a novel strategy for estimation and correction of Faraday rotation. Three approaches to estimate the (one-way) Faraday rotation angle Ω directly from linear (quad-) polarized synthetic aperture radar (SAR) backscatter data obtained by a spaceborne SAR system are described. Each approach can initially be applied to the signature of any scatterer within the scene. Sensitivity analyses are presented that show that at least one of the measures can be used to estimate Ω to within ±3° to 5°, with reasonable levels of residual crosstalk, noise floor, channel amplitude, and phase imbalance. Ambiguities may be present in the estimates of Ω of ±npi/2-the impact of this is discussed, and several approaches are suggested to deal with this possibility. The approach described in this paper is relevant for future L-band spaceborne SARs and removes one key obstacle to the deployment of even longer wavelength SARs (e.g., an ultrahigh frequency or P-band SAR) in Earth orbit. [J143]

"Propagation in rectangular waveguides periodically loaded with cylindrical posts"

The analysis of propagation in periodically loaded waveguide structures is conducted. The eigenvalue equation is derived to determine the propagation constants of the Floquet modes. Theoretical and experimental investigations of semi-periodic structures and their scattering matrices are performed. The existence of passbands and stopbands, which are characteristic for periodic structures, is shown. [J144]

"Target decomposition analysis of SIR-C imagery for characterization of scattering mechanisms and their dependence on observation parameters"

Multitemporal Shuttle Imaging Radar C (SIR-C) images taken over the Sarobetsu test site were analyzed using target decomposition to characterize the scattering mechanisms and relate them with the target conditions. Analysis results indicate a change in the dominant scattering mechanism with a change in the observation parameters, which is reasonably related with the surface conditions estimated from aerial photographs. [J145]

"Two-dimensional scattering by a periodic array of gyrotropic cylinders embedded in a dielectric slab"

Two-dimensional scattering of a periodic array of circular homogeneous and gyrotropic-type cylinders embedded in an isotropic dielectric slab is studied using the T-matrix of an isolated circular cylinder and the lattice sums. The T-matrix of a single circular gyrotropic cylinder is given numerically and then the generalized reflection and transmission matrices for the embedded array are obtained using the T-matrix and lattice sums. The harmonic fields in each of the four regions are given analytically. Numerical results of the power reflection and transmission coefficients based on the fundamental mode and the near-scattered field distribution are shown and discussed. [J146]

"Distributed target detection in compound-Gaussian noise with Rao and Wald tests"

The problem of detecting distributed targets in compound-Gaussian noise with unknown statistics is considered. At the design stage, in order to cope with the a priori uncertainty, we model noise returns as Gaussian vectors with the same structure of the covariance matrix, but possibly different power levels. We also assume that a set of secondary data, free of signal components, is available to estimate the covariance matrix of the disturbance. Since no uniformly most powerful test exists for the problem at hand we devise and assess two detection strategies based on the Rao test, and the Wald test respectively. Remarkably these detectors ensure the constant false alarm rate property with respect to both the structure of the covariance matrix as well as the power levels. Moreover, the performance assessment, conducted also in comparison with the generalized likelihood ratio test based receiver, shows that the Wald test outperforms the others and is very effective in scenarios of practical interest for radar systems. [J147]

"Temporal Mueller matrix solution for polarimetric scattering from inhomogeneous random media of nonspherical scatterers"

Polarimetric scattering from inhomogeneous random media of nonspherical scatterers under a pulse incidence is studied. The time-dependent Mueller matrix solution of vector radiative transfer for layering random media is derived. Copolarized and cross-polarized bistatic and back- scattering are numerically calculated. The shape and intensity of polarized echoes well depict the inhomogeneous fraction profile of random scatterers. Its functional dependence upon the fraction profile, layering thickness, and other parameters are discussed. This technique is applicable to reconstruction of inhomogeneous fraction profile and inversion of the media thickness. [J148]

"Recent advances in extra-wide-band polarimetry, interferometry and polarimetric interferometry in synthetic aperture remote sensing and its applications"

The development of radar polarimetry and radar interferometry is advancing rapidly, and these novel radar technologies are revamping 'synthetic aperture radar imaging' decisively. The successive advancements are sketched eginning with the fundamental formulations and highlighting the salient points of these diverse remote sensing techniques. Whereas with radar polarimetry the textural fine-structure, target orientation and shape, symmetries and material constituents can be recovered with considerable improvements above that of standard 'amplitude-only polarisation radar'; with radar interferometry the spatial (in depth) structure can be explored. In 'polarimetric-interferometric synthetic aperture radar (POL-IN-SAR) imaging' it is possible to recover such co-registered textural plus spatial properties simultaneously. This includes the extraction of 'digital elevation maps (DEM)' from either 'fully polarimetric (scattering matrix)' or 'interferometric (dual antenna) SAR image data takes' with the additional benefit of obtaining co-registered three-dimensional 'POL-IN-DEM' information. Extra-wide-band POL-IN-SAR imaging-when applied to 'repeat-pass image overlay interferometry'-provides differential background validation and measurement, stress assessment, and environmental stress-change monitoring capabilities with hitherto unattained accuracy, which are essential tools for improved global biomass estimation and also for wetland assessment and monitoring. More recently, by applying multiple parallel repeat-pass EWB-POL-D(RP)-IN-SAR imaging along stacked (altitudinal) or displaced (horizontal) flight-lines will result in 'tomographic (multi-interferometric) polarimetric SAR stereo-imaging', including foliage- and ground-penetrating capabilities. In addition, various closely related topics of (i) acquiring additional and protecting existing spectral windows of the 'natural electromagnetic spectrum (NES)' pertinent to remote sensing; and (ii) mitigation against common 'radio frequency interference (RFI)' and intentional 'directive jamming of airborne and spaceborne POL-IN-SAR imaging platforms' are appraised. [J149]

"Speckle filtering and coherence estimation of polarimetric SAR interferometry data for forest applications"

Recently, polarimetric synthetic aperture radar (SAR) interferometry has generated much interest for forest applications. Forest heights and ground topography can be extracted based on interferometric coherence using a random volume over ground coherent mixture model. The coherence estimation is of paramount importance for the accuracy of forest height estimation. The coherence (or correlation coefficient) is a statistical average of neighboring pixels of similar scattering characteristics. The commonly used algorithm is the boxcar filter, which has the deficiency of indiscriminate averaging of neighboring pixels. The result is that coherence values are lower than they should be. In this paper, we propose a new algorithm to improve the accuracy in the coherence estimation based on speckle filtering of the 6Ч6 polarimetric interferometry matrix. Simulated images are used to verify the effectiveness of this adaptive algorithm. German Aerospace Center (DLR) L-Band E-SAR data are applied to demonstrate the improved accuracy in coherence and in forest height estimation. [J150]

"Development of a retrodirective PARC for ALOS/PALSAR calibration"

Polarimetric radar calibration is a procedure that corrects the polarization distortion of a measured scattering matrix by referring to the scattering matrix of a known target. The present paper describes the principle, design, manufacture and measurement results of a novel retrodirective polarimetric active radar calibrator (PARC). It accommodates both the depolarization characteristic by using dual-polarized antennas and retrodirectivity with the Van Atta array concept simultaneously. The PARC was designed for Phased Array L-band SAR (PALSAR) calibration based on the proposed principle. It consists of a 6Ч6-element antenna array with a 1-m-square aperture and four amplifiers with a 20-dB gain. The whole array is divided into four 3Ч3-element subarrays to form a two-dimensional (2-D) Van Atta array. Retrodirectivity extends the angular width, where the radar cross section exceeds 35 dBm2, which is a preliminary design goal, to almost twice the width of a conventional array reflector of the same size. However, it should be noted that the present design needs at least four times as many amplifiers as a conventional fixed-beam array reflector to be capable of 2-D source tracking. A prototype model of the present retrodirective PARC is manufactured in the L-band to allow Advanced Land-Observation Satellite (ALOS)/PALSAR calibration. The results we obtained through measurement agree well with the theoretical predictions, and substantiate the premise behind the present design of the retrodirective PARC for polarimetric SAR calibration. [J151]

"Inversion of surface parameters from polarimetric SAR"

Proposes a new model for the inversion of surface roughness and soil moisture from polarimetric synthetic aperture radar (SAR) data, based on the eigenvalues and eigenvectors of the polarimetric coherency matrix. It demonstrates how three polarimetric parameters, namely the scattering entropy (H), the scattering anisotropy (A), and the alpha angle (α) may be used in order to decouple surface roughness from moisture content estimation offering the possibility of a straightforward inversion of these two surface parameters. The potential of the proposed inversion algorithm is investigated using fully polarimetric laboratory measurements as well as airborne L-band SAR data and ground measurements from two different test sites in Germany, the Elbe-Auen site and the Weiherbach site. [J152]

"A numerical investigation of interior resonances in the hybrid FEM/MoM method"

The interior resonance problem that can occur when using a hybrid finite-element method/method of moments (FEM/MoM) method to model electromagnetic scattering problems is investigated. Calculations of the bistatic radar cross section of a coated dielectric sphere are presented using different formulations, solution approaches, and solvers. The solutions using the electric-field integral equation have significant errors near an interior resonance frequency. When the combined-field integral equation is employed, satisfactory solutions can be obtained that do not depend on the particular solution approach or solver. [J153]

"A test statistic in the complex Wishart distribution and its application to change detection in polarimetric SAR data"

When working with multilook fully polarimetric synthetic aperture radar (SAR) data, an appropriate way of representing the backscattered signal consists of the so-called covariance matrix. For each pixel, this is a 3Ч3 Hermitian positive definite matrix that follows a complex Wishart distribution. Based on this distribution, a test statistic for equality of two such matrices and an associated asymptotic probability for obtaining a smaller value of the test statistic are derived and applied successfully to change detection in polarimetric SAR data. In a case study, EMISAR L-band data from April 17, 1998 and May 20, 1998 covering agricultural fields near Foulum, Denmark are used. Multilook full covariance matrix data, azimuthal symmetric data, covariance matrix diagonal-only data, and horizontal-horizontal (HH), vertical-vertical (VV), or horizontal-vertical (HV) data alone can be used. If applied to HH, VV, or HV data alone, the derived test statistic reduces to the well-known gamma likelihood-ratio test statistic. The derived test statistic and the associated significance value can be applied as a line or edge detector in fully polarimetric SAR data also. [J154]

"Scalable multilevel fast multipole method for multiple targets in the vicinity of a half space"

We extend the multilevel fast multipole algorithm (MLFMA) to the case of electromagnetic scattering from an arbitrary number of dielectric and/or perfectly conducting targets in the presence of a half space. This multitarget MLFMA is implemented in an iterative fashion, in which the fields incident on and scattered from each target are updated sequentially by considering each target in isolation, with appropriate field updating to account for intertarget scattering. Each target is analyzed in parallel on a separate computer node, and intertarget interaction is addressed via message passaging between the processors. We also utilize the aforementioned iterative formulation employed for handling interactions between multiple targets to develop a new means of solving the

MLFMA matrix equation for an isolated target. This new formulation generally results in significant acceleration in the analysis of scattering from single targets, thereby also accelerating the analysis of scattering from multiple targets (within the context of the iterative multitarget analysis developed). [J155]

"Maximum-likelihood estimation of specific differential phase and attenuation in rain"

Precise estimation of propagation parameters in precipitation media is of interest to improve the performance of communications systems and in remote sensing applications. In this paper, we present maximum-likelihood estimators of specific attenuation and specific differential phase in rain. The model used for obtaining the cited estimators assumes coherent propagation, reflection symmetry of the medium, and Gaussian statistics of the scattering matrix measurements. No assumptions about the microphysical properties of the medium are needed. The performance of the estimators is evaluated through simulated data. Results show negligible estimators bias and variances close to Cramer-Rao bounds. [J156]

"10 million unknowns: is it that big? [Jcomputational electromagnetics]"

At the Center for Computational Electromagnetics at the University of Illinois, we recently solved a very-large-scale electromagnetic scattering problem. We computed the bistatic radar cross-section of a full-size aircraft at 8 GHz, involving the solution of a dense matrix equation with nearly 10.2 million unknowns. We regarded this as the "ultimate test" of a massively parallel implementation of the multilevel fast multipole algorithm (MLFMA), called ScaleME. In this paper, we narrate the technical difficulties faced and the experience gained from a very informal point of view. We describe the various methods developed for surmounting each of the obstacles. [J157]

"Development of a ground-based radar for scattering measurements"

A ground-based C-band scatterometer system has been constructed at the Multimedia University, Malaysia. This is an inexpensive FM-CW radar that was efficiently constructed from a combination of commercially available components and in-house fabricated circuitry. The system has full polarimetric capability for determining the complete backscattering matrix of a natural target. It will be used to conduct in-situ backscatter measurements on Earth terrain, such as vegetation fields, forests, and soil surfaces. This paper presents the system design and the evaluation results of the scatterometer system. The system was tested at a football field. A metal sphere was used as the calibration target. The backscattering matrices of an 8" trihedral corner reflector and of a 4" Ч 8" dihedral corner reflector were measured. The dihedral was rotated at different angles to provide different sets of polarimetric data. The results were compared with the theoretical values to verify the effectiveness of the calibration technique. The external calibration and internal calibration procedures, as well as the approach used in measuring the relative phase response, are discussed. [J158]

"CFAR detection of distributed targets in non-Gaussian disturbance"

The subject of detection of spatially distributed targets in non-Gaussian noise with unknown statistics is addressed. At the design stage, in order to cope with the a priori uncertainty, we model noise returns as Gaussian vectors with the same structure of the covariance matrix, but possibly different power levels (heterogeneous environment). We also assume that a set of secondary data, free of signal components, is available to estimate the correlation properties of the disturbance The proposed detector assumes no a priori knowledge about the spatial distribution of the target scatterers and ensures the constant false alarm rate (CFAR) property with respect to both the structure of the covariance matrix and the power levels. Finally, the performance assessment, conducted modeling the disturbance as a spherically invariant random process (SIRP), confirms its validity to operate in real radar scenarios [J159]

"The multiple interaction model for nonshallow scatterers buried beneath 2-d random rough surfaces"

The multiple interaction model is hybridized with the robust Steepest Descent Fast Multipole Method (SDFMM) to compute the signature of nonshallow penetrable scatterers buried beneath two-dimensional random rough surfaces. The most attractive feature of the multiple interaction model with using the SDFMM is removing the quasi-planar structure constraint for analyzing nonquasi-planar scatterers. The results show that the buried object's signature is largely due to the first interaction mechanism; however, the contribution of each additional interaction is explicitly calculated, though they may become insignificant especially for lossy background soil [J160]

"Low altitude target model for radar simulation"

A simulation model of antenna array signals from a low altitude target is considered. Explicit expressions for

statistical and spectral characteristics of the scattered signals are obtained in the Kirchhoff approximation. The model permits to evaluate the efficiency of different techniques of low altitude target tracking. It benefits the comprehension of the influence of multipath propagation on tracking radars [J161]

"Characterization of target symmetric scattering using polarimetric SARs"

Cameron's coherent target decomposition (CTD) theory and the classification method that Cameron developed for operational use of his CTD are reconsidered. It is shown that Cameron's classification leads to a coarse scattering segmentation because of the large class dispersion that corresponds to a synthetic aperture radar (SAR) system with about ±8-dB channel imbalance. The application of Cameron's method within known SAR radiometric calibration requirements limits the utility of the classification. In addition, Cameron's classification is applied under the implicit assumption on the coherence nature of target scattering, and this might yield erroneous results within areas of noncoherent scattering. A new method, named the symmetric scattering characterization method (SSCM), is introduced to better exploit the information provided by the largest target symmetric scattering component in the context of coherent scattering. The Poincarer' sphere is used as the basis for a more complete representation of symmetric scattering than Cameron's unit disk, thus enabling the SSCM to generate better segmentation of target symmetric scattering with much higher resolution. In order to limit the application of the SSCM to targets of coherent scattering, new methods are developed for assessment and validation of the coherent nature of point and extended target scattering. [J162]

"Polarimetric scattering indexes and information entropy of the SAR imagery for surface monitoring"

The Mueller matrix solution and eigenanalysis of the coherency matrix for completely polarimetric scattering have been applied to the analysis of synthetic aperture radar (SAR) imagery. Copolarized and cross-polarized backscattering for any polarized incidence can be obtained. The polarization index is usually defined as a parameter to classify the difference between polarized scattering signatures from the terrain surfaces. The eigenvalues of the coherency matrix and information entropy are derived to directly relate with measurements of the copolarized and cross-polarized indexes. Thus, it combines the Mueller matrix simulation, the information entropy of the coherence matrix, and two polarization indexes together and yields a quantitative evaluation for surface classification in the SAR imagery. This theory is applied to analysis of the AirSAR images and field measurements. [J163]

"Adaptive RLS algorithm for blind source separation using a natural gradient"

By using the natural gradient on the Stiefel manifold to minimize a nonlinear principle component analysis criterion, this letter proposes a new adaptive recursive-least-squares (RLS) algorithm with prewhitening for blind source separation (BSS), which makes full use of the orthogonality constraint of the separating matrix. Simulations show that the new natural-gradient-based RLS algorithm has faster convergence than the existing least-mean-square algorithms and RLS algorithm for BSS. [J164]

"A new scattering mechanism enhancement scheme for polarimetric SAR images"

A new scattering mechanism enhancement scheme has been developed for natural (distributed) targets based on the eigenvalues and corresponding eigenvectors of the covariance matrix in order to identify different scattering events. First, three new vectors (v1, v2, and v3) were constructed from the eigenvectors of the covariance matrix with some modifications. Then, those modified vectors were weighted by the eigenvalues of the covariance matrix as a weighting function. Thus, three vertices (A, B, and C) could be obtained in the three-dimensional space. In order to utilize them equally, a triangle (ΔABC) was constructed by connecting these three vertices. The shape of the triangle may be changed due to the different scattering mechanisms because the vertices are obtained from the combination of eigenvalues and eigenvectors. The result indicated that different scattering mechanisms can be represented by using an exterior angle derived from the interior angles of the triangle. Results obtained from the newly developed scattering enhancement scheme, when compared with the results derived from existing schemes, were in agreement in terms of the dominant scattering mechanisms, including surface scattering, double-bounce scattering, and volume scattering. The experimental results with the Spaceborne Imaging Radar version C (SIR-C) L-band full polarimetric data demonstrate the effectiveness of the new scattering enhancement scheme. [J165]

"Ultra-wideband continuous-wave random noise arc-SAR"

A coherent ultra-wideband random noise radar system operating in the 1-2-GHz frequency range has been developed at the University of Nebraska. A unique signal processing procedure based on heterodyne correlation techniques preserves phase coherence within the system, thereby enabling it to be used for synthetic aperture

radar (SAR) imaging. Data acquisition is performed using a rotating boom with antennas installed atop a van containing radar equipment. This setup facilitates a simple and low-cost mobile SAR implementation, best suited for short-range quasi-stripmap Arc-SAR imaging. The use of ultra-wideband signals provides reasonable resolution of the obtained imagery. The amplitude and the phase response of the system are used to form the frequency-domain target scattering profile matrix, which are then transformed into a SAR image. The paper discusses the theory of SAR imaging using random noise signals and presents a detailed description of the radar and experimental imagery obtained using this system. [J166]

"The far-zone scattering calculation of frequency-dependent materials objects using the TLM method"

The transmission-line matrix method is used for the calculation of the far scattered field and radar cross section of frequency dependent materials objects. Three different materials have been considered, namely, Debye, plasma, and Lorentz for which the electric susceptibility is complex. The proposed model is based on the computation of the equivalent currents and on a time domain near-to-far-field transformation technique. To illustrate this study, the far-zone scattering results for different spheres using the three materials indicated above are presented. [J167]

"Application of adaptive basis functions for a diagonal moment matrix solution of arbitrarily shaped three-dimensional conducting body problems"

We present the application of specially constructed adaptive basis functions that generate a diagonal matrix in the method of moments solution procedure for the calculation of scattered electromagnetic fields from arbitrarily shaped conducting bodies excited by a plane electromagnetic wave. The arbitrary body is modeled using planar triangular patches. The crucial step in the solution procedure is the construction of the adaptive basis functions to generate the diagonal matrix. This task is accomplished with the help of well-known RWG basis functions. The solution thus obtained is very efficient, accurate, and applicable to truly arbitrary bodies. Several numerical examples are presented to validate the new method. [J168]

"Semi-empirical model of the ensemble-averaged differential Mueller matrix for microwave backscattering from bare soil surfaces"

A semi-empirical model of the ensemble-averaged differential Mueller matrix for microwave backscattering from bare soil surfaces is presented. Based on existing scattering models and data sets measured by polarimetric scatterometers and the JPL AirSAR, the parameters of the co-polarized phase-difference probability density function, namely the degree of correlation α and the co-polarized phase-difference ς, in addition to the backscattering coefficients σvv0,σhh0and σvh0, are modeled empirically in terms of the volumetric soil moisture content mvand the surface roughness parameters ks and kl, where k=2pif/c, s is the rms height and l is the correlation length. Consequently, the ensemble-averaged differential Mueller matrix (or the differential Stokes scattering operator) is specified completely by σvv0,σhh0,σvh0,α, and ζ. [J169]

"Using cross-entropy for polarimetric radar discrimination problem"

Cross-entropy for measuring the difference between two scatterers in the polarimetric radar discrimination problem is introduced. Two cross-entropy measures in favour of one scatterer over another are obtained for two independent probability mass functions that indicate the average scattering mechanism and the scattering randomness [J170]

"A comparison between different polarimetric measurement schemes"

The usefulness of polarization information in remote sensing applications has been clearly demonstrated in the last two decades. Land covers and meteorological targets are complex and their backscatter returns are time varying. Their polarimetric characteristics should be determined in terms of second order statistics of scattering matrix elements. These are contained. in the polarimetric covariance matrix. Estimation of polarimetric covariance matrix elements has been addressed by different authors based on different scattering matrix measurement methods. The most widely used and implemented method consists in the alternate transmission of two orthogonal polarizations while. receiving with both. Recently, a method that considers simultaneous transmission of two orthogonal polarizations, which are phase coded with orthogonal signals, has been proposed. Another method, specifically developed to obtain the polarimetric covariance matrix, is based on transmitting three different polarizations and receiving their corresponding co-polar and cross-polar counterparts. Different data sets result from each measurement technique and different estimators of polarimetric covariance matrix elements have been developed for the different data sets available. These various methods are investigated in here.

Based on simulated data the performance of the different estimators under different working conditions are analyzed. Effects on the estimators of operation frequency, pulse repetition frequency (PRF) and temporal properties of targets are discussed [J171]

"An ultrafast wide-band millimeter-wave (MMW) polarimetric radar for remote sensing applications"

With the advent of high-frequency radio frequency (RF) circuits and components technology, millimeter-wave (MMW) radars are being proposed for a large number of military and civilian applications. Accurate and high-resolution characterization of the polarimetric radar backscatter responses of both clutter and man-made targets at MMW frequencies is essential for the development of radar systems and optimal detection and tracking algorithms. Toward this end, a new design is developed for ultrafast, wide-band, polarimetric, instrumentation radars that operate at 35 and 95 GHz. With this new design, the complete scattering matrix of a target (magnitude and phase) can be measured over a bandwidth of 500 MHz in less than 2 μs. In this paper, the design concepts and procedures for the construction and calibration of these radars are described. In addition, the signal processing algorithm and data-acquisition procedure used with the new radars are presented. To demonstrate the accuracy and applicability of the new radars, backscatter measurements of certain points and distributed targets are compared with their analytical radar cross section (RCS) and previously measured σ° values, respectively, and good agreements are shown. These systems, which can be mounted on a precision gimbal assembly that facilitates their application as high-resolution imaging radar systems, are used to determine the MMW two-way propagation loss of a corn field for different plant moisture conditions. [J172]

"On the fast approximation of Green's functions in MPIE formulations for planar layered media"

The numerical implementation of the complex image approach for the Green's function of a mixed-potential integral-equation formulation is examined and is found to be limited to low values of κoρ (in this context κ0ρ = 2piρ/λ0, where ρ is the distance between the source and the field points of the Green's function and λ0 is the free space wavelength). This is a clear limitation for problems of large dimension or high frequency where this limit is easily exceeded. This paper examines the various strategies and proposes a hybrid method whereby most of the above problems can be avoided. An efficient integral method that is valid for large κ0ρ is combined with the complex image method in order to take advantage of the relative merits of both schemes. It is found that a wide overlapping region exists between the two techniques allowing a very efficient and consistent approach for accurately calculating the Green's functions. In this paper, the method developed for the computation of the Green's function is used for planar structures containing both lossless and lossy media [J173]

"Polarimetric adaptive detection of range-distributed targets"

We address the problem of polarimetric adaptive detection of range-spread targets in Gaussian noise with unknown covariance matrix. At the design stage, we model the target echo from each polarimetric channel as a deterministic signal known up to a scaling factor (possibly varying from cell to cell), which accounts for the polarimetric scattering properties of the target. We first show the failure of the generalized likelihood ratio test (GLRT) procedure to deal with this kind of problem, and thus, we propose a fully adaptive detector based on the method of sieves. We also derive the analytical expression for the probability of false alarm and show that the newly introduced receiver can be made bounded constant false alarm rate (CFAR). Finally, we present simulation results highlighting the performance gain that can be achieved by resorting to polarization diversity in conjunction with high resolution. [J174]

"Improved target classification using optimum polarimetric SAR signatures"

We present a new method for automatic target/object classification by using the optimum polarimetric radar signatures of the targets/objects of interest. The state-of-the-art in radar target recognition is based mostly either on the use of single polarimetric pairs or on the four preset pairs of orthogonal polarimetric signatures. Due to these limitations, polarimetric radar processing has been fruitful only in the area of noise suppression and target detection. The use of target separability criteria for the optimal selection of radar signal state of polarizations is addressed here. The polarization scattering matrix is used for the derivation of target signatures at arbitrary transmit and receive polarization states (arbitrary polarization inclination angles and ellipticity angles). Then, an optimization criterion that minimizes the within-class distance and maximizes the between-class metrics is used for the derivation of optimum sets of polarimetric states. The results of the application of this approach on real synthetic aperture radar (SAR) data of military vehicles are obtained. The results show that noticeable improvements in target separability and consequently target classification can be achieved by the use of the optimum over nonoptimum signatures [J175]

"The characteristic polarization states and the equi-power curves"

Characteristic polarization state theory is restudied for the symmetric coherent Sinclair scattering matrix case. First, the geometric relations of the characteristic polarization states on the Poincare sphere are derived. Based on these relations, simple formulas are given for all of the characteristic polarization states of this Sinclair matrix in Stokes vector form. From the formulation, it is clear that the CO-POL Nulls are fundamental characteristic polarization states for the symmetric coherent Sinclair scattering matrix case, in that the others can straightforwardly be obtained from the Stokes vectors of the CO-POL Nulls. For further study of the characteristic polarization state and the distribution of the received powers on the Poincare sphere, the authors introduce the concept of the equi-power curve. It is defined as the curve on the Poincare sphere on which the received powers in some defined channel have the same value. They deal with the characteristics of the equi-power curves for various special cases. In addition, they show how the characteristic polarization states are generated by the equi-power curves. It is demonstrated that the characteristic polarization states can usually be regarded as the points of contact of the Poincare sphere and a conicoid representing a power-related quadratic form. This leads to a new method to introduce the characteristic polarization states [J176]

"Fully polarimetric bistatic radar scattering behavior of forested hills"

The bistatic radar scattering measurements of forested hills were performed at grazing incidence and at azimuth scattering angles from 28° to 66° from the forward scatter plane. Using pulse-to-pulse switching between orthogonal transmitted polarizations, the radar simultaneously measures two orthogonally polarized components of the scattered wave to obtain full polarimetric information about the scattering process. These are the first fully polarimetric terrain clutter measurements to be conducted at large bistatic angles. The complete Stokes matrix, computed by averaging successive realizations of the polarization scattering matrix, is used to examine the polarization sensitivity of the bistatic clutter. It is found that the polarization state of the EM wave scattered out of the plane of incidence strongly depends on the polarization orientation of the incident electric field. Unlike the monostatic case, these two incident wave polarization states are found to produce substantially different scattered wave behavior when trees are viewed at large bistatic angles. Scattered fields resulting from vertically oriented incident fields are found to be highly polarized and to produce bistatic clutter power levels that are strongly dependent on the polarization of the receiving antenna. In contrast, horizontally oriented incident fields are found to produce weakly polarized scattered waves with bistatic clutter power levels that are insensitive to the polarization of the receiving antenna [J177]

"New block ILU preconditioner scheme for numerical analysis of very large electromagnetic problems"

Large electromagnetic scattering and radiation problems are tackled by iterative solvers, which require the use of huge preconditioners. Most often, the incomplete LU decomposition (ILU) of the preconditioner is applied to the system matrix at each iteration. However, the preconditioner ILU cannot be done in-core when the size of the preconditioning matrix exceeds the available memory. This paper presents a new preconditioning scheme to do the preconditioner ILU in small blocks that fit in core memory. The resulting approach allows the solution of very large problems in small computers [J178]

"Analysis of low frequency scattering from penetrable scatterers"

A method is presented for solving the surface integral equation using the method of moments (MoM) at very low frequencies, which finds applications in geoscience. The nature of the Helmholtz decomposition leads the authors to choose loop-tree basis functions to represent the surface current. Careful analysis of the frequency scaling property of each operator allows them to introduce a frequency normalization scheme to reduce the condition number of the MoM matrix. After frequency normalization, the MoM matrix can be solved using LU decomposition. The poor spectral properties of the matrix, however, makes it ill-suited for an iterative solver. A basis rearrangement is used to improve this property of the MoM matrix. The basis function rearrangement (BFR), which involves inverting the connection matrix, can be viewed as a pre-conditioner. The complexity of BFR is reduced to O(N), allowing this method to be combined with iterative solvers. Both rectilinear and curvilinear patches have been used in the simulations. The use of curvilinear patches reduces the number of unknowns significantly, thereby making the algorithm more efficient. This method is capable of solving Maxwell's equations from quasistatic to electrodynamic frequency range. This capability is of great importance in geophysical applications because the sizes of the simulated objects can range from a small fraction of a wavelength to several wavelengths [J179]

"Wavelet-based simulations of electromagnetic scattering from large-scale two-dimensional perfectly conducting random rough surfaces"

Simulations of electromagnetic waves scattering from two-dimensional perfectly conducting random rough

surfaces are performed using the method of moment (MoM) and the electric field integral equation (EFIE). Using wavelets as basis and testing functions, the resulting moment matrix is generally sparse after applying a threshold truncation. This property makes wavelets particularly useful in simulating large-scale problems, in which reducing memory storage requirement and CPU time are crucial. In this paper, scattering from Gaussian conducting rough surfaces of a few hundred square wavelengths are studied numerically using Haar wavelets. A matrix sparsity less than 10% is achieved for a range of root mean square (RMS) height at eight sampling points per linear wavelength. Parallelization of the code is also performed. Simulation results of the bistatic scattering coefficients are presented for different surface RMS heights up to 1 wavelength. Comparisons with sparse-matrix/canonical-grid approach (SM/CG) and triangular discretized (RWG basis) results are made as well. Depolarization effects are examined for both TE and TM incident waves. The relative merits of the SM/CG method and the present method are discussed [J180]

"Complex natural resonances of conducting planar objects buried in a dielectric half-space"

A scheme is presented to incorporate a mixed potential integral equation (MPIE) using Michalski's “formulation C” with the method of moments (MoM) for analyzing the scattering of a plane wave from conducting planar objects buried in a dielectric half-space. The robust complex image method with a two-level approximation is used for the calculation of the Green's functions for the half-space. To further speed up the computation, an interpolation technique for filling the matrix is employed. While the induced current distributions on the object's surface are obtained in the frequency domain, the corresponding time domain responses are calculated via the inverse fast Fourier transform (FFT). The complex natural resonances of targets are then extracted from the late time response using the generalized pencil-of-function (GPOF) method. The authors investigate the pole trajectories as they vary the distance between strips and the depth and orientation of single, buried strips. The variation from the pole position of a single strip in a homogeneous dielectric medium was only a few percent for most of these parameter variations [J181]

"Coupled canonical grid/discrete dipole approach for computing scattering from objects above or below a rough interface"

A numerical model for computing scattering from a three-dimensional (3D) dielectric object above or below a rough interface is described. The model is based on an iterative method of moments solution for equivalent electric and magnetic surface current densities on the rough interface and equivalent volumetric electric currents in the penetrable object. To improve computational efficiency, the canonical grid method and the discrete dipole approach (DDA) are used to compute surface to surface and object to object point couplings, respectively, in O(N log N), where N is the number of surface or object sampling points. Two distinct iterative approaches and a preconditioning method for the resulting matrix equation are discussed, and the solution is verified through comparison with a Sommerfeld integral-based solution in the flat surface limit. Results are illustrated for a sample landmine detection problem and show that a slight surface roughness can modify object backscattering returns [J182]

"Effective medium theory for large particulate size composites"

The present study extends our previous work that concerned the effective permittivities and absorptivities of particulate composites consisting of graphite-type microsphere inclusions in a dielectric matrix, and their suitability as radar-absorbing materials. Whereas in that work spheres of one size (radius a=50 mcm)had been considered only, we here study the dependence of the results on the sphere radius of up to one or several millimeters, and find sizable effects on permittivities for a≥1 mm,and below that for the absorptivities, indicating the increasing importance of multiple scattering effects. While the multiple-scattering formulas utilized here are based on a low-frequency approximation, we devise a modification of these formulas in order to extend their validity to higher frequencies (or larger particle sizes). copyright 2001 American Institute of Physics. [J183]

"Similarity between two scattering matrices"

The similarity parameter between two scattering matrices, based on a special correlation coefficient, is presented. This parameter is not only independent of the spans of the scattering matrices, but also independent of the target orientation angles. As an application, the parameters of similarities to several typical scattering matrices are derived and used to analyse characteristics of a radar target [J184]

"Estimation of frequencies and damping factors by two-dimensional ESPRIT type methods"

In this paper, we consider two-dimensional (2-D) signals modeled by the sum of damped cisoids. We propose two high-resolution approaches to estimate their frequencies and damping factors. Both high-resolution methods are based on the shift-invariance structure of the signal subspace related to each dimension. The first one

estimates the frequency components in both dimensions as in the matrix enhancement and matrix pencil (MEMP) method before pairing them with a new algorithm. The second one consists of the direct estimation of the signal frequency pairs without an additional step to pair the frequencies related to each dimension. We show how these methods can estimate the scattering points of radar images [J185]

"Development of target null theory"

In a co- or cross-polarized channel, the polarization states of the transmitting and receiving antennas are the same or orthogonal, and the corresponding target nulls (i.e., the co-pol nulls or x-pol nulls) are defined as the polarization states of the transmitting antenna such that the received power equals zero. However, no systematic studies have been carried out to solve the problem of the corresponding target nulls if the polarization states of the transmitting and receiving antennas are independent. In this paper, the target null theory is extended to the case of two independent polarization states. For two arbitrary independent symmetric scattering matrices, it is proved that there exists only one pair of polarization states such that both of the received powers equal zero. This polarization states' pair is called the co-null of the two targets, which can easily be obtained by solving an eigenvalue problem. Based on this concept and algebraic theory, the concept of the co-null space is introduced for the symmetric scattering matrix case, and many important results are presented, e.g., the relations between the co-null and the co-pol/x-pol nulls, the properties of the co-null space, and the relation between the co-null and target decomposition. Finally, the co-null for the asymmetric scattering matrix case is studied. The concepts of the mono-co-null space and the bi-co-null space are introduced, and the relations between both spaces are presented [J186]

"Recognizing occluded objects in SAR images"

Recognizing occluded vehicle targets in synthetic aperture radar (SAR) images is addressed. Recognition algorithms, based on local features, are presented that successfully recognize highly occluded objects in both XPATCH synthetic SAR signatures and real SAR images of actual vehicles from the MSTAR data. Extensive experimental results are presented for a basic recognition algorithm, using SAR scattering center relative locations as features with the XPATCH data and for an improved algorithm, using scatterer locations and magnitudes with the real SAR targets in the MSTAR data. The results show the effect of occlusion on recognition performance in terms of probability of correct identification, receiver operating characteristic curves, and confusion matrices [J187]

"SAR ATR performance using a conditionally Gaussian model"

A family of conditionally Gaussian signal models for synthetic aperture radar (SAR) imagery is presented, extending a related class of models developed for high resolution radar range profiles. This signal model is robust with respect to the variations of the complex-valued radar signals due to the coherent combination of returns from scatterers as those scatterers move through relative distances on the order of a wavelength of the transmitted signal (target speckle). The target type and the relative orientations of the sensor, target, and ground plane parameterize the conditionally Gaussian model. Based upon this model, algorithms to jointly estimate both the target type and pose are developed. Performance results for both target pose estimation and target recognition are presented for publicly released data from the MSTAR program [J188]

"Unsupervised classification of multifrequency and fully polarimetric SAR images based on the H/A/Alpha-Wishart classifier"

Introduces a new classification scheme for dual frequency polarimetric SAR data sets. A (6Ч6) polarimetric coherency matrix is defined to simultaneously take into account the full polarimetric information from both images. This matrix is composed of the two coherency matrices and their cross-correlation. A decomposition theorem is applied to both images to obtain 64 initial clusters based on their scattering characteristics. The data sets are then classified by an iterative algorithm based on a complex Wishart density function of the 6Ч6 matrix. A class number reduction technique is then applied on the 64 resulting clusters to improve the efficiency of the interpretation and representation of each class. An alternative technique is also proposed which introduces the polarimetric cross-correlation information to refine the results of classification to a small number of clusters using the conditional probability of the cross-correlation matrix. These classification schemes are applied to full polarimetric P, L, and C-band SAR images of the Nezer Forest, France, acquired by the NASA/JPL AIRSAR sensor in 1989 [J189]

"Radar target identification using one-dimensional scattering centres"

Identification concerning different types of radar targets can be achieved by using various radar signatures, such

as one-dimensional (1-D) range profiles, 2-D radar images, and 1-D or 2-D scattering centres on a target. To solve the target identification problem, the authors utilise 1-D scattering centres, which correspond to the highest peaks in the 1-D range profile. The proposed approach obtains scale and translational-invariant features based on the central moments from the distribution of the 1-D scattering centres on the target; these 1-D scattering centres can be extracted from various techniques such as the inverse fast Fourier transform (IFFT), fast root-multiple signal classification (fast root-MUSIC), total least squares-Prony (TLS-Prony), generalised eigenvalues utilising signal subspace eigenvectors (GEESE), and the matrix-pencil (MP) algorithm. The information redundancy contained in these features, as well as their dimensions, are further reduced via the Karhunen-Loeve transform, followed by adequate scaling of the computed central moments. The resulting small dimensional and redundancy-free feature vectors are classified using the Bayes classifier. Finally, this new strategy for radar target identification is demonstrated with data measured in the compact range facility, and the above five different techniques for 1-D scattering centre extraction are compared and investigated in the context of target identification [J190]

"Quantitative comparison of classification capability: fully polarimetric versus dual and single-polarization SAR"

Addresses the land-use classification capabilities of fully polarimetric synthetic aperture radar (SAR) versus dual-polarization and single-polarization SAR for P-, L-, and C-band frequencies. A variety of polarization combinations are investigated for application to crop and tree age classification. Based on the complex Wishart distribution for the covariance matrix, maximum likelihood classifiers for all polarization combinations are used to assess quantitative classification accuracy. Thus, this allows optimally selecting the frequency and the combination of polarizations for various applications [J191]

"Iterative MMSE method and recurrent Kalman procedure for ISAR image reconstruction"

This work presents a novel approximate iterative and recurrent approach for image reconstruction from inverse synthetic aperture radar (ISAR) data. Mathematical models of the quadrature components of the ISAR signal, reflected by an object with a complex geometry, are devised. Approximation matrix functions are used to describe deterministic signals reflected by point scatterers located at nodes of the uniform grid (model) during inverse aperture synthesis. Minimum mean square error (MMSE) equations and Kalman equations are derived. To prove the validity and correctness of the developed iterative MMSE method and recurrent Kalman procedure, numerical experiments were performed. The computational results demonstrate high resolution images, unambiguous and convergent estimates of the point scatterers' intensities of a target from simulated ISAR data [J192]

"Scattering from lossy dielectric objects buried beneath randomly rough ground: validating the semi-analytic mode matching algorithm with 2-D FDFD"

A new semi-analytic mode matching (SAMM) algorithm is verified by two-dimensional (2-D) finite difference frequency domain (FDFD) simulations of scattering resulting from uniform plane waves incident on randomly rough dielectric half-spaces containing buried dielectric targets. The SAMM algorithm uses moderately low-order modal superpositions of cylindrical waves, each of which satisfies the 2-D-Helmholtz equation in its appropriate region (air, ground, or mine) and then matches all nonzero electric and magnetic field components at each interface by inverting a highly overconstrained dense linear matrix equation by singular value decomposition. That is, the set of cylindrical mode coefficients is found which best fits the boundary conditions in a least squares sense. For smooth ground, coordinate scattering centers (CSCs) are chosen at the mine center and at its image above the plane to model scattering. For randomly rough ground, additional CSCs are located within the rough boundary layer. Excellent agreement between 2-D-FDFD and the 2-D version of SAMM is observed, with 2-D-SAMM being at least an order of magnitude faster. 3-D-SAMM is estimated to be four orders of magnitude faster than 3-D-FDFD, with drastically reduced memory requirements [J193]

"Estimation of directions of arrival of multiple scattered sources"

We consider the problem of estimating the directions of arrival (DOA) of multiple sources in the presence of local scattering. This problem is encountered in wireless communications due to the presence of scatterers in the vicinity of the mobile or when the signals propagate through a random inhomogeneous medium. Assuming a uniform linear array (ULA), we develop DOA estimation algorithms based on covariance matching applied to a reduced-size statistic obtained from the sample covariance matrix after redundancy averaging. Next, a computationally efficient estimator based on AR modelling of the coherence loss function is derived. A theoretical expression for the asymptotic covariance matrix of this estimator is derived. Finally, the corresponding Cramer-Rao bounds (CRBs) are derived. Despite its simplicity, the AR-based estimator is shown to possess performance

that is nearly as good as that of the covariance matching method [J194]

"Theoretical and experimental waveguide characterization of small wire scatterers"

A simple method is presented in this paper that allows us to verify numerically obtained polarizability tensors of electrically small scatterers by waveguide measurements. To this end, a model of the scattering process within the waveguide is developed. Measurements performed on a small helix in two different waveguide setups are compared to the theoretical data obtained from the model. A good agreement is demonstrated. Furthermore, the measured data are highly sensitive to the orientation of the scatterer within the waveguide. Thus, the polarizability tensors can be verified [J195]

"GLRT-based adaptive detection algorithms for range-spread targets"

We address adaptive detection of a range-spread target or targets embedded in Gaussian noise with unknown covariance matrix. To this end, we assume that cells (referred to in the following as secondary data) that are free of signal components are available. Those secondary data are supposed to possess either the same covariance matrix or the same structure of the covariance matrix of the cells under test. In this context, we design detectors relying on the generalized likelihood ratio test (GLRT) and on a two-step GLRT-based design procedure. Remarkably, both criteria lead to receivers ensuring the constant false alarm rate (CFAR) property with respect to the unknown quantities. A thorough performance assessment of the proposed detection strategies, together with the evaluation of their processing cost, highlights that the two-step design procedure is to be preferred with respect to the plain GLRT. In fact, the former leads to detectors that achieve satisfactory performance under several situations of practical interest and are simpler to implement than those designed resorting to the latter [J196]

"A macro-element compression for the moment method"

A new approach based on QR compression of the off-diagonal blocks of the impedance matrix arising in integral equations solutions of electromagnetic (EM) scattering problems, previously implemented for finite and irregular gratings, is extended here to an arbitrarily shaped obstacle. The main tool consists in dividing the entire surface scatterer into subdomains and in assembling the global impedance matrix as a combination of the macromatrices associated to each interaction of any patch on the other. The correlation between compression rate and accuracy of field computation is drawn up. An experimental study is performed to optimize the method relatively to the two competing parameters: accuracy and cost. Finally, it is shown that this method works equally well in both the high and the low frequency domain and also with an inclusion of a small detail in a large object [J197]

"High resolution 3D “snapshot” ISAR imaging and feature extraction"

We have developed a new formulation for three dimensional (3D) radar imaging of inverse synthetic aperture radar (ISAR) data based on recent developments in high resolution spectral estimation theory. Typically for non real-time applications, image formation is a two step process consisting of motion determination and image generation. The technique presented focuses on this latter process, and assumes the motion of the target is known. The new technique offers several advantages over conventional techniques which are based on the correlation imaging function. In particular, the technique provides for a direct 3D estimate (versus back projection to a 3D target grid matrix) of the locations of the dominant scattering centers using only a minimum set of independent 2D range-Doppler ISAR “snapshots” of the target. Because of the snapshot nature of the technique, it is particularly applicable to 3D imaging of sectors of sparse-angle data, for which the sidelobes of the correlation imaging integral become high. Furthermore, the technique provides for an estimate of amplitude and phase of each scattering center as a function of aspect angle to the target, for those aspect angles which encompass the set of 2D range-Doppler snapshots. Results illustrating the technique developed are presented for both simulated and static range data [J198]

"Numerical methods for solving the optimal problem of contrast enhancement"

This paper proposes two effective numerical methods to solve the optimal problem of contrast enhancement for the coherent and incoherent cases, respectively. For the coherent case, the objective function of the optimal problem is transformed into a bilinear form. Then a numerical method is presented by using the idea of the Sequential Unconstrained Minimization Technique (SUMT). For the incoherent case, a cross-iterative method is proposed for solving the optimal problem of contrast enhancement, based on the formula of the optimal contrast polarization state in the matched-polarized channel. Both the proposed methods are convergent and straightforward for programming. In addition, the proposed methods can be used for the bistatic radar case because in this paper, it is unnecessary to restrict the symmetry of the scattering matrix and the Kennaugh

matrix. For showing the effectiveness of the proposed methods, the authors give three examples. The results of the calculation are completely identical with other papers', showing the validity of the proposed methods. In these three examples, if the receiving polarization state is independent of the transmitting's, the power ratios may be much larger than those in the cases of the co-polarized, the cross-polarized, and the matched-polarized channels, showing the importance of the considered models. In addition, the computation costs are estimated by these illustrative examples, illustrating that the proposed methods are very effective [J199]

"The use of the transfinite interpolation in the method of moments applied to electromagnetic scattering by dielectric cylinders"

The method of moments (MoM) solution of electromagnetic scattering presents two major numerical difficulties: the number of unknowns and the computation time necessary to calculate the matrix elements. To circumvent these problems, a MoM using the transfinite interpolation and a reduced integration scheme is presented here. The so-called h and p versions of the new method are applied to the scattering of an electromagnetic wave by an infinite dielectric cylinder (TM case) in the Richmond formulation. The transfinite and classical methods are compared in terms of the convergence rates of the radar cross section and of the total electric field inside the dielectric. The results confirm the superiority of the new schemes as predicted by the theory [J200]

"Passive localization of moving emitters using out-of-plane multipath"

The purpose of this work is to establish how a moving emitter, such as a jammer, can be localized by a passive receiver through the use of out-of-plane multipath signals reflected by the terrain. This is a novel localization technique that assumes no a priori knowledge of the localization of the multipath sources. The emitter parameters of range, heading, velocity, and altitude are estimated by exploiting the correlation between the direct-path signal and the delayed and Doppler modulated signals. Two basis assumptions about the scattering properties of the terrain lead to different maximum likelihood estimators (MLEs). The Cramer-Rao lower bounds (CRLB) are used to study estimator performance versus emitter velocity for each case. The proposed estimators are successfully demonstrated using field data collected at White Sands Missile Range (WSMR) during the DARPA/Navy Mountaintop program [J201]

"Observation of extended targets with antenna arrays"

Moments of the scattering function are a superb set of parameters representing an extended radar target. This set perfectly matches the adopted radar observation sequence (detection, position estimation, resolution, recognition and tracking). The problem of the moment estimation in radar systems with antenna arrays is considered [J202]

"Compensation for the effects of mutual coupling on direct data domain adaptive algorithms"

This paper investigates the effects of mutual coupling between the elements of an array on direct data domain algorithms. Mutual coupling severely undermines the interference suppression capabilities of direct data domain algorithms. The method of moments (MoM) is used to evaluate the mutual coupling between the elements of a given array. The MoM admittance matrix is then used to eliminate the effects of mutual coupling [J203]

"Numerical simulation of scattering from rough surfaces: a wavelet-based approach"

In this paper, a preliminary study is carried out to demonstrate the application of wavelets for improving the computation time and reducing computational memory required for evaluating the statistics of the scattered field from rough surfaces using the method of moments (MoM) in conjunction with a Monte Carlo simulation. In specific, Haar and the first order B-spline wavelet basis functions are applied to the MoM formulation of one-dimensional rough surfaces in order to compare the computation time and sparsity for wavelets in the same family but of higher order. Since the scattering coefficient (the second moment of the backscatter field per unit area) is a gentle function of the surface parameters and the radar attributes, it is demonstrated that a relatively high thresholding level can be applied to the impedance matrix, which leads to a sparser impedance matrix and faster computation time. It is also shown that applying a high threshold level the coefficients of the high-order wavelets would increase out of proportion, however, the effect of these current components averages out when computing the scattering coefficients. The resulting sparse impedance matrices are solved efficiently using fast search routines such as the conjugate gradient method. A systematic study is carried out to investigate the effect of different threshold levels on the accuracy versus computing speed criterion. The computed scattering coefficients are compared to previous results computed using a conventional pulse basis function as well as the existing theoretical solutions for rough surfaces. It is shown that wavelet basis functions provide substantial reductions in both memory requirements and computation time [J204]

"Polarimetric SAR data compensation for terrain azimuth slope variation"

This paper addresses the problem of polarimetric SAR (POLSAR) data correction for changes in radar cross sections, which are caused by azimuth slopes. Most radiometric slope corrections remove slope effects to account for the effective scattering pixel area. However, few studies address the slope effect on the radar cross section as a function of polarization states. The authors propose two approaches to compensate for this azimuth slope effect for POLSAR data. In the first approach, the digital elevation model (DEM), obtained from interferometric SAR or from other means, is used to estimate orientation angles, and in the second approach, orientation angles are derived directly from the POLSAR data. They have developed three new methods to implement this second approach. One is based on the right-right and left-left circular polarizations, and the other two are based on Cloude's and Huynelt's decompositions. The results are compared with the original polarization signature method using the DEM-generated orientation angles as the reference. POLSAR data is then compensated using the derived orientation angles. Significant changes were observed in many elements of the coherency matrix. The compensated POLSAR data should improve the accuracy of geophysical parameter estimation techniques. NASA/JPL AIRSAR data for an area in central California is used for illustration [J205]

"Enhancement of reflected waves in single-hole polarimetric borehole radar measurement"

A polarimetric approach is presented to extract information of reflected waves that is masked by the transmitter-receiver directly coupled wave in a single-hole borehole radar measurement. Radar polarimetry theory is expanded to an omnidirectional radar system with electric and magnetic dipoles arranged on the same axis. First, we formulate the transfer functions directly coupled between the antennas for cross-hole and single-hole arrangements in copolarized channels. We found that the theoretical scattering matrices of the direct-wave coupling is identical to the scattering matrix from a dihedral corner reflector. Second, we also consider signals in polarimetric channel of a wave reflected from a plane scatter in single-hole arrangements. As advanced reflection borehole radar measurement, we demonstrate a technique for both reduction of the directly coupled wave and enhancement of the reflected waves from a plane fracture with measured data in dipole-dipole and slot-slot antenna combinations. For quantitative determination of the scattering matrix, we use a technique to compensate the antenna transfer functions by the time derivative of the directly coupled signals in single-hole measurement. Also, we propose a technique to reduce the directly coupled component by adding vertical (VV) and horizontal (HH) signals and we showed that the directly coupled wave is effectively reduced and reflected waves are enhanced with experimental data. Finally, we show that this technique is more useful for near-range reflector detection than a conventional subtraction technique with moving average of the measured waveforms [J206]

"Electromagnetic scattering from an electrically dense vegetation medium"

A vegetation medium can generally be modeled as a discrete random medium where scatterers such as disks, needles, and cylinders are used to represent the leaves, branches, and trunks. At low frequency, it is possible that the spacing between the scatterers is comparable or smaller than the wavelength. This medium is considered electrically dense, and the coherence effect from the scatterers indicates that the assumption of independent scattering of the scatterers is no longer valid. In addition, in a dense vegetation medium where the scatterers are close to each other, near field interactions should also be considered. In this paper, the coherence effect from the various correlated scatterers is taken into account by introducing the array phase correction to the phase matrices of the scatterers. For the near field interaction effect, both the Fresnel phase correction and the amplitude correction are considered. The Fresnel phase correction is incorporated by including the higher order terms in the phase of the scattered field from a scatterer, whereas the amplitude correction is obtained from the near field amplitude term of the scattered field. These corrected phase matrices for the disks, needles, and branches are applied in the single layer random discrete medium where the second order iterative radiative transfer solutions are obtained. Theoretical analyses of the effects of these corrections to the backscattering returns for various volume fractions, frequencies, incident angles, orientations, and sizes are carried out. It is found that the array phase correction is important for an electrically dense medium, whereas the amplitude and the Fresnel phase corrections are required when the frequency increases and enters into the Fresnel region. Good agreements are obtained from the comparisons of the theoretical predictions with the multifrequency and multipolarization measurement results of the Japanese cypress and boreal forest [J207]

"Scattering from 3-D cavities with a plug and play numerical scheme combining IE, PDE, and modal techniques"

In this paper, we present a multidomain and multi-method coupling scheme called FACTOPO, based on generalized scattering matrix computations on three-dimensional (3-D) subdomains. The global target Ω is split in NVsubdomains (Vi)(i=1, NV), separated by NIfictitious surfaces (Γ j)(j=1,NI). We use a modal representation of

the tangent fields on the interfaces. In each domain, the generalized scattering matrix Siis computed with different methods such as the 3-D finite-element method (FEM) or the electric field integral equation (EFIE). This coupling scheme leads to an important reduction in computational resources, especially for cavities with one dimension much larger than the other two. The advantages of this formulation for parametric studies is illustrated by two cases: computing the RCS of an air-intake terminated with a flat PEC or a fan (CHANNEL) and of an antenna structure coupled to an electronic feed with a varying parameter (DENEB). Numerical as well as experimental results are presented [J208]

"Fast converging adaptive detection of Doppler-shifted, range-distributed targets"

A generalized likelihood ratio test (GLRT) for the adaptive detection of a target or targets that are Doppler-shifted and distributed in range is derived. The unknown parameters associated with the hypothesis test are the complex amplitudes in range of the desired target and the unknown covariance matrix of the additive interference, which is assumed to be characterized as complex zero-mean correlated Gaussian random variables. The target's or targets' complex amplitudes are assumed to be distributed across the entire input data block (sensor Ч range). The unknown covariance matrix is constrained to have the reasonable form of the identity matrix (the internal noise contribution) plus an unknown positive semidefinite (psdh) matrix (the external interference contribution). It is shown via simulation for a variety of interference scenarios that the new detector has the characteristic of having a bounded constant false alarm rate (CFAR), i.e., for our problem, the probability of false alarm PFfor a given detection threshold is bounded by the PFthat results when no external interference is present. It is also shown via simulation that the new detector converges relatively fast with respect to the number of sample vectors K necessary in order to achieve a given probability of detection PD [J209]

"An investigation of new FETD/ABC methods of computation of scattering from three-dimensional material objects"

Finite-element time-domain (FETD) and absorbing boundary condition (ABC) methods for computation of scattering from three-dimensional (3-D) material objects are developed and investigated. The methods involve discrete-time FETD solution of the time-domain Helmholtz equation in a region that comprises the 3-D scatterer and its immediate vicinity. Coupling of the solution to the surrounding infinite space is achieved through the ABC. This FETD/ABC formulation is examined for a number of various geometries: sphere, plate, and ogive [J210]

"Adaptive nulling of SAR sidelobe discretes"

By using adaptive subarrays for crossrange imaging we have developed a computationally simple method that removes any image degradation caused by strong, discrete clutter located in the crossrange sidelobes of a synthetic aperture radar (SAR) image. The procedure is based on the minimization of the mean interference power with the constraint that the image of a desired scatterer is undistorted. The applicability of the approach has been illustrated by simulation [J211]

"Fast algorithm for electromagnetic scattering by buried 3-D dielectric objects of large size"

A fast algorithm for electromagnetic scattering by buried three dimensional (3-D) dielectric objects of large size is presented by using the conjugate gradient (CG) method and fast Fourier transform (FFT). In this algorithm, the Galerkin method is utilized to discretize the electric field integral equations, where rooftop functions are chosen as both basis and testing functions. Different from the 3-D objects in homogeneous space, the resulting matrix equation for the buried objects contains both cyclic convolution and correlation terms, either of which can be solved rapidly by the CG-FFT method. The near-scattered field on the observation plane in the upper space has been expressed by two-dimensional (2-D) discrete Fourier transforms (DFTs), which also can be rapidly computed. Because of the use of FFTs to handle the Toeplitz matrix, the Sommerfeld integrals' evaluation which is time consuming yet essential for the buried object problem, has been reduced to a minimum. The memory required in this algorithm is of order N (the number of unknowns), and the computational complexity is of order NiterN log N, in which Niteris the iteration number, and Niter≪N is usually true for a large problem [J212]

"Effective-medium model dependence of the radar reflectivity of conducting particle films"

We present a numerical study of the frequency dependent, complex effective permittivity E for a composite material which consists of lossy graphite-type microsphere inclusions randomly imbedded in a dielectric matrix, with a view towards assessing the suitability of such a composite for its use as a radar absorbing material (RAM). This suitability is determined by the material possessing a large effective absorptivity while at the same time not giving rise to an overly large reflectivity. In this vein we here evaluate, as a function of frequency up to 20 GHz, the effective magnitudes of Re Eand Im Efor particulate composites and their dependence on the volume fraction Φ of the particles, while independently varying conductivities. Our calculations are carried out

using both the effective-medium theory (mixture theory, valid for small Φ), and the multiple-scattering theory of Tsang and Kong valid for general Φ but for small particle sizes. Multiple-scattering effects lead to increased effective absorptivities by adding scattering losses to the intrinsic losses of the media. We comment on the optimal values of the medium parameters and packing fractions for composite RAM materials. Percolation effects (transition from matrix dominance to particle dominance) are studied, both for the effective-medium theory and for the multiple-scattering theory, and compared for the two cases. copyright 1999 American Institute of Physics. [J213]

"Bistatic RCS calculations with the vector parabolic equation method"

The vector parabolic equation (PE) method provides accurate solutions for electromagnetic scattering from three-dimensional (3-D) objects ranging from a size comparable to the wavelength of the incident wave to several tens of wavelengths. A paraxial version of Maxwell's equations is solved with a marching solution that only requires limited computing resources, even for large scatterers. By decoupling the PE paraxial direction from the direction of incidence, the bistatic radar cross section (RCS) can be computed at all scattering angles. A sparse-matrix formulation is used to implement electromagnetic boundary conditions, ensuring that polarization effects are treated fully. Computing costs are kept to a minimum through the use of a double-pass method so that calculations can be carried out on a desktop computer for realistic targets and radar frequencies. The method has been validated on simple canonical shapes and tested on complex targets [J214]

"A boundary-element solution of the Leontovitch problem"

A boundary-element method is introduced for solving electromagnetic scattering problems in the frequency domain relative to an impedance boundary condition (IBC) on an obstacle of arbitrary shape. The formulation is based on the field approach; namely, it is obtained by enforcing the total electromagnetic field, expressed by means of the incident field and the equivalent electric and magnetic currents and charges on the scatterer surface, to satisfy the boundary condition. As a result, this formulation is well-posed at any frequency for an absorbing scatterer. Both of the equivalent currents are discretized by a boundary-element method over a triangular mesh of the surface scatterer. The magnetic currents are then eliminated at the element level during the assembly process. The final linear system to be solved keeps all of the desirable properties provided by the application of this method to the usual perfectly conducting scatterer; that is, its unknowns are the fluxes of the electric currents across the edges of the mesh and its coefficient matrix is symmetric [J215]

"A novel efficient algorithm for scattering from a complex BOR using mixed finite elements and cylindrical PML"

An efficient finite-element method (FEM) is developed to compute scattering from a complex body of revolution (BOR). The BOR is composed of a perfect conductor and impedance surfaces and arbitrary inhomogeneous materials. The method uses edge-based vector basis functions to expand the transverse field components and node-based scalar basis functions to expand the angular component. The use of vector basis functions eliminates the problem of spurious solutions suffered by other three component FEM formulations. The FEM mesh is truncated with a perfectly matched layer (PML) in cylindrical coordinates. The use of PML in cylindrical coordinates avoids the wasted computation which results from a spherical mesh boundary with an elongated scatterer. The FEM equations are solved by ordering the unknowns with a reverse Cuthill-McKee algorithm and applying a banded-matrix solution algorithm. The method is capable of handling large, realistic radar targets, and good agreement with measured results is achieved for benchmark targets [J216]

"On the use of finite surfaces in the numerical prediction of rough surface scattering"

Method of moments (MOM)-based Monte Carlo calculations are widely used in determining the average radar cross section of randomly rough surfaces. It is desirable in these numerical calculations to truncate the scattering surface into as short a length as possible to minimize the solution time. However, truncating the surface tends to change the solution for the surface fields near the truncation points and may alter the scattered far fields. In this paper, these end effect errors are examined for one-dimensional (i.e., grooved or corduroy) surfaces which are Gaussian distributed in height and have either a Gaussian or a Pierson-Moskowitz spectra. In the case of the Pierson-Moskowitz type surface, it is shown that a relatively short surface of 80-120 wavelengths can be used to obtain the average backscattered radar cross section for backscattering angles as large as 60° from normal. For a comparatively smooth Gaussian surface, on the other hand, its is shown that the truncation effects can be very significant at moderate backscattering angles. Also, great care should be taken when examining the scattering from Gaussian surfaces which are dominated by specular scattering. It is shown that in this situation, a very large number of calculations may be needed to obtain a good numerical average [J217]

"Adaptive detection of range distributed targets"

A modified generalized likelihood ratio test (MGLRT) for the adaptive detection of a target or targets that are distributed in range is derived. The unknown parameters associated with the hypothesis test are the complex amplitudes in range of the desired target and the unknown covariance matrix of the additive interference, which is assumed to be characterized as complex zero-mean correlated Gaussian random variables. The target's or targets' complex amplitudes are assumed to be distributed across the entire input data block (sensorЧrange). Results on probabilities of false alarm and detection are derived, and a bounded constant false alarm rate (CFAR) detector is developed. Simulation results are presented. It is shown that the derived MGLRT of range distributed targets is much more effective in detecting targets distributed in range than an M out of K detector, which is cascaded with a single-point target Kelly (1986) detector [J218]

"Optimal polarizations and application to meteorological targets"

Optimal polarizations of targets that yield partially polarized backscatter are considered. Closed-form solutions for the extrema locations for targets that present reflection symmetry are provided. It is also found that for this class of targets the extrema locations define a fork as in the coherent case [J219]

"Subsurface fracture measurement with polarimetric borehole radar"

A full-polarimetric borehole radar system is presented with combinations of dipole antennas and axial slot antennas and is applied to subsurface fracture measurement. First, to determine a scattering matrix from measurements with antennas having different antenna transfer functions between orthogonal polarizations, the authors present an antenna compensation algorithm that is achieved by an inverse filtering method with the antenna transfer functions experimentally determined by crosshole measurements. The results of crosshole and single-hole measurements carried out in granite at the Kamaishi Mine are shown to verify the proposed method. In the crosshole measurement, the authors find that the used dipole and slot antennas have almost the same radiation pattern and frequency dependency from 50 to 120 MHz. The transmission matrices through the host rock are the unit matrix for most paths, while depolarization is observed in some sections. Reflections from subsurface fractures show significant depolarization in the polarimetric single-hole reflection measurements. Using the scattering matrix, it is evaluated that subsurface fractures have a randomly isotropic rough surface for wavelengths between 1 and 2 m on the rotation of polarization basis [J220]

"A hybrid experimental/theoretical scattering model for dense random media"

The subject of scattering of electromagnetic waves by dense media has been one of intense interest in recent years. The present paper describes polarimetric backscatter measurements made at Ku-band on layers of a dense medium under very carefully controlled circumstances. The experiments have a dual purpose: 1) to evaluate the degree to which the experimental observations are predicted by theoretical, particle-based, random media models and 2) to test a proposed hybrid model by which the scattering and extinction properties of a dense medium are characterized experimentally, allowing future modeling of the polarimetric response for any arbitrary configuration of the medium. The hybrid model assumes that first-order vector radiative transfer (RT) is a suitable theoretical structure, providing that the extinction and phase matrix components are appropriately specified; the specification is accomplished through an inversion algorithm involving polarimetric backscatter measurements. The major conclusions of the study are the following: 1) hybrid model is an adequate description of the dense medium scattering behavior; 2) conventional RT appears to give a reasonable estimate of the observed radar response, but dense medium RT gives a very low estimate; 3) phase function of the effective volume scattering element of the medium, obtained via the hybrid model, suggests a larger effective scatterer than the physical ones [J221]

"Multistage partially adaptive STAP CFAR detection algorithm"

A new method of partially adaptive constant false-alarm rate (CFAR) detection is introduced. The processor implements a novel sequence of orthogonal subspace projections to decompose the Wiener solution in terms of the cross-correlation observed at each stage. The performance is evaluated using the general framework of space-time adaptive processing (STAP) for the cases of both known and unknown covariance. It is demonstrated that this new approach to partially adaptive STAP outperforms the more complex eigen-analysis approaches using both simulated DARPA Mountain Top data and true pulse-Doppler radar data collected by the MCARM radar [J222]

"A novel 3-D scattering model of 1.8-GHz radio propagation in microcellular urban environment"

This work presents a novel three-dimensional (3-D) scattering model to predict the path loss of a microcellular

radio channel in an urban environment. The analytical scattering model combined with a patched-wall model predicts the median path loss more accurately than the conventional analytical ray-tracing model in the cases studied. Comparing the path loss with the measured one at 1.8 GHz demonstrates the effectiveness of the scattering model. The scattering model includes three major propagation modes: (1) a direct-path wave; (2) a ground-reflected wave; and (3) the scattered field from the walls aligned along a street. The proposed model with a polarization scattering matrix associated with the patched-wall model aptly describes the third mode, which is usually neglected or oversimplified [J223]

"Low grazing incidence millimeter-wave scattering models and measurements for various road surfaces"

Systematic characterization of the scattering behavior of traffic targets, clutter, and their associated interactions are required in order to design and assess the performance of millimeter-wave-based sensors for automated highway system (AHS) applications. In this paper, the polarimetric radar backscatter response of various road surfaces is investigated both theoretically and experimentally. In general, it is found that the overall scattering response of road surfaces is composed of volume and surface scattering components. Previously a hybrid volume scattering model was developed for predicting the backscatter response of smooth asphalt surfaces at millimeter-wave frequencies. There, only the volume scattering was accounted for, however, experimental results show that the surface scattering cannot be ignored when the surface roughness parameters become comparable to the radar wavelength. In this paper, the previous study is extended to include the radar backscatter response of concrete surfaces, snow-covered smooth surfaces, and rough asphalt or concrete surfaces. Radiative transfer (RT) theory is used to model the volume scattering and the integral equation model is used to describe the surface scattering. Asphalt and concrete mixtures are dense random media whose extinction and phase matrices are characterized experimentally. Ice and water over asphalt and concrete surfaces are modeled by homogeneous layers. Fresh snow is modeled by a sparse random medium whose extinction and phase matrices are obtained analytically. The University of Michigan 94-GHz polarimetric radar system was used to perform polarimetric backscatter measurements of the aforementioned road surfaces at near grazing incidence angles (70°-88°). Comparison of the measured and theoretically predicted backscattering coefficients and polarimetric phase difference statistics shows excellent agreement [J224]

"Co-null of targets and co-null Abelian group"

A new concept is introduced, the co-null of two targets, and some interesting results are presented. Based on these results and group theory, the concept of the co-null Abelian group is derived and used to form two important classes of targets: symmetric targets and N-targets. Finally, an important result concerning N-targets is obtained [J225]

"Unsupervised classification using polarimetric decomposition and the complex Wishart classifier"

The authors propose a new method for unsupervised classification of terrain types and man-made objects using polarimetric synthetic aperture radar (SAR) data. This technique is a combination of the unsupervised classification based on polarimetric target decomposition, S.R. Cloude et al. (1997), and the maximum likelihood classifier based on the complex Wishart distribution for the polarimetric covariance matrix, J.S. Lee et al. (1994). The authors use Cloude and Pottier's method to initially classify the polarimetric SAR image. The initial classification map defines training sets for classification based on the Wishart distribution. The classified results are then used to define training sets for the next iteration. Significant improvement has been observed in iteration. The iteration ends when the number of pixels switching classes becomes smaller than a predetermined number or when other criteria are met. The authors observed that the class centers in the entropy-alpha plane are shifted by each iteration. The final class centers in the entropy-alpha plane are useful for class identification by the scattering mechanism associated with each zone. The advantages of this method are the automated classification, and the interpretation of each class based on scattering mechanism. The effectiveness of this algorithm is demonstrated using a JPL/AIRSAR polarimetric SAR image [J226]

"Monte Carlo simulations of scattering and emission from lossy dielectric random rough surfaces using the wavelet transform method"

Recently, a fast computational technique based on the banded-matrix iterative approach/canonical grid (BMIA/CG) method has been developed for the analysis of random rough surfaces. However, there are situations that the matrix-vector multiplication associated with strong near-field interactions may dominate the CPU and memory storage requirement. In this paper, the wavelet transform method in conjunction with a screening window scheme is used to address these problems. It is noted that the wavelet-transformed matrix for each submatrix is implemented only once for different incident polarizations. Based on the idea of multiresolution

analysis, the matrix-vector multiplication in an iterative solver is then efficiently evaluated for its higher sparsity. Numerical simulations are then used to study scattering and emission from the lossy dielectric random rough surfaces. All the four Stokes parameters are calculated in this paper [J227]

"Robust statistical feature based aircraft identification"

The statistical feature based (StaF) classifier is presented for robust high range resolution (HRR) radar aircraft identification (ID). HRR signature peak features are selected “on the fly” with no a priori assumptions about the number or location of the features. Features extracted depends on the information content of the observed signature making the number, location, and amplitude of features random variables. A primary goal for this research is to increase classifier robustness by maintaining high known target ID while minimizing unknown target errors. Results are presented demonstrating that the StaF classifier can significantly reduce errors associated with unknown targets while maintaining a high probability of correct classification [J228]

"Spatially distributed target detection in non-Gaussian clutter"

Two detection schemes for the detection of a spatially distributed, Doppler-shifted target in non-Gaussian clutter are developed. The non-Gaussian clutter is modeled as a spherically invariant random vector (SIRV) distribution. For the first detector, called the non-scatterer density dependent generalized likelihood ratio test (NSDD-GLRT), the detector takes the form of a sum of logarithms of identical functions of data from each individual range cell. It is shown under the clutter only hypothesis, that the detection statistic has the chi-square distribution so that the detector threshold is easily calculated for a given probability of false alarm PF. The detection probability PDis shown to be only a function of the signal-to-clutter power ratio (S/C)optof the matched filter, the number of pulses N, the number of target range resolution cells J, the spikiness of the clutter determined by a parameter of an assumed underlying mixing distribution, and PF. For representative examples, it is shown that as N, J, or the clutter spikiness increases, detection performance improves. A second detector is developed which incorporates a priori knowledge of the spatial scatterer density. This detector is called the scatterer density dependent GLRT (SDD-GLRT) and is shown for a representative case to improve significantly the detection performance of a sparsely distributed target relative to the performance of the NSDD-GLRT and to be robust for a moderate mismatch of the expected number of scatterers. For both the NSDD-GLRT and SDD-GLRT, the detectors have the constant false-alarm rate (CFAR) property that PFis independent of the underlying mixing distribution of the clutter, the clutter covariance matrix, and the steering vector of the desired signal [J229]

"Fast Illinois solver code (FISC)"

FISC (Fast Illinois solver code), co-developed by the Center for Computational Electromagnetics, University of Illinois, and DEMACO, is designed to compute the RCS of a target described by a triangular-facet file. The problem is formulated using the method of moments (MoM), where the Rao, Wilton, and Glisson (1982) basis functions are used. The resultant matrix equation is solved iteratively by the conjugate gradient (CG) method. The multilevel fast multipole algorithm (MLFMA) is used to speed up the matrix-vector multiplication in the CG method. The complexities for both the CPU time per iteration and the memory requirements are of O(Nlog N), where N is the number of unknowns. A 2.4-million unknown problem is solved in a few hours on the SGI GRAY origin 2000 at NCSA of the University of Illinois at Urbana-Champaign [J230]

"Integral equation modeling of cylindrically periodic scatterers in the interior of a cylindrical waveguide"

We examine the scattering from cylindrically periodic engine-like structures using integral-equation methods. The periodic scatterer is enclosed in a cylindrical waveguide, and the primary goal of this paper is to show that this type of geometry affords substantial computational reductions by exploiting the periodicity of the blade structure and characteristics of the modal scattering matrix of the engine-like termination. Also, as a result of the periodic waveguide termination, a limited number of modes are excited by a given incoming mode, and this is exploited for a further reduction of the storage requirements of the modal scattering matrix [J231]

"Sidewall inclined slot in a rectangular waveguide: theory and experiment"

A novel analysis is used to compute the admittance characteristics of the slots cut in the narrow wall of a rectangular waveguide, which includes the corner diffraction effects and the finite waveguide wall thickness, is presented. A coupled magnetic field integral equation is formulated at the slot aperture which is solved by the Galerkin approach of the method of moments using entire domain sinusoidal basis functions. The externally scattered fields are computed using the finite difference method (FDM) coupled with the measured equation of invariance (MEI). The guide wall thickness forms a closed cavity and the fields inside it are evaluated using the standard FDM. The fields scattered inside the waveguide are formulated in the spectral domain for faster

convergence compared to the traditional spatial domain expansions. The computed results have been compared with the experimental results and also with the measured data published in previous literature. Good agreement between the theoretical and experimental results is obtained to demonstrate the validity of the present analysis [J232]

"Compact range radar cross-section measurements using a noise radar"

This paper discusses the measurement of radar cross section (RCS) with a very low-cost system that transmits band-limited random noise over the band from 1.0 to 4.0 GHz. The received signal is correlated with a delayed version of the transmitted signal. A variable delay line is used to obtain the response at various delay times. This yields the radar target impulse response as a function of delay. This can be transformed to yield both the amplitude and phase of the scattering matrix in the frequency domain [J233]

"A fast full-wave analysis of scattering and radiation from large finite arrays of microstrip antennas"

A fast full-wave analysis technique that can be used to analyze the scattering and radiation from large finite arrays of microstrip antennas is presented. The technique discretizes the mixed potential integral equation (MPIE) in the spatial domain by means of a full-wave discrete complex image method. The del operators on the Green's functions are transferred from the singular kernel to the expansion and testing functions. The resultant system of equations is solved using the biconjugate gradient (BCG) method in which the matrix-vector product is evaluated efficiently using the fast Fourier transform (FFT). This results in an efficient and accurate computation of the scattering and radiation from finite arrays of microstrip antennas. Several numerical results are presented, demonstrating the accuracy, efficiency, and capability of this technique [J234]

"Scattering properties of circular cylinders with periodical corrugations in the azimuthal direction"

A multilayered mode-matching method incorporating reflection matrices is developed to study the scattering properties of conducting cylinders with periodical corrugations in the azimuthal direction. The effects of corrugation profile and filling permittivity on the radar cross section (RCS) are demonstrated [J235]

"The Fast Illinois Solver Code: requirements and scaling properties"

To solve large scale computing and scattering problems and to expand knowledge about iterative solvers, the authors developed the Fast Illinois Solver Code, which uses the multilevel fast multipole algorithm (MLFMA). They discuss FISC's memory requirements and CPU time and give some empirically derived formulas and charts. The authors also plot examples they used to obtain these conclusions [J236]

"Wide-band multiport antenna characterization by polarimetric RCS measurements"

A theoretical description of the scattering of multiport antennas is derived in accordance with the polarimetric radar target characterization. For two-port antennas with dual linear orthogonal polarization, a procedure for the determination of the antenna mode scattering parameters and the structural scattering parameters of the complete polarimetric antenna scattering matrix [S] is given. A measurement setup and experimental results of wide-band polarimetric radar cross section (RCS) antenna measurements are presented. For two-port antennas, in total, 24 unknowns have to be determined. The load variation method is used. The polarimetric RCS antenna measurement is especially advantageous over a wide bandwidth; for example 2-40 GHz with only one single calibration. From the antenna scattering matrix [S], the antenna parameters like polarimetric gain, optimum gain, gain bandwidth, wave admittance, structural scattering, etc., are derived. Results are shown for an X-band horn antenna and a 2-18-GHz dual linearly polarized horn. The measurement technique and evaluation gives the most complete and very accurate information about antenna radiation, antenna characteristics, and scattering obtainable with one single measurement setup. Some quantities determined here, like the maximum available gain and the polarization characteristics, are difficult to access with standard transmission measurements. No cable from the antenna to the receiver is necessary. This helps avoid some difficulties usually experienced at low signal levels [J237]

"Application of iterative moment-method solutions to ocean surface radar scattering"

Numerical methods such as the banded matrix iterative approach (BMIA) represent a major advance in the direct numerical simulation of rough surface-wave scattering. This paper considers the application of iterative methods such as the BMIA to ocean-radar scattering. It is shown that for typical microwave radar frequencies and sea-surface roughness, the BMIA is actually of limited use. A more general iterative solution based on a multigrid decomposition and the generalized conjugate residual (GCR) method, is thus developed. The multigrid approach is ideally suited to the broad-band ocean surface, as it solves the scattering problem on a sequence of grids,

each corresponding to a different range of spatial frequencies or length scales. This approach is applied here to several sea scattering problems, including very low grazing angles and both horizontal and vertical polarization. Good agreement is obtained with perturbation theory in the appropriate limits and several qualitative characteristics of radar backscatter data are reproduced [J238]

"Backscattering of TE waves by periodical surface with dielectric cover"

Several types of periodical surfaces are studied on their backscattering to a normally incident TE plane wave. The surfaces are perfect conductor and are covered with dielectric materials to make a flat surface due to aerodynamic consideration. The effects of frequency, surface profile shape, period-to-depth ratio, and cover permittivity are analyzed. It is observed that a sawtooth profile can be used to reduce the backscattering at high frequencies and elliptical profiles can be used to reduce the backscattering at certain low frequencies when a cover material is filled in the grooves [J239]

"Real-time and full polarimetric FM-CW radar and its application to the classification of targets"

The Sinclair scattering matrix plays a decisive role in radar polarimetry. For realization of a real-time and full polarimetric radar, there are some technical problems associated with hardware implementations. Since the FM-CW radar system is suitable for short-range sensing applications, we modified an FW-CW radar to a real-time and polarimetric system by adding a PIN diode-switching circuitry for antenna polarization changes. A parallel operation scheme in the signal processing and the radar control is employed in a personal computer, which enables 44 snapshots for acquiring scattering matrices and displays the polarimetric target classification results along 43 radar ranges per second. In this paper, we present the hardware design of the system and its fundamental application to the classification of targets using the three-component decomposition theorem [J240]

"Simple method for obtaining characteristic polarisation states"

For a completely polarised wave, a simple method is proposed for obtaining the characteristic polarisation states, in the form of the Stokes vector, showing that the co-polarisation (CO-POL) nulls are the most fundamental characteristic polarisation states, and that the other states can easily be obtained from the expressions of the CO-POL nulls [J241]

"A new decomposition of radar polarization signatures"

A method for the decomposition of radar polarization signatures is developed. The polarization backscattering model is assumed to consist of odd, double, Bragg, and cross backscattering components, and the Mueller matrix is the sum of the Mueller matrices of these four scattering mechanisms. The technique of least squares (LS) is then used to find the best combination of these four components. Using NASA/Jet Propulsion Laboratory (JPL) AirSAR data, the results of the decomposition agree with the general understanding of radar backscatter. In most cases, the accuracy of the decomposition is more than 95% for linear polarizations and more than 85% for any other polarizations [J242]

"Modeling and measurements of scattering from road surfaces at millimeter-wave frequencies"

Millimeter-wave radar-based sensors are being considered for a number of automotive applications including obstacle detection and collision warning, true-speed, and road-surface recognition. The interaction of electromagnetic waves with asphalt road surfaces, possibly covered with ice or water, at millimeter-wave frequencies is studied. First, an experimental procedure for determining the effective dielectric constant of bituminous mixtures used in road-surface constructions is developed. In this procedure, the effective dielectric constant is derived using a simple inverse-scattering algorithm to the measured radar cross sections of cylindrical specimen of a standard asphalt mixture. Then the vector radiative transfer equation is used to formulate the scattering from a multilayer medium representing an ice- or water-covered asphalt surface. The University of Michigan polarimetric 94-GHz radar system was deployed for characterizing the polarimetric backscatter responses of asphalt surfaces under many physical conditions near grazing incidence angles (70°-88°). The measured backscatter coefficients and parameters of copolarized phase difference statistics of a dry asphalt surface with smooth interface at one incidence angle were used to derive the phase and extinction matrices of the asphalt medium. The experimentally determined phase and extinction matrices are substituted in the radiative transfer formulation to predict the scattering from asphalt surfaces under all conditions. Excellent agreement between theoretical predictions and measured quantities is obtained [J243]

"Comments on “The specular null polarization theory” (and Reply)"

J.C. Hubbert and V.N. Bringi have recently published two papers concerning radar specular null polarisation for

coherent and incoherent backscatter, see ibid., vol.32, p.658-71 (1994) and ibid., vol.34, p.859-73 (1995). They claimed to have introduced a new polarisation theory comparable to Kennaugh polarisation theory (KPT). They have also introduced the optical backscattering term "optical polarisation theory". The present authors discuss the first authors work for the coherent case. The present authors claim that Hubbert et al. have two misconceptions about KPT. They believe KPT is a combination of backscattering behaviour and radar network performance and that a recast of the voltage equation would change the transformation of the Sinclair matrix [J244]

"Novel microstrip-line directional filters"

This paper presents two new structures of four-port microwave directional filters incorporating microstrip-line resonators, uniplanar 180° phase-reversal units, and two or four identical p-i-n diodes. These filters provide substantially improved frequency characteristics compared to the conventional constructions. The unique feature of them is that they ensure high-level isolation independent of frequency between opposite ports. Due to this electrical property the proposed filters may be suitable for some pulse-radar applications [J245]

"Radar backscatter from a dense discrete random medium"

A dense medium phase matrix developed based on the concept of random lattice perturbation is employed in the radiative transfer theory to calculate the coand cross-polarized backscatter from a layer of randomly distributed spherical scatterers. The position randomness properties are characterized by the variance and correlation function of scatterer positions within the medium. The dense medium phase matrix differs from the conventional one in two major aspects, i.e., there is an amplitude and a phase correction. These corrections account for the effects of close spacing and position correlation between scatterers in a dense discrete random medium. This study shows that phase coherency and close-spacing amplitude modifications are two separate corrections necessary for an electrically dense medium. Results indicate that there is a need to distinguish between spatially and electrically dense medium. The phase correction is found to have a greater impact on cross-polarized than like-polarized backscatter coefficients; the converse is true of the amplitude correction. Backscattering calculations from the theory are compared with measurements from controlled microwave experiments on random media consisting of closely packed spheres, and from field measurements of dry snowpack. Predictions from such a theory agree well with the measured data [J246]

"Scattering from a cylindrically conformal slotted waveguide array antenna"

A numerical method is developed to investigate electromagnetic scattering by a cylindrically conformal waveguide-fed slot array. The problem is first formulated in terms of integral equations using the equivalence principle. The integral equations are then solved using the method of moments (MoM) in conjunction with global sinusoidal basis functions and Galerkin's testing procedure. The MoM solution requires the evaluation of the generalized admittance matrices involving various dyadic Green's functions. The slow convergence of the series associated with the summation of waveguide modes is accelerated using the Kummer transformation and the slow convergence of the series associated with the summation of the exterior modes is avoided by using the asymptotic solutions with proper treatment for singular integrals. The evaluation of the excitation vector and scattered field is also accelerated using Watson's transformation and asymptotic solutions. Numerical results are presented to illustrate the scattering characteristics of the cylindrically conformal waveguide-fed slot arrays, such as the effects of curvature, slot thickness, and waveguide termination on the radar cross section (RCS) of the arrays [J247]

"Forward and inverse scattering for discrete layered lossy and absorbing media"

A complete digital signal processing (DSP) theory is developed for forward and inverse scattering in discrete (piecewise-constant) layered lossy systems, generalizing previous work for discrete lossless systems and continuous lossy systems. This paper is motivated by radar reflections from stratified dielectrics and interchip communication modeled by lossy transmission lines. The DSP formulation allows exact solutions, without discretization approximations, and includes all multiple reflections, transmission scattering losses, and absorption effects. For the forward problem, discrete matrix Green's functions are derived for the lossy medium, as are fast algorithms for computing impulse reflection and transmission responses for the medium. For the inverse problem, asymmetric Toeplitz systems of equations which function as discrete counterparts to integral equations are derived, as are fast algorithms for reconstructing the medium from its impulse transmission and reflection responses. Data sufficiency and feasibility are discussed. Finally, these results are applied to the LCRG transmission line and layered dielectric medium problems, dispersion effects are discussed, and a numerical example is presented [J248]

"Multilevel fast multipole algorithm for electromagnetic scattering by large complex objects"

The fast multipole method (FMM) and multilevel fast multipole algorithm (MLFMA) are reviewed. The number of modes required, block-diagonal preconditioner, near singularity extraction, and the choice of initial guesses are discussed to apply the MLFMA to calculating electromagnetic scattering by large complex objects. Using these techniques, we can solve the problem of electromagnetic scattering by large complex three-dimensional (3-D) objects such as an aircraft (VFY218) on a small computer [J249]

"Calibration and measurement of a wideband six-port polarimetric measurement system"

The principle of operation, calibration procedure, and experimental results of a wideband six-port polarimetric measurement system are described in this paper. This measurement system can measure the polarization states of incoming waves and the polarimetric scattering matrices of scattering targets from the wideband power data. The imbalances and coupling between antenna polarization channels and the characteristics of microwave components used in the measurement system are calibrated using three partly unknown scattering calibrators that are illuminated by four unknown-polarized calibrating waves [J250]

"A frequency-domain approach to shallow-water depth measurement"

A new formulation for ocean-depth measurement using a frequency-domain approach is proposed. This technique uses two high-resolution eigensubspace methods to estimate the ocean depth from backscattered noisy data. The problem has been addressed both for real and complex attenuation coefficients by utilizing a double eigenstructure decomposition procedure on a Toeplitz as well as a Hankel matrix structure. The approach is similar to obtaining the best rational approximation that fits the actual measured data in a least-square sense [J251]

"An entropy based classification scheme for land applications of polarimetric SAR"

The authors outline a new scheme for parameterizing polarimetric scattering problems, which has application in the quantitative analysis of polarimetric SAR data. The method relies on an eigenvalue analysis of the coherency matrix and employs a three-level Bernoulli statistical model to generate estimates of the average target scattering matrix parameters from the data. The scattering entropy is a key parameter is determining the randomness in this model and is seen as a fundamental parameter in assessing the importance of polarimetry in remote sensing problems. The authors show application of the method to some important classical random media scattering problems and apply it to POLSAR data from the NASA/JPL AIRSAR data base [J252]

"Degree of polarization of radar backscatters from a mixed target"

When an extended radar target is a mixture of two kinds of random media, the degree of polarization of a backscattered wave from the target changes with the mixing ratio of two random media. Using measured modified Mueller matrices of (a) four dielectric surfaces with different roughness, and (b) a tree (Japanese pine), dependencies of the degree of polarization on the mixing ratio are discussed. A unified relation between the mixing ratio and the degree of polarization that does not depend on the difference of the four surfaces is derived. The approach discussed in this paper will provide a potential tool for analyzing mixed-target areas in polarimetric SAR images [J253]

"Fast solution methods in electromagnetics"

Various methods for efficiently solving electromagnetic problems are presented. Electromagnetic scattering problems can be roughly classified into surface and volume problems, while fast methods are either differential or integral equation based. The resultant systems of linear equations are either solved directly or iteratively. A review of various differential equation solvers, their complexities, and memory requirements is given. The issues of grid dispersion and hybridization with integral equation solvers are discussed. Several fast integral equation solvers for surface and volume scatterers are presented. These solvers have reduced computational complexities and memory requirements [J254]

"The complex bi-conjugate gradient solver applied to large electromagnetic scattering problems, computational costs, and cost scalings"

The complex bi-conjugate gradient iterative method is applied to an isoparametric boundary integral equation formulation for frequency-domain electromagnetic scattering problems. It is demonstrated to work well on large and geometrically complex examples, including a 20 wavelength slender dipole, the NASA almond, and a resonant cavity. On such problems, with asymmetric curvilinear irregular meshes and nontrivial geometries, the

number of iterations required seems to increase rather more than linearly with body size, indicating an overall ~sixth power cost scaling. This scaling is essentially as for direct methods, but with costs still a small fraction of the direct approach. A method is proposed for the selection of a termination condition designed to avoid seeking the approximate answer too precisely; it typically permits a further halving of costs [J255]

"Distributed source modeling and direction-of-arrival estimation techniques"

In direction-of-arrival (DOA) estimation, the direction of a signal is usually assumed to be a point. If the direction of a signal is distributed due to some environmental phenomenon, however, DOA estimation methods based on the point source assumption may result in poor performance. We consider DOA estimation when the signal sources are distributed. Parametric and nonparametric models are proposed, and estimation methods are considered under these models. In addition, the asymptotic distribution of estimation errors is obtained to show the models' statistical properties [J256]

"Full-wave investigation of a corner reflector proposed as reference line target for automotive applications"

The backscattering property of the 90° dihedral corner reflector is exploited to define a distributed target for automotive applications. In the analysis, the scatterer is described as a junction among three radial waveguides and the problem is solved by applying the mode-matching technique in a convenient matrix form. Once the structure is characterized in terms of a multimodal scattering matrix, the evaluation of the scattered fields at any observation point is straightforward [J257]

"Parallel computation of time-domain integral equation analyses of electromagnetic scattering and RCS"

Electromagnetic scattering analyses for radar cross-section (RCS) prediction present very large computational demands. Processing on parallel machines will contribute to increasing the size of problem tractable. We present a parallel implementation of the time-domain integral equation method. The issues and options in its parallelization are identified, and domain decomposition strategies to suit these are implemented. Good parallelization is exhibited, with the most costly parts of the algorithm displaying essentially linear speedup. Demonstrations using the Cray T3D are given with, for example, results on the ~12 wavelength NASA almond obtained in ~30 min per illumination angle, using 256 processors [J258]

"A phase matrix for a dense discrete random medium: evaluation of volume scattering coefficient"

In the derivation of the conventional scattering phase matrix of a discrete random medium, the far-field approximation is usually assumed. In this paper, the phase matrix of a dense discrete random medium is developed by relaxing the far-field approximation and accounting for the effect of volume fraction and randomness properties characterized by the variance and correlation function of scatterer positions within the medium. The final expression for the phase matrix differs from the conventional one in two major aspects: there is an amplitude and a phase correction. The concept used in the derivation is analogous to the antenna array theory. The phase matrix for a collection of scatterers is found to be the Stokes matrix of the single scatterer multiplied by a dense medium phase correction factor. The close spacing amplitude correction appears inside the Stokes matrix. When the scatterers are uncorrelated, the phase correction factor approaches unity. The phase matrix is used to calculate the volume scattering coefficients for a unit volume of spherical scatterers, and the results are compared with calculations from other theories, numerical simulations, and laboratory measurements. Results indicate that there should be a distinction between physically dense medium and electrically dense medium [J259]

"Proceedings of Second International Workshop on Active Matrix Liquid Crystal Displays"

The following topics are dealt with: active matrix LCD; flat panel displays; displays technology; a-Si:H TFT LCD; AMLCD design; polycrystalline Si thin film transistors; modelling; TFT technology advancements; and LCD drivers [J260]

"Polarimetric detection of objects buried in snowpack by a synthetic aperture FM-CW radar"

Presents experimental results of polarimetric detection of objects buried in a natural snowpack by a synthetic aperture FM-CW radar. First, the principle of polarimetric imaging in the Co- and Cross(X)-pol radar channels is outlined based on the scattering matrix and the characteristic polarization states for a specific target. Then, polarimetric measurements were carried out to detect objects buried in a natural snowpack 230 cm deep. The targets included two orthogonally placed metallic plates, an ice layer within the snowpack, and a human body. It

is shown that the polarimetric FM-CW radar clearly enhances target signatures and that it serves to significantly improve detection in snowpack. Several polarimetric detection results are displayed, demonstrating the potential capability of characteristic polarization imaging and the usefulness of FM-CW radar [J261]

"A review of target decomposition theorems in radar polarimetry"

In this paper, we provide a review of the different approaches used for target decomposition theory in radar polarimetry. We classify three main types of theorem; those based on the Mueller matrix and Stokes vector, those using an eigenvector analysis of the covariance or coherency matrix, and those employing coherent decomposition of the scattering matrix. We unify the formulation of these different approaches using transformation theory and an eigenvector analysis. We show how special forms of these decompositions apply for the important case of backscatter from terrain with generic symmetries [J262]

"Shielding and reflection properties of periodic fiber-matrix composite structures"

The plane-wave shielding and reflection properties of a single-layer composite material are analyzed, based on a filament-current phase-correction model that treats the composite material as a lossy periodic structure of fibers situated in a dielectric matrix. The scattering effect of the fibers is dealt with by calculating the scattered fields from the fiber currents, which are assumed to be concentrated along the centers of the fibers. To include the effect of the dielectric matrix, multiple reflection and transmission at the air-matrix interfaces, as well as the phase correction across the fiber grating, are incorporated in the analysis. In this study, only numerical results for the TM case are presented for graphite/epoxy composite materials. In particular, the parameters that influence the shielding and reflection characteristics, such as the angle of incidence and the frequency of the incident wave, the conductivity and radius of the fibers, and the dielectric constant of the matrix, are investigated in detail. Also included are results to illustrate the frequency-selective phenomena associated with composite structures [J263]

"A novel bistatic scattering matrix measurement technique using a monostatic radar"

Presents a new technique for measuring the bistatic scattering matrix of point targets using a monostatic radar. In this technique, the complexity of the traditional bistatic measurement setup and difficulties in retaining the phase coherence between the transmitter and the receiver are circumvented completely. The bistatic measurement is performed using a wideband, polarimetric, monostatic radar in conjunction with a rotatable ground plane positioned behind the target. Assuming that the distance between the target and the ground plane is larger than the radar resolution, the desired bistatic response (image contribution) can be isolated from the unwanted backscatter. Noting that the radar operates in the backscatter mode and using the reciprocity theorem, it is shown that the measured cross-polarized responses (σvhand σhv) cannot be determined uniquely. To rectify this problem, additional independent measurements are required. Additional equations for characterizing the cross-polarized components are obtained by placing an anisotropic lossless slab over the perfectly conducting flat surface. The validity and accuracy of the new bistatic measurement technique is demonstrated by measuring a number of point targets with known theoretical bistatic responses. Also, a new approach for determining the effective dielectric constant of dense random media based on the new bistatic measurement technique is developed [J264]

"Polarimetric backscatter from fresh and metamorphic snowcover at millimeter wavelengths"

This paper presents 35, 95, and 225 GHz polarimetric radar backscatter data from snowcover. It compares measured backscatter data with detailed in situ measurements of the snowcover including microstructural anisotropies within the snowpack. Observations of backscatter mere made during melt-freeze cycles, and measurable differences in the normalized radar cross section between older metamorphic snow and fresh low-density snow were observed. In addition, these data show that the average phase difference between the copolarized terms of the scattering matrix, Svvand Shh, is nonzero for certain snow types. This phase difference was found to be related to snowpack features including anisotropy, wetness, density, and particle size. A simple backscatter model based on measured particle size and anisotropy is found to predict the Mueller matrix for dry snowcover with reasonable accuracy [J265]

"In-band scattering from arrays with parallel feed networks"

Approximate closed-form expressions are derived for in-band scattering from an array antenna with parallel (corporate) feed networks. Multiple reflections are neglected and feed devices of the same type are assumed to have identical electrical characteristics. The model is shown to be in good agreement with results generated using a scattering matrix formulation. Based on computed data, the characteristics of array scattering are discussed [J266]

"Scattering from an infinite conducting cylinder covered with a finite two-layer dielectric coating (modal approach)"

The electromagnetic scattering problem of a conducting infinite circular cylinder partially shielded with a finite two-layer dielectric coating has been analyzed. Cylindrical eigenfunctions with unknown modal coefficients are used to expand the interior EM fields in terms of Fourier-Bessel series. Enforcing field boundary conditions at the dielectric-dielectric interface leads to a single set of modal coefficients for field expansions inside the inner and the outer dielectric layers. Replacing the dielectric coating with the induced polarization sources and utilizing pertinent Green's functions, the dielectric-scattered fields are then formulated in terms of the modal coefficients. Imposing field equivalence conditions yields sets of linear algebraic equations for numerical computation of the unknown modal coefficients and subsequently other parameters of interest. Computed backscattered fields based on the modal technique developed are compared to experimental and numerical data obtained for the 2-D problem of a dielectric coated conducting cylinder [J267]

"Simulated polarimetric signatures of primitive geometrical shapes"

Polarimetric signatures of two primitives shapes (dihedral and edge) are simulated using high-frequency electromagnetic scattering methods. Signatures are predicted for a variety of orientations of the shapes. Polarimetric responses are analyzed using a polarization scattering matrix decomposition developed by Cameron and Leung (1990, 1992). It is shown that symmetric scatterer responses can be represented as points contained in the unit disc of the complex plane. The simulation shows that the polarimetric responses of the primitive shapes are remarkably stable as the shapes are rotated about various axes [J268]

"Electromagnetic scattering from a chiral cylinder-general case"

A generalized finite-difference (FD) scheme combined with the measured equation of invariance (MEI) is presented for the analysis of electromagnetic scattering from an inhomogeneous and lossy chiral cylinder with electrically large, arbitrarily shaped cross section. A new FD mesh in both chiral and achiral regions is formed, and the FD equations in a chiral medium are derived; then a large sparse matrix is formulated. The numerical results of bistatic scattering width (two-dimensional radar cross section) are given for the chiral cylinders of rectangular, elliptical, and complex cross section, respectively. Some results are compared with available data [J269]

"Specular null polarization theory: applications to radar meteorology"

Specular null polarization theory (SNPT) has been recently introduced for the case of coherent scattering where a 2Ч2 scattering matrix is sufficient to describe the scattering process. In this paper, SNPT is extended to the case of incoherent scattering. Optimum polarization states are derived and the results are discussed in relation to the classic radar optimum polarizations. In traditional radar polarimetry, modeling of the radar receive/transmit network is included in the radar voltage equation and consequently this affects the optimum polarizations and polarization responses of scatterers. SNPT eliminates this effect and therefore allows for a more direct analysis of scatterers. Modeling of ensembles of precipitation particles is used to illustrate the results of the analysis [J270]

"The discrete wavelet transform and the scale analysis of the surface properties of sea ice"

The formalism of the one-dimensional discrete wavelet transform (DWT) based on Daubechies wavelet filters is outlined in terms of finite vectors and matrices. Both the scale-dependent wavelet variance and wavelet covariance are considered and confidence intervals for each are determined. The variance estimates are more accurately determined with a maximal-overlap version of the wavelet transform. The properties of several Daubechies wavelet filters and the associated basis vectors are discussed. Both the Mallat orthogonal-pyramid algorithm for determining the DWT and a pyramid algorithm for determining the maximal-overlap version of the transform are presented in terms of finite vectors. As an example, the authors investigate the scales of variability of the surface temperature and albedo of spring pack ice in the Beaufort Sea. The data analyzed are from individual lines of a Landsat TM image (25-m sample interval) and include both reflective (channel 3, 30-m resolution) and thermal (channel 6, 120-m resolution) data. The wavelet variance and covariance estimates are presented and more than half of the variance is accounted for by scales of less than 800 m. A wavelet-based technique for enhancing the lower-resolution thermal data using the reflected data is introduced. The simulated effects of poor instrument resolution on the estimated lead number density and the mean lead width are investigated using a wavelet-based smooth of the observations [J271]

"Radar resolution of ideal point scatterers"

The conventional definition of resolution ignores that recognizing two responses is insufficient. We also must measure the scatterer positions. When we redefine resolution to permit an accurate measurement, the resolution cell is 2/T or 2/B when we use the intensity output, but 1/T or 1/B with the complex output. [J272]

"A three-dimensional radar backscatter model of forest canopies"

A three-dimensional forest backscatter model, which takes full account of spatial position of trees in a forest stand is described. A forest stand was divided into cells according to arbitrary spatial resolution. The cells may include “crown”, “trunk”, and “gap” components, determined by the shape, size and position of the trees. The forest floor is represented by a layer of “ground” cells. A ray tracing method was used to calculate backscattering components of 1) direct crown backscatter, 2) direct backscattering from ground, 3) direct backscattering from trunk, 4) crown-ground scattering, and 5) trunk-ground scattering. Both the attenuation and time-delay of microwave signals within cells other than “gap” were also calculated from ray tracing. The backscattering Mueller matrices of these components within the same range intervals were incoherently added to yield the total backscattering of an image pixel. By assuming a zero-mean, multiplicative Gaussian noise for image speckle, the high-resolution images were aggregated to simulate a SAR image with a given spatial resolution and number of independent samples (looks). A well-characterized 150 mЧ200 m forest stand in Maine, USA, was used to parameterize the model. The simulated radar backscatter coefficients were compared with actual JPL SAR data. The model gives reasonable prediction of backscattering coefficients averaged over the entire stand with agreement between model and data within 1.35 dB for all channels. The correlations between simulated images and SAR data (10 by 15 pixels) were positive and significant at the 0.001 level for all frequencies (P, L, and C bands) and polarizations (HH, HV, and VV) [J273]

"Two-dimensional and full polarimetric imaging by a synthetic aperture FM-CW radar"

Applies the principle of radar polarimetry to a synthetic aperture frequency-modulated continuous wave (FM-CW) radar and presents results based on two-dimensional (2D) full polarimetric imaging. It is shown that the polarimetric target reflection coefficients obtained by the synthetic aperture FM-CW radar are elements of a Sinclair scattering matrix, although the coefficients are derived from a wide band signal. Using the scattering matrix optimization procedure, a 2D polarimetric imaging experiment (including Co-Pol maximum, minimum, span, and phase imaging) of an orthogonally placed linear target set was successfully carried out in the laboratory. This result demonstrates the validity of N-band (8.2-9.2 GHz) FM-CW radar polarimetry, and it presents a demonstration of a full polarimetric 2D FM-CW imaging radar system [J274]

"Radar sensitivity to tree geometry and woody volume: a model analysis"

A model, based on radiative transfer theory and the matrix doubling algorithm, is described and used to compute the backscatter coefficients σ°s of forests. The objective is to investigate the radar sensitivity to woody biomass and some geometrical tree properties like branch dimensions and orientation. Model computations show that the backscatter coefficient is sensitive to the woody volume, particularly at HV polarization, P and L band; however, the radar response is appreciably influenced also by branch dimensions and orientation. Comparisons with experimental results available in the literature are shown. The correspondence between predicted and measured σ°s is generally good, although a slight overestimation is noted at L band, while uncertainties about data calibration and soil properties make the comparisons more difficult, in some cases, at P band [J275]

"Dual-channel and multifrequency radar system calibration"

Uncertainty in absolute gain and crosstalk factors are the primary sources of error in dual-channel radar measurements. A full two-port calibration technique compensates for the errors introduced due to an imperfect antenna system and improves the isolation between orthogonal polarization channels as long as the observed cross section is above the equivalent system noise cross section. A novel technique for calibrating a dual-polarized network analyzer-based scatterometer system is discussed. Rigorous two-port S-parameter representation is used to describe absolute gain and crosstalk characteristics. Validity of the crosstalk correction is demonstrated by measuring the point target scattering matrix. Correction factors are obtained by measuring the S-parameters of trihedral and dihedral corner reflectors of known sizes. Results of absolute gain of the antenna system are verified using independent test target cross section measurements [J276]

"CFAR detection in clutter with unknown correlation properties"

We develop a constant false-alarm rate (CFAR) approach for detecting a random N-dimensional complex vector in the presence of clutter or interference modeled as a zero mean complex Gaussian vector whose correlation

properties are not known to the receiver. It is assumed that estimates of the correlation properties of the clutter/interference may be obtained independently by processing the received vectors from a set of reference cells. We characterize the detection performance of this algorithm when the signal to be detected is modeled as a zero-mean complex Gaussian random vector with unknown correlation matrix. Results show that for a prescribed false alarm probability and a given signal-to-clutter ratio (to be defined in the text), the detectability of Gaussian random signals depends on the eigenvalues of the matrix Rc-1Rs. The nonsingular matrix Rcand the matrix Rsare the correlation matrices of clutter-plus-noise and signal vectors respectively. It is shown that the "effective" fluctuation statistics of the signal to be detected is determined completely by the eigenvalues of the matrix Rc-1Rs. For example the signal to be detected has an effective Swerling II fluctuation statistics when all eigenvalues of the above matrix are equal. Swerling I fluctuation statistics results effectively when all eigenvalues except one are equal to zero. Eigenvalue distributions between these two limiting cases correspond to fluctuation statistics that lie between Swerling I and II models.> [J277]

"Inband scattering from arrays with series feed networks"

Approximate equations are presented for the radar cross section (RCS) of a phased array antenna with a series feed beamforming network. The incident radar wave is assumed to be at the same frequency as the antenna operating frequency. In deriving the RCS formulas, multiple reflections are neglected, and like devices in the feed are assumed to have identical transmission and reflection coefficients. The approximate results are shown to be in excellent agreement with results obtained using a scattering matrix approach. The behavior of the RCS as a function of several feed design parameters is also investigated [J278]

"High resolution polarimetric radar scattering measurements of low grazing angle sea clutter"

This paper presents fully polarimetric radar scattering measurements of low grazing angle sea clutter. The measurements were obtained at a three degree grazing angle using a high range resolution (1.5 m) X-Band polarimetric radar operated from a shore site overlooking the Chesapeake Bay. The radar employs pulse-to-pulse switching between orthogonal transmitted polarizations and simultaneously measures two orthogonally polarized components of the backscattered wave to obtain full polarimetric information about the scattering process. The complete Stokes matrix, computed by averaging successive realizations of the polarization scattering matrix, is used to obtain polarization signatures and to determine the polarization dependence of the clutter. Sea spike echoes are shown to be weakly polarized and to exhibit polarization signatures indicative of multiple independent scattering mechanisms. Clutter echoes in the absence of sea spikes are shown to be highly polarized and to exhibit polarization signatures indicative of a single dominant scattering mechanism [J279]

"An analysis technique for buried inhomogeneous dielectric objects in the presence of an air-Earth interface"

Complex geological structures are modelled in the presence of an air-Earth interface. A cross-borehole configuration of target, source, and receiver is assumed, with the target itself not restricted as to geometrical cross section or complex permittivity value. Two-dimensional method-of-moment formulations are employed, utilizing cylindrical pulse basis functions and point matching. Scattering from buried dielectric objects is computed near the air-Earth interface for both TE and TM incident fields. A Sommerfeld-Green function is used to represent the effect of the air-Earth interface on the incident fields and the impedance matrix. The TE case is examined for scattering of both the copolarized and cross-polarized electric fields, and several examples are given for a cylindrical target at depths that vary from one to twenty four wavelengths, after which the presence of the air-Earth interface can be neglected. Some experimental results utilizing a 1/40th laboratory scale model and a tunnel-like target are also included for comparison. The technique enables the user to investigate electromagnetic scattering from a variety of complex buried objects whose dimensions are typically in or below the resonance region. The simultaneous relaxation of restrictions on cross section, material properties, and burial depth, together with experimental validation, is not found in the literature to date [J280]

"A bistatic polarimeter calibration technique"

A procedure for calibrating a bistatic polarimeter system without using reference scattering targets is described. Transmitter and receiver subsystem distortion matrices are determined via transmission link measurements in conjunction with an inexpensive test source and a linearly polarized test antenna [J281]

"Using the matrix pencil method to estimate the parameters of a sum of complex exponentials"

The approximation of a function by a sum of complex exponentials is a problem that is at least two centuries old. Fundamentally, all techniques discussed in this article proceed from using the same sequence of data samples and vary only, but importantly, in how those samples are used in achieving the parameter estimation. All of these

techniques, in other words, seek the same quantitative parameters to represent the sampled data, but use different routes to get there. The techniques for estimating the parameters are either linear or nonlinear. The linear techniques are emphasized in this presentation. In particular, the matrix pencil method is described, which is more robust to noise in the sampled data. The matrix pencil approach has a lower variance of the estimates of the parameters of interest than a polynomial-type method (Prony's method belongs to this category), and is also computationally more efficient. A bandpass version of the matrix pencil can be implemented in hardware, utilizing an AT&T DSP32C chip operating in real time. A copy of the computer program implementing the matrix pencil technique is given in the appendix [J282]

"Hybrid finite element-modal analysis of jet engine inlet scattering"

With the goal of characterizing jet engine inlets, a hybrid finite element-modal formulation is presented for the analysis of cavities with complex terminations. The finite element method (FEM) is used to find the generalized scattering matrix for an N-port representation of the complex termination. Where N is the number of traveling modes in the cavity. The cavity is assumed to be circular at the termination (engine) but the remainder of the cavity can be of arbitrary cross section. The scattered fields are obtained by tracing the fields back out of the cavity via a high frequency or modal technique with the generalized scattering matrix used in determining the fields at an aperture near the irregular cavity termination. “Proof of concept” results are presented and several issues relating to the implementation of the FEM are addressed. Among these, a new artificial absorber is developed for terminating the FEM mesh and the suitability of edge or node based elements is examined [J283]

"Scattering from ice crystals at 94 and 220 GHz millimeter wave frequencies"

Polarimetric scattering from cloud ice crystals modeled as hexagonal columns, hexagonal plates and stellar crystals are calculated at 94 and 220 GHz frequencies using the finite difference time domain (FDTD) method. Two orientation models are considered, In the first model the long axes of columns and broad surfaces of plates and stellar crystals are parallel to the horizontal plane and randomly oriented on this plane. The second model assumes uniform random orientation in three dimensions (3-D). The ratio of the backscattering cross sections at 220 and 94 GHz exhibits a steady decrease with increasing size up to about 1000 μm (2000 μm for columns) for horizontally aligned ice crystals at side incidence as well as for 3-D random orientation. This dual frequency ratio (DFR) may be useful in gauging the size of ice crystals, DFR may also be useful in discriminating between ice crystal types since it shows major differences between columns and planar crystals. The linear depolarization ratio (LDR), i.e. the ratio of the cross-polar to co-polar backscattering cross sections, at vertical incidence for the horizontal alignment model is much higher for columns (over 20 dB) compared to plates and stellar crystals. As a result LDR also has the potential for discriminating columns from planar crystals, Furthermore, the normalized Mueller matrices for horizontally aligned columns at vertical incidence are shown to be diagonal and a function of only LDR. This same result applies to the 3-D random orientation model for all three crystal types [J284]

"New polarimetric calibration technique using a single calibration dihedral"

A new polarimetric RCS calibration technique using a dihedral corner reflector as the single calibration target is presented. This scheme is valid for any monostatic or quasi-monostatic radar system and characterised by five aspects: (a) scattering matrix measurements of only a single calibration dihedral at two orientations are needed; (ii) the radiation polarisation effect and the four measurement channels are separated in this new model; (iii) the frequency responses of four measurement channels are modelled as mutually independent and thus, no special care has to be taken for signal paths and nonreciprocal properties in a measurement system; (iv) the calibration procedure is simplified by taking advantage of small cross-polarised terms and no complicated matrix algebra is involved; (v) the calibrated results are valid for wideband applications because no assumptions are made relative to the theoretical solution for the calibration dihedral. This technique has been verified by several 2-18 GHz wideband RCS measurements using various feeds in the compact range at the Ohio State University ElectroScience Laboratory. Based on these measurements, an effective polarisation isolation close to -60 dB has been demonstrated [J285]

"Electromagnetic plane wave scattering by a system of two uniformly lossy dielectric prolate spheroids in arbitrary orientation"

By means of modal series expansions of electromagnetic fields in terms of prolate spheroidal vector wave functions, an exact solution is obtained for the scattering by two uniformly lossy dielectric prolate spheroids in arbitrary orientation embedded in free space, the excitation being a monochromatic plane electromagnetic wave of arbitrary polarization and angle of incidence. Rotational-translational addition theorems for spheroidal vector wave functions are employed to transform the outgoing wave from one spheroid into the incoming wave at the other spheroid. The field solution gives the column vector of the unknown coefficients of the series expansions of

the scattered and transmitted fields expressed in terms of the column vector of the known coefficients of the series expansions of the incident field and the system matrix which is independent of the direction and polarization of the incident wave. Numerical results in the form of curves for normalized bistatic and monostatic radar cross sections are given for a variety of two-body system of uniformly lossy dielectric prolate spheroids in arbitrary orientation having resonant or near resonant lengths and different distances of separation [J286]

"Modeling of electromagnetic waves scattered by a system of spherical particles"

This paper presents an analytic method allowing us to take into account the multiple scattering effect in heterogeneous media made with spherical inclusions dispersed in a dielectric matrix. The Mie formalism used in the case of a single sphere, is extended to calculate the multiple scattered fields between two particles. The translation addition theorem for vector spherical waves functions is used to express the field scattered by one sphere in terms of the spherical coordinates of the other spheres and impose the boundary conditions. Numerical results of RCS and scattering diagrams of systems of two spheres are compared with free-space measurements made by using vectorial network analyzer [J287]

"Electromagnetic scattering by a system of two parallel uniformly lossy dielectric prolate spheroids"

By means of modal series expansions of electromagnetic fields in terms of prolate spheroidal vector wave functions, an exact solution is obtained for the electromagnetic plane wave scattering by a system of two parallel uniformly lossy dielectric prolate spheroids. The incident excitation is a monochromatic plane electromagnetic wave of arbitrary polarization and angle of incidence. Translational Addition Theorems for spheroidal vector wave functions are employed in order to transform the outgoing wave from one spheroid into the incoming wave at the other spheroid. Application of appropriate boundary conditions gives the column vector of the unknown coefficients of the series expansions of the scattered and transmitted fields expressed in terms of the column vector of the known incident field expansion coefficients and the system matrix which is independent of the direction and polarization of the incident wave. Numerical results in the form of curves for normalized bistatic and monostatic radar cross sections are given for a variety of parallel two-body system of uniformly lossy dielectric prolate spheroids and different values of distances of separation [J288]

"An iterative physical optics approach for analyzing the electromagnetic scattering by large open-ended cavities"

A formulation based on the high frequency asymptotic principles of physical optics is developed for analyzing the scattering by relatively arbitrary open-ended waveguide cavities containing complex interior terminations. A magnetic field integral equation (MFIE) is obtained for the equivalent currents on the interior cavity walls and is solved using an iterative physical optics (IPO) algorithm which iteratively applies physical optics to account for multiple reflections inside the cavity. The number of iterations required for convergence is related to the expected number of important reflections. The IPO method is more approximate than a matrix solution of the MFIE, but it is quite accurate for electrically large cavities and is much more efficient. Numerical results are presented which demonstrate the convergence and accuracy of the method by comparison with modal reference solutions [J289]

"A calibration technique for polarimetric coherent-on-receive radar systems"

A new technique for calibrating a coherent-on-receive polarimetric radar system is proposed. A coherent-on-receive polarimetric radar is capable of measuring the Mueller matrix of point or distributed targets directly by transmitting at least four independent polarizations and measuring the vertical and horizontal components of the backscatter signal simultaneously. The technique requires the use of two calibration targets, a target with known scattering matrix (such as a metallic sphere or a trihedral corner reflector) and any depolarizing target (for which knowledge of its scattering matrix is not required) to determine the system distortion parameters. The system distortion parameters, which include the channel imbalances, the cross-talk factors of both the transmit and the receive antennas, and the phase shifts and amplitude variations of the transmitter polarizers, are determined by measuring the calibration targets for four different transmit polarizations. The validity of the new calibration technique is examined by measuring the scattering matrices of spheres and cylinders as test targets using a coherent-on-receive radar operating at 34.5 GHz. Excellent agreement between the theoretical and the measured scattering matrices for the test targets are obtained [J290]

"The application of FDTD in hybrid methods for cavity scattering analysis"

In a previous paper (see ibid., vol.41, p.1560-1569, no.11, 1993), we presented the hybrid ray-FDTD method for analyzing the electromagnetic scattering from two-dimensional cavities with complex terminations. In this paper, we present three hybrid methods for analyzing the scattering from three-dimensional (3-D) inlet cavities. In these hybrid methods, the finite-difference time-domain (FDTD) method is used to determine the reflection matrix

associated with the termination. Modal analysis, physical optics (PO), or rays are used to analyze the remaining front section of the cavity. Representative results are presented [J291]

"A hybrid approach for calculating the scattering from obstacles within large, open cavities"

A hybrid method to analyze the high-frequency scattering from an obstacle within a large, open cavity is developed by using a generalized reciprocity integral and utilizing a plane wave expansion (PWE). The PWE is used because it is efficient, straightforward to implement, and can be used for relatively general geometries. In the hybrid method, the cavity's front section is analyzed independently from the termination section containing the obstacle. The termination section is accurately characterized by a PWE scattering matrix which may be stored and used in conjuction with different front-section geometries. The accuracy of the hybrid method is confirmed by comparing the radar cross section patterns of some simple cavity and obstacle geometries where each pattern is computed using the hybrid method and a more accurate reference method (such as the method of moments or waveguide modes) [J292]

"Target spinor calibration (TSC) for polarimetric radar cross-section measurements"

A new polarimetric calibration method is proposed based on scattering matrix decomposition, via Pauli matrices. This scheme operates with the Pauli target vectors instead of the scattering matrix. The base elements of the Pauli target vectors are the vectors corresponding to the usual calibrators such as sphere, dihedral and 45° rotated dihedral. This fact allows direct and easy calculation of the error coefficients. An experimental validation of this method is presented [J293]

"Analysis of electromagnetic scattering using arrays of fictitious sources"

The use of models of fictitious elemental current sources, located inside the scatterer to simulate the scattered field, has proved to be an efficient computational technique for analyzing scattering by metallic bodies. This paper presents a novel modification of the technique in which the omnidirectional elemental sources are arranged in groups of array sources with directional radiation patterns, and the boundary testing points are arranged in groups of testing arrays with directional receiving patterns. This modification which is motivated by physical understanding is equivalent to mathematical basis transformations. It renders the system matrix more localized and thereby enables the analysis of larger bodies. The new approach is applied to the case of TM scattering by a perfectly conducting square cylinder with side-length of 20λ. Reduction of 50% in the number of the nonzero elements of the system matrix is achieved with virtually no degradation in the accuracy of the radar cross section (RCS) calculations [J294]

"Reinventing electromagnetics: emerging applications for FD-TD computation"

Computed solutions to Maxwell's equations continue to lead to engineering advances of immense importance to society, the finite-difference time-domain method opens up a wide range of applications, traditional as well as novel [J295]

"Analysis of scattering from rough surfaces at large incidence angles using a periodic-surface moment method"

The moment method is used to calculate electromagnetic backscattering from one-dimensionally rough surfaces at near-grazing incidence (angles of incidence up to 89°). A periodic representation of the scattering surface is used to prevent edge effects in the calculated scattering without the use of an artificial illumination weighting function. A set of universal series common to all elements of the moment interaction matrix are derived that allow the efficient application of the moment method to the periodic surface. Comparison with other moment method implementations demonstrates the efficiency of this approach. The scattering from surfaces with Gaussian roughness spectra is calculated at both horizontal and vertical polarizations, and the results are compared with the theoretical predictions of the small-perturbation method (SPM) and Kirchhoff approximation (KA). SPM shows the expected loss of accuracy in predicting the vertically polarized backscattering from small-roughness, short-correlation-length surfaces at large incidence angles. SPM accurately predicts the backscattering from the same type of surface at incidence up to 89° at horizontal polarization, KA provides accurate estimates of the scattering from long correlation-length surfaces as long as the incidence angle is small enough that surface self-shadowing does not occur. When shadowing occurs, KA severely underpredicts vertically polarized backscattering and less severely overpredicts backscattering at horizontal polarization [J296]

"Overlapping modal and geometric symmetries for computing jet-engine inlet scattering"

By examining the scattering from a cylindrical inlet terminated by a fan-like structure possessing discrete angular

symmetry, it is found that only very limited intermodal coupling is possible. This fact is exploited in a hybrid finite element/modal scheme to develop a very efficient solution where only one slice of the geometry need be modeled. It is shown that a phase boundary condition at the interior walls of the mesh is sufficient for the complete solution of the problem. The implementation of the phase boundary condition is detailed for the full three-dimensional case, including special considerations for enforcing the boundary conditions along the axis. A simple example is shown for the sliced, hybrid finite element/modal scheme to validate the method [J297]

"Polarimetric scattering from heterogeneous particulate media"

Electromagnetic (EM) scattering in a medium containing discrete scatterers is a problem with broad interdisciplinary interest. The Mueller matrix solution has been applied to the study of EM polarimetric scattering and the vector radiative transfer from a layer of random medium. In this article, we report the methods to polarimetric scattering from a layer of particulate media containing: randomly dense spherical particles, nonuniformly oriented spheroids, or random clusters of spheroids. The complex scattering amplitude functions and phase matrix are explicitly obtained. Numerical results of the Mueller matrix solution show the properties of completely polarimetric scattering of those random media and its functional dependence on the relevant physical parameters. copyright 1995 American Institute of Physics. [J298]

"Investigations in the numerical behavior of the adaptive rank-revealing QR factorization"

We present a tracking procedure based on the rank-revealing QR (RRQR) factorization and investigate its numerical properties by applying it to the direction-of-arrival problem. We address numerical issues raised by the related work proposed earlier by Prasad et al. (1991), and we compare the performance of the proposed algorithm to that obtained using an EVD-based technique [J299]

"RCS of arbitrarily-shaped targets with the TLM method"

The radar cross section (RCS) of several bodies proposed by the Electromagnetic Code Consortium (EMCC) is calculated using the transmission-line matrix (TLM) method with the symmetrical condensed node. The results are in good agreement with experimental and moments-method solutions when the TLM is used together with an appropriate boundary condition and a near- to far-zone transformation approach [J300]

"The principle of speckle filtering in polarimetric SAR imagery"

The principle of speckle reduction in polarimetry is reconsidered. It is shown that polarimetric data can be speckle reduced if and only if all the elements of the Mueller matrix are filtered, which is equivalent to filtering the scattering vector covariance matrix. Assuming that speckle is multiplicative and stationary, the algorithms proposed by S.L.Lee et al. (1991) and S.Goze et al. (1993) are extended to filter the covariance matrix of reciprocal and nonreciprocal targets on one-look and multilook images. The problem of estimation of the first- and second-order statistics of the four-channel speckle vector is discussed, and a solution is proposed for one-look and multilook images [J301]

"Image processing of synthetic aperture radar range ambiguous signals"

If wide-range swath scenes are illuminated by a synthetic aperture radar with high-pulse repetition frequencies, ambiguous scattered signals from an undesired range may appear in its receiver at the same time from consecutive transmitted pulses. This simplified analysis shows that range ambiguous signal returns result in a defocused image because they are convolved with the phase history of the desired range signal. A satellite borne SAR example is presented [J302]

"Integral equation analysis of artificial media"

This paper presents an integral equation and method of moments (MM) solution to determine the effective permittivity and permeability of an artificial medium. The artificial medium is modeled as a triple infinite periodic array of identical scattering elements. A plane wave of unknown phase constant is assumed to propagate in the periodic medium in a given direction, and the periodic moment method (PMM) is used to set up a matrix equation for the currents on the center element of the periodic array. By setting the determinant of the PMM impedance matrix to zero, one can determine the phase constant of the plane wave, and then the effective permittivity and permeability of the artificial medium [J303]

"Iterative solution of a 3-D scattering problem from arbitrary shaped multidielectric and multiconducting bodies"

We present an iterative algorithm used for the computation of the scattering from arbitrary shaped bodies made of dielectric and conducting material. The harmonic problem is discretized by a hybrid boundary integral method/finite element method. To solve the discretized linear system, a modified version of a minimal residual algorithm has been developed for complex matrices. It takes into account the Lagrange multiplier constraint in a special way. This modified version also allows the linear system to be solved for many right-hand sides in an efficient manner [J304]

"Scattering from two-dimensional objects embedded in multilayered media"

The paper presents a hybrid numerical model for simulating electromagnetic scattering from a two dimensional object embedded in multilayered media. The domain is first divided into interior and exterior regions using a cylindrical surface. Finite element formulation is used to solve for the field in the internal region, and the solution of the field is used to find the induced current in the elements that discretize the 2D object. The scatterer is represented as a summation of line sources embedded in multilayered media, and the scattered field is found by summing the contributions from these sources. Simulation results are presented [J305]

"Polarimetric scattering from a layer of random clusters of small spheroids"

Employing the volume integral equation formulation with self-interaction term for internal fields, the Jones scattering matrix and phase matrix for random clusters of small spheroids are derived. The mutual coherent wave interactions among clustered spheroids are included. Clustering enhances the internal fields and the scattering amplitude function. Substituting the newly derived phase matrix into the Mueller matrix in the approach of vector radiative transfer for a layer of random clusters of small spheroids, fully polarimetric copolarized and cross-polarized backscattering are numerically calculated. Clustering effects of a layer of random spheroids are quantitatively illustrated, and the backscattering enhancement of several dB order and its functional dependence on parameters are discussed [J306]

"Electromagnetic scattering from objects composed of multiple homogeneous regions using a region-by-region solution"

The paper presents an efficient procedure to calculate the electromagnetic field scattered by an inhomogeneous object consisting of N+1 linear isotropic homogeneous regions. The procedure is based on surface integral equation (SIE) formulations and the method of moments. The method of moments (MM) is used to reduce the integral equations for each homogeneous dielectric region into individual matrices. These matrices are each solved for the equivalent electric current in terms of the equivalent magnetic current. A simple algebraic procedure is used to combine these solutions and to solve for the magnetic current on the outer dielectric surfaces of the scatterer. With the magnetic current determined, the electric current on the outer surface of the scatterer is calculated. Because the matrix corresponding to each dielectric region is solved separately, the authors call this procedure the region-by-region method. The procedure is simple and efficient. It requires less computer storage and less execution time than the conventional MM approach, in which all the unknown currents are solved for simultaneously. To illustrate the use of the procedure, the bistatic and monostatic radar cross sections (RCS) of several objects are computed. The computed results are verified by comparison with results obtained numerically using the conventional numerical procedure as well as via the series solution for circular cylindrical structures. The possibility of nonunique solutions has also been investigated [J307]

"Intensity and phase statistics of multilook polarimetric and interferometric SAR imagery"

Polarimetric and interferometric SAR data are frequently multilook processed for speckle reduction and data compression. The statistical characteristics of multilook data are quite different from those of single-look data. The authors investigate the statistics of their intensity and phase. Probability density function (PDF's) of the multilook phase difference, magnitude of complex product, and intensity and amplitude ratios between two components of the scattering matrix are derived, and expressed in closed forms. The PDF's depend on the complex correlation coefficient and the number of looks. Comparisons of these theoretically derived PDF's are made to measurements from NASA/JPL AIRSAR data. The results of this paper can be applied to feature classification using polarimetric SAR and to the estimation of decorrelation effects of the interferometric SAR [J308]

"Numerical simulation of scattering from three-dimensional randomly rough surfaces"

Randomly rough surface patches in three dimensions are generated on the computer. The FD-TD method is used to compute scattering from surface patches by converting the Maxwell's equations into difference equations using a central difference approximation for the space and time derivatives. The volume of grids above the rough surface is divided into the total field and the scattered field regions. In between these two regions,

obliquely incident waves are generated. To reduce computation, the volume of grids is chosen to be small, and a transformation is used to convert the scattered field into far zone fields for bistatic scattering coefficient calculations. Possible errors near the edge of the surface due to the use of a relatively small volume are suppressed by introducing a windowing function. Very good agreements are obtained between the results obtained by this method and those calculated by an integral equation method (IEM) for scattering from randomly rough perfectly conducting and dielectric surfaces [J309]

"A unified algorithm for phase and cross-talk calibration of polarimetric data-theory and observations"

A unified approach to phase and cross-talk calibration of polarimetric data which can be applied to calibrating scattering matrix data or to extraction of the descriptors of distributed targets is described. It relies on the scene being dominated by targets with uncorrelated like and cross-polarized backscattering coefficients, but provides cross-talk calibration of targets for which this is not true. The algorithm needs unsymmetrized data, but uses only quantities derived from the covariance matrix of large areas. It makes no assumptions about system reciprocity, permits ready interpretation of the terms in the calibration procedure, allows comparison of the relative magnitude of the system-induced mixing of terms in the observed covariance matrix, is noniterative, and produces indicators which allow testing of whether it meets its own underlying assumptions. The linear distortion model is shown to lead to an inconsistent system of equations; this inconsistency can be removed by introducing an extra parameter which has properties expected of system noise. The modulus of the copolarized correlation coefficient, which is important in polarimetric classification and as a phase descriptor, is shown to be invariant under all effects embodied in the linear distortion model. Calibration of the scattering matrix data is based on a minimum least squares principle. This suggests that current methods of symmetrization are not optimal. The same analysis shows that estimates of parameters needed to form an equivalent reciprocal system are also nonoptimal. The method is more general than the well-known van Zyl algorithm for cross-talk removal, and permits an analysis of the conditions under which the van Zyl algorithm will yield valid results. Correction of phase distortion induced by channel imbalance Is treated as an optional extra step relying on a known HH-VV phase difference in some region of the image. Results from the algorithm are discussed using scattering matrix data from the 1989 MAESTRO campaign [J310]

"Optimum polarizations in the bistatic scattering from layered random media"

Investigates the polarimetric bistatic scattering characteristics of layered random media. On applying the Born approximation, the authors have calculated the bistatic Mueller matrix of a half-space random medium. The power received by a receiving antenna is the quantity chosen to optimize. The variables of the problem are the polarizations of the transmitting and receiving antennas. For the case when the polarizations of the transmitting and receiving antennas are identical, the authors have calculated the optimum polarizations and they have found that the optimum polarizations include both linear and elliptical polarizations. The conditions for maximum and minimum received power are also obtained. In the backscattering case, they have considered the situation when the transmitting and receiving antennas have independent polarizations. For a two-layer problem, they have observed the influence of the thickness of the layer in the classification of the optimum polarizations [J311]

"Polarization signatures of frozen and thawed forests of varying environmental state"

During the two different overflights of the Bonanza Creek Experimental Forest (near Fairbanks, Alaska) by the NASA/JPL radar polarimeter in March 1988, the environmental conditions over the region changed significantly with temperatures ranging from unseasonably warm (1 to 9°C) during one day to well below freezing (-8 to -15°C) during the other. The moisture content of the snow and trees changed from a liquid to frozen state causing significant changes in the radiometric and polarimetric responses of the forest to the radar wave. The L-band polarimetric observations are summarized in this paper. Up to a 6 dB change in the backscatter was observed in certain forest stands at L-band. Features extracted from the Stokes matrices of the same stands from the thawed and frozen days suggest the changes in the relative contribution of the different scattering mechanisms to the radar return. Comparison of the polarimetric signatures indicate relatively higher contribution from diffuse scatterers on the thawed day than on the frozen day. The sensitivity of the polarimetric signatures to changing environmental conditions is clearly demonstrated [J312]

"Estimation of the covariance matrix for dependent signal samples: polarization diversity systems"

The problem of the estimation of covariance matrices in multichannel radar system when signal samples are statistically dependent is addressed. An optimal maximum likelihood (ML) estimate is derived. Probability characteristics and sensitivity to signal models of the estimate are evaluated for a polarization diversity system [J313]

"Power lines: radar measurements and detection algorithm for polarimetric SAR images"

Polarimetric radar backscattering measurements of a variety of powerline cables are presented. The objective of the first part of the investigation was to study the effect of braiding of the cables on the backscattering at skew incidence. The measurements were performed for four different actual size powerline samples at C-, X-, and Ka-band over a wide range of incidence angles. The data were collected over a 500 MHz bandwidth at C- and X-band with a 1.25 MHz increment and a 1 GHz bandwidth at Ka-band with a 2.5 MHz increment. Also the effect of nonuniform illumination and measurement in the near field of the cables were studied. Experimental data shows a significant radar backscatter for W-polarization (σvv) at angles away from normal incidence. This backscatter is proportional to the number and diameter of the strands on the surface of the cables. There is also noticeable backscatter for the HH and VH components of the scattering matrices. Their magnitudes, relative to that of the W component, are proportional to the pitch angle of the helix. Since detection of these cables is an important safety issue for low-flying airplanes a detection algorithm using polarimetric synthetic aperture radar (SAR) images was developed using the knowledge gleaned from the measurements. The detection algorithm was tested on a simulated image and worked well, detecting a power line whose backscatter power was 6 dB below the average background power [J314]

"Wire-junction matrix model for the TLM method"

The additional capacitance and inductance introduced by a conducting wire can be modelled in the transmission line modelling (TLM) method by a special node. A symmetrical transmission-line structure is proposed for the modelling of wire junctions in a coarse mesh. The model is tested by calculating the response of a wire-cross scatterer and the RCS of a perfectly conducting plate simulated by means of a square wire mesh. Although, initially, TLM was not developed for solving wire structures, the results are in good agreement with the theoretical and moment-method solutions traditionally used for this type of structure [J315]

"Probability density functions for multilook polarimetric signatures"

Derives closed-form expressions for the probability density functions (PDF's) for copolar and cross-polar ratios and for the copolar phase difference for multilook polarimetric SAR data, in terms of elements of the covariance matrix for the backscattering process. The authors begin with the case in which scattering-matrix data are jointly Gaussian-distributed. The resulting copolar-phase PDF is formally identical to the phase PDF arising in the study of SAR interferometry, so the authors' results also apply in that setting. By direct simulation, they verify the closed-form PDF's. They show that estimation of signatures from averaged covariance matrices results in smaller biases and variances than averaging single-look signature estimates. They then generalize their derivation to certain cases in which backscattered intensities and amplitudes are K-distributed. They find in a range of circumstances that the PDF's of polarimetric signatures are unchanged from those derived in the Gaussian case. They verify this by direct simulation, and also examine a case that fails to satisfy an important assumption in their derivation. The forms of the signature distributions continue to describe data well in the latter case, but parameters in distributions fitted to (simulated) data differ from those used to generate the data. Finally, the authors examine samples of K-distributed polarimetric SAR data from Arctic sea ice and find that their theoretical distributions describe the data well with a plausible choice of parameters. This allows the authors to estimate the precision of polarimetric-signature estimates as a function of the number of SAR looks and other system parameters [J316]

"Calibration of a polarimetric synthetic aperture radar using a known distributed target"

Existing methods for external calibration of polarimetric synthetic aperture radars (SAR) are all based on point targets with known scattering matrices. The quantity of interest in radar measurement of distributed targets is the backscattering coefficient, which is different from the radar cross section (RCS) formulated for point targets. Therefore, in order to infer the backscattering cross section of a distributed target from a point target rigorously, the polarimetric ambiguity function of the SAR (unknown) is needed for the computation of the effective illumination area. In existing methods the illumination area is approximated by the area of a pixel. The second problem is the uncertainty in the RCS of point calibration targets. The large physical size of the point targets and their interaction with the background produce uncertainties in the measurement of the calibration targets. The third problem with existing methods arises from the application of the calibration algorithm to individual pixels. The measured response of a distributed target by a SAR is the convolution of the actual radar reflectivity of the target with the ambiguity function of the SAR. Thus, the statistics derived from individual pixels is influenced by the ambiguity function and the measurement becomes system dependent. In this paper a calibration algorithm is proposed that circumvents all of the mentioned problems. It is shown that the radar distortion parameters and effective illumination area can be obtained from a homogeneous distributed target with a known differential Mueller matrix. The distortion parameters are then used in an algorithm to provide the calibrated differential

Mueller matrix for the other homogeneous targets in the image. This algorithm is tested for the JPL L- and C-band SAR using four different distributed targets measured with polarimetric scatterometers [J317]

"Calibration of a polarimetric radar using a rotatable dihedral corner reflector"

Based on the existing mathematical formalisms of radar polarimetry, it is necessary to perform accurate and diversified polarimetric measurements in the real world to thoroughly investigate signature definition, identification, and classification of radar targets. For this study the Delft Atmospheric Research Radar (DARR) is used. This ground-based polarimetric FM-CW radar operates in the S-band. The purpose of the present paper is the polarimetric calibration of the DARR. Among the passive reflectors, a rotatable dihedral corner reflector is a suitable calibration object. It enables one to measure different scattering matrices with only one reflector. One alignment must be performed and the scattering matrices are measured at the same range. By measuring several scattering matrices, the accuracy of the calibration result can be estimated. A measurement campaign with a rotatable dihedral corner reflector was therefore performed. The experimental results and the calibration procedure are presented in this paper [J318]

"Edge-based FEM solution of scattering from inhomogeneous and anisotropic objects"

This paper presents an application of the edge-based vector finite element method to scattering problems of anisotropic and inhomogeneous objects. Based on conventional FEM functional, a hybrid finite element-surface integral formulation is established by introducing permittivity and permeability tensors. The space domain is divided into interior and exterior regions by an imaginary surface conformal to the scatterer. Edge vector finite elements are used to model the anisotropic and inhomogeneous interior, and a surface integral equation is used to model the unbounded exterior. Compared to other hybrid techniques, the approach here retains the symmetry and sparsity of the FEM matrix and introduces only one type of unknown equivalent current in the moment matrix equation. To validate the theory, typical 2-D numerical results are first presented, which show excellent agreement with exact eigenmode expansion solutions or accurate MoM data [J319]

"Mueller and Kennaugh matrices in radar polarimetry"

This paper is concerned with the notions of the Mueller matrix and the Kennaugh (or Stokes scattering) matrix, that are commonly used in the field of radar polarimetry. Although these two matrices are quite similar, there exists a basic difference between them that seems to have been overlooked by a number of researchers, resulting in a great deal of confusion. An attempt is made to clarify this point and to present the basic relationships of radar polarimetry in a compact form [J320]

"A comparison of radar, optic, and specular null polarization theories"

The fields of radar and optical polarimetry are compared. Both fields have defined scattering matrices that describe the coherent scattering of monochromatic electric fields. This paper compares the mathematics of the two disciplines and it is then shown that Kennaugh's optimum polarizations can be derived in the context of optical polarimetry, which always employs a local right-handed coordinate system. In addition, a novel definition of the receive copolar polarization state is given: that polarization state that results when a plane wave is reflected by a specular surface. The resulting mathematics when this definition is used in termed specular null polarization theory. It is shown that this new definition facilitates the analysis of backscatterers by focusing on those polarization state changes that are only due to the scatterer [J321]

"Phase calibration of polarimetric radars from slightly rough surfaces"

The phase calibration problem for polarimetric radars is discussed. More specifically, the assumption that the copolar vertical and horizontal returns from a slightly rough surface are in phase is critically reviewed. It is concluded by means of a theoretical analysis that the phase difference for moist soil targets can reach up to 10° at 15 GHz and for incidence angles of 50°. However the assumption of zero phase difference is a good approximation for dry soils, lower frequencies, and low incidence angles [J322]

"Numerical eigenanalysis of the coherency matrix for a layer of random nonspherical scatterers"

By using the first-order iterative solution of vector radiative transfer in small albedo for a layer of nonuniformly-oriented, random, nonspherical scatterers, the Mueller matrix and coherency matrix are obtained. Eigenanalysis of the coherency matrix is numerically calculated. The eigenanalysis of the coherency matrix is proposed as a better method for identifying physical scattering mechanisms than direct inspection of the Mueller matrix. The functional dependence of polarimetric scattering is also discussed [J323]

"An ultrawideband, polarimetric radar for the study of sea scatter"

An ultrawideband radar system is described which has the capability of making pulse-to-pulse polarimetric measurements of the dynamic water features responsible for radar backscatter from the sea. The fast risetime voltage step produced by a Tektronix time-domain reflectometer (TDR) is used to excite a 6-12-GHz amplifier, producing a short (15 cm) radar pulse, A pair of 2- to 18-GHz antennas and appropriate pulse-to-pulse transmit and receive switching capability allows the collection of four consecutive equivalent-time-sampled pulses, one for each combination of the linear transmit and receive antenna polarizations. A polarimetric scattering matrix is then obtained at a sequence of frequencies across the 6-12-GHz band through the Fourier transform of each of the four waveforms and the application of an ultrawideband, polarimetric calibration procedure. The effect of motion on the computed scattering matrix is discussed and quantified, as this is an important consideration for polarimetric investigations of the water features responsible for radar sea scatter, A technique is then presented which compensates for the effects of target translation during the sampling interval. Scattering measurements of several rigid targets and of small breaking waves in a wave tank are used to illustrate the unique capabilities of this system and its applicability to sea scatter studies [J324]

"Higher order impedance boundary conditions applied to scattering by coated bodies of revolution"

In this paper higher order impedance boundary conditions will be employed in the solution of scattering by coated conducting bodies of revolution. The higher order impedance solution reduces the total number of unknowns relative to the exact solution, and produces a system matrix which is less dense than that of the exact solution. The construction of the solution involves two distinct steps. In the first step the body of revolution is replaced by an equivalent set of electric and magnetic currents on its exterior surface which generate the true fields outside the body. An integral equation relating these currents through the free space Green's function is derived. Step two employs the higher order impedance boundary condition to relate the electric and magnetic currents on the surface of the body. This replaces the rigorous solution of the interior problem. The higher order impedance boundary conditions are derived by obtaining an exact impedance boundary condition in the spectral domain for the coated ground plane, approximating the impedances as ratios of polynomials in the transform variables, and employing the Fourier transform. The resulting spatial domain differential equations are solved in conjunction with the integral equation using the method of moments. Several examples of bistatic and monostatic radar cross section for coated bodies of revolution are used to illustrate the accuracy of the higher order impedance boundary condition solution relative to the standard impedance boundary condition solution and the exact solution. The effects of coating thickness, loss, and curvature on the accuracy of the solution are discussed [J325]

"The use of estimation techniques to reduce noncoherent polarimetric measurement errors"

Polarimetric measurements contain errors owing to random thermal energy in the receiver and system phase noise. These errors can be reduced using estimation techniques that account for general properties of the Mueller matrix. In this paper, we show how Kalman (1960) filter techniques improve and speed up the estimation of a target's Mueller matrix when the noncoherent measurement technique is used. Measurements obtained with a 95-GHz polarimeter demonstrate that fewer independent samples of the backscattered fields are needed to obtain an accurate estimate if Kalman filtering is used than if a pseudo inversion process is used [J326]

"The RCS of a microstrip dipole deduced from an expansion of pole singularities"

The singularity expansion method (SEM) is applied to the steady-state analysis of plane wave scattering from microstrip dipoles. The current induced on the antenna is expanded in a series of natural modes, where the amplitude of each term in the expansion is expressed as a coupling coefficient weighted by a simple frequency pole. Natural modes occur at pole singularities of the antenna current in the complex frequency plane, and are found by a numerical root search of a homogeneous matrix equation. This formulation results in an accurate and efficient calculation of the radar cross section (RCS) of microstrip dipoles which exhibit some appreciable resonant characteristics, where it is found that the current resonance dominates the response of the antenna. The SEM applied yields good physical insight into the scattering behavior of such antennas. Results obtained with the SEM analysis are compared with a full-wave method-of-moments solution [J327]

"Microwave emission of vegetation: sensitivity to leaf characteristics"

The effects of leaf characteristics on the microwave emission of land surfaces are analyzed. In order to simulate these effects, a radiative transfer model is presented. The medium consists of a vegetated layer containing randomly oriented leaves, modeled as elliptic-shaped scatterers, over the ground surface. Radiative transfer equations are solved with a discrete-ordinate-eigenanalysis method. The calculation of the phase matrix of the

elliptic scatterers is based on the generalized Rayleigh-Gans approximation, which increases the frequency range of the modeling. The sensitivity of brightness temperature and polarization ratio to leaf characteristics, volume fraction, gravimetric moisture, size, shape, and inclination distribution is investigated at C-, and X-band. The behavior of the simulated emission of a soybean canopy versus frequency and incidence angle is studied for different soil moisture levels. Up to 10 GHz the microwave emission appears to contain significant information on underlying soil moisture [J328]

"A new clustering algorithm applicable to multispectral and polarimetric SAR images"

The authors applied a scale-space clustering algorithm to the classification of a multispectral and polarimetric SAR image of an agricultural site. After the initial polarimetric and radiometric calibration and noise cancellation, a 12-dimensional feature vector for each pixel was extracted from the scattering matrix. The clustering algorithm partitioned a set of unlabeled feature vectors from 13 selected sites, each site corresponding to a distinct crop, into 13 clusters without any supervision. The cluster parameters were then used to classify the whole image. The classification map is much less noisy and more accurate than those obtained by hierarchical rules. Starting with every point as a cluster, the algorithm works by melting the system to produce a tree of clusters in the scale space. It can cluster data in any multidimensional space and its insensitive to variability in cluster densities, sizes and ellipsoidal shapes. This algorithm, more powerful than existing ones, may be useful for remote sensing for land use [J329]

"Comments on a “A neural network approach to MVDR beamforming problem”"

Several corrections to the above-titled paper by P.R. Chang et al. (ibid, vol. 40, pp 313-322, 1992) are given by the commenter, who also discusses a number of Chang et al.'s results. The commenter also discusses the practical issues that arise when an array operates in a nonstationary environment [J330]

"Deriving the linear depolarisation ratio of precipitation from copolar radar measurements"

Usually, the polarisation-dependent scattering matrix is measured with the receive and transmit antennas alternately co- and crosspolarised. For scattering parameters with negligible differential phase, however, three copolar measurements can be used to obtain the complete scattering matrix. Less stringent demands on the signal-to-noise ratio are then necessary, which is especially convenient in the case of weak radar returns. [J331]

"Monte Carlo simulation of scattering from a layer of vertical cylinders"

Electromagnetic scattering by a collection of randomly distributed vertical cylinders over a half-space dielectric is considered, using two approaches. In the first approach, a Monte Carlo simulation that takes into account scattering terms up to second order is used. Closed-form expressions for the second-order scattering terms are derived for cylinders that are in each other's near field. The second approach is based on the radiative transfer equations, which are solved by an iterative method up to and including the second-order terms. Radar backscatter measurements at X-band for a collection of metallic cylinders over a conducting ground plane are compared with the Monte Carlo and radiative transfer solutions. The data were acquired polarimetrically from 144 independent spots of the cylinder layer at incidence angles ranging from 20° to 60°. The simulation results agree well with the measured data and are used to check the validity of the radiative transfer results for a medium with large particles. It is shown that both the phase function computed for the cylinders and the extinction matrix of the layer are overestimated in the radiative transfer solution [J332]

"Imaging of point scatterers from step-frequency ISAR data"

A high-resolution method for imaging of point scatterers from step-frequency inverse synthetic-aperture radar (ISAR) data is presented. An analysis of the noise sensitivity of the method is provided to show the high performance of the method. Simulation results are given to show the robustness of the method against model errors [J333]

"Electromagnetic scattering from an arbitrary, inhomogeneous 2-D object-a finite and infinite element solution"

The application of finite elements to the open region associated with scattering problems necessarily requires the truncation of the solution region. This work investigates the use of infinite elements to extend the solution region beyond that of the finite elements which can be truncated by a noncircular boundary. A finite/infinite element formulated is developed in two dimensions and tested on dielectric, magnetic, and conducting scatterers with known analytic solutions [J334]

"Polarimetric radar modeling of mixtures of precipitation particles"

With the advances of dual-polarized radar techniques in meteorology it is now possible to deduce precipitation microphysical characteristics in far more detail than possible with reflectivity measurements alone. Radar parameters such as differential reflectivity and differential phase between horizontal and vertical polarizations have been studied in detail as well as linear depolarization ratio, copolar correlation coefficient, and backscatter differential phase. While these parameters can be linked to certain microphysical properties of specific classes of precipitation such as raindrops or hail, very little study has been directed at the practically important cases of mixtures of different types of precipitation particles such as rain, hail, graupel, ice crystals, and snow. Each type can have different size, shape, orientation, and dielectric constant distributions. The present treatment is rigorous and is based on the Mueller matrix formulation. Radar parameters are derived from the averaged Mueller matrix computations. Careful consideration is given to the orientation and size distributions of the different particle types. After calculating single particle scattering characteristics, some simple two-component mixtures such as rain/hail and ice crystals/snow are considered. Finally, a 2D numerical cloud model is used to simulate the rain, hail/graupel, and snow fields of an evolving convective storm from which the radar parameters are derived for the initial, peak, and dissipating stages of the storm. Model computations are performed at C and S-band frequencies [J335]

"Radar target scattering matrix measurement through orthogonal signals"

A method recently proposed for the simultaneous measurement of all four elements of the target scattering matrix in polarimetric radars is considered and analysed. The method makes use of pulse signal coding and is theoretically based on the simultaneous independent transmission of two orthogonal signals on two orthogonally polarised channels feeding the same antenna. The elements of the target scattering matrix are retrieved by correlating the received signal on each orthogonally polarised channel with both the transmitted waveforms. The potential advantages offered by this measurement method are discussed, with particular reference to the accuracy of the scattering matrix measurement in the presence of point targets. Related radar system implications and improvements are discussed, and applications of different types of transmission waveforms are considered [J336]

"A multilevel formulation of the method of moments [JEM scattering]"

The modeling of electromagnetic scattering and radiation problems using the method of moments (MoM) is limited to resonant frequencies because of the extensive computational requirements of solving large matrix equations. In this study, a multilevel formulation of MoM which allows substantial computational savings and, thus, extends the application of MoM to higher frequencies is presented. Using a hierarchy of discretization levels, the multilevel technique extracts different modal components of the solution by focusing on a specific portion of the spectrum of the solution at a given level. The fundamental features of this process for the MoM solution of the electric field integral equation (EFIE) are developed and implemented. This multilevel MoM allows the rapid evaluation of the current distributions on a variety of 2-D scatterers with thousands of unknowns in fewer than ten cycles and in fractions of the normal CPU times. The method is stable, fast, suitable for multiple excitations, and adaptable as a `solve' module for almost any MoM code [J337]

"Two near-to far-zone approaches for scattering problems using the TLM method"

The far-scattered field and radar cross section (RCS) are calculated by transforming the results of the transmission-line-matrix (TLM) method with the symmetrical condensed node (from the near-to the far-zone) by means of two different approaches, in the time domain. The first approach is based on the electromagnetic equivalence principle, and the second is based on the Kirchhoff theory of integration. Details and a complete description of the two approaches are given. Examples of far-zone-scattering results for three-dimensional conducting bodies are given to validate and compare the two methods [J338]

"Calculation of Mueller matrices and polarization signatures for a slab of random medium using vector radiative transfer"

The Mueller matrix which characterizes a slab of random medium containing spherical particles is calculated by using the vector radiative transfer theory. The vector radiative transfer equation is solved for arbitrarily polarized incident waves. The background refractive index of the slab is allowed to be different from the surrounding media. The scattering specific intensities for four independent polarized incident waves are calculated and used to construct the Mueller matrix, which contains multiple scattering due to the randomly distributed particles governed by the vector radiative transfer theory. The calculated are found to be symmetrical, and there are eight nonvanishing matrix elements. Polarization signatures are obtained in the backscattering direction from the

Mueller matrix of the reflection side [J339]

"Analysis of wire scatterers with nonlinear or time-harmonic loads in the frequency domain"

The time-harmonic scattering properties of wire scatterers with nonlinear or time-harmonic loads are analyzed in the frequency domain. First, the scattering problem is treated as a network problem that is analyzed by the method of moments. Then, the harmonic balance technique is applied in the nonlinear load case, and the conversion matrix technique is applied in the time-harmonic load case. The analysis is shown to be efficient for the calculation of steady-state response compared with the conventional time-domain approach. Numerical simulation shows the effect of nonlinear loads on changing the scatterer radar cross section (RCS), the intermodulation phenomenon as the incident wave containing two different frequencies, and the effect of time-harmonic loads on modulating the scattered field of wire scatterer [J340]

"Polarimetric observations and theory of millimeter-wave backscatter from snow cover"

Polarimetric radar measurements carried out at 95 and 225 GHz are presented for fresh and refrozen snow cover. These data indicate that the Mueller matrix for snow cover consisting of spherical ice particles has a relatively simple form, with 10 of the 16 elements approximately zero. Measurements of new-fallen snow consisting of predominantly nonspherical snow crystals are also presented. The anisotropic structure of such snow cover results in a more complex Mueller matrix, fitting the general form for natural surfaces. An analytic expression for the Mueller matrix of isotropic snow cover is derived by computing the response of a semi-infinite layer of scatterers that are insensitive to the orientation of the incident polarization. This matrix is shown to accurately predict the polarimetric response of the snow cover comprised of spherical ice particles based solely on copolarized and cross-polarized radar cross-section measurements [J341]

"A radar coal thickness sensor"

A radar coal thickness sensor is being developed by the Bureau of Mines to measure both the dielectric constant and thickness of a coal seam as part of a sensor array supporting a computer-assisted coal mining machine. The noncontacting stepped-CW radar sensor measures the complex reflection of coefficient of the coal-shale interface to resolve the coal thickness to sub-wavelength accuracies. The technique uses a monostatic antenna configuration. Transfer function errors are identified by using spatial modulation created by antenna motion. Synthetic range gating is used for clutter rejection. Finally, polarimetric scattering matrix techniques are used to calculate the dielectric constant and thickness of the multilayered coal/shale media. Data taken both in the laboratory and in an underground mine, in the 0.6-1.4 GHz range, with a network analyzer and dipole antenna, have validated the technique. Accurate in situ measurements were made of a coal seam 6 in (15.2 cm) thick with a dielectric constant of 4. The coal thickness was confirmed by physical measurement. An independent measurement of the coal dielectric constant confirmed the accuracy of the noncontacting dielectric measurement technique [J342]

"Electromagnetic scattering from a stratified bi-isotropic (nonreciprocal chiral) slab: numerical computations"

A transversely polarized time-harmonic plane wave normally incident on a stratified bi-isotropic (nonreciprocal chiral) slab is considered. The invariant embedding method is used to derive the differential equations for the scattering coefficient matrices, which are solved using appropriate boundary conditions. With the calculated reflected field as the boundary value, the differential equations for the Green functions are solved numerically. Numerical results are presented [J343]

"Radar cross-section of dielectric-coated conducting cylinder loaded with periodic metallic strips using mixed SDM, CGM and FFT:TE incidence"

A mixed technique is presented for calculating the radar cross-section characteristics of a dielectric-coated conducting cylinder with TE-wave incidence loaded with periodic metallic strips. The technique is based on the spectral-domain method (SDM), conjugate gradient method (CGM) and fast Fourier transform (FFT). Since the property of circular Toeplitz matrix has been used, only memory directly proportional to NsNb(Nsis the number of strips and Nbis the number of basis functions for approximating the currents on the strips) is needed, which allows treatment of the cylinder loaded with tens or even hundreds of strips. The RCS of a dielectric-coated conducting cylinder loaded with many periodic metallic strips are first calculated. Numerical results show that the RCS can be effectively controlled by adjusting the period or the spaces between strips [J344]

"Detection of tunnels in low loss media illuminated by a transient pulse"

The field scattered from a subsurface object illuminated by a transient pulse is determined using the T-matrix method. Although the method itself is a resonance-region, frequency-domain technique, it is shown that it can be applied to problems in which the pulse has energy that spans several decades in the frequency domain. The illuminating pulse simulates one used in an actual VHF subsurface radar exploration device. The pulse is radiated from an electric dipole in a vertical borehole. The scattered pulse is obtained by first calculating the components in the spectral description of the transmitting antenna current. The T-matrix method is then used to determine the system transfer function, which, in turn, gives the scattered energy in terms of the antenna current. An inverse Fourier transform yields the temporal scattered field. The scatterer is modeled as a dielectric ellipsoid, which is presented as an approximation to a cylindrical tunnel [J345]

"Measurement of ocean wave spectra using narrow-beam HE radar"

A data interpretation algorithm is developed to extract ocean wave information from HF radar backscatter observed by a narrow-beam antenna system. The basis of this measurement is the inversion of the integral equation representing the second-order radar cross section of the ocean surface. This equation is numerically inverted by approximating it as a matrix equation and pseudoinverting the kernel matrix using a singular value decomposition. As a test of this algorithm, comparisons are made between wave spectrum estimates obtained from a WAVEC buoy and a pair of 25.4-MHz ground wave radars, using data collected during the 1986 Canadian Atlantic Storms Program (CASP). Overall, the results of this experiment have been positive and have demonstrated both the basic feasibility of the inversion algorithm and the wave sensing capability of HF radar. For example, significant wave height estimates deduced by two radars differed from the buoy, in an absolute value sense, by only 0.12 m on average. When using only one radar, the mean difference of this important parameter from the buoy was a reasonable 0.33 m [J346]

"Numerical electromagnetic inverse-scattering solutions for two-dimensional infinite dielectric cylinders buried in a lossy half-space"

An approach to microwave imaging in a half-space geometry and to treating infinite dielectric cylinders buried in a lossy medium is proposed. The two-dimensional integral equation for the inverse-scattering problem is discretized by the moment method. The resulting ill-conditioned system is solved by pseudoinversion. A multi-incidence process based on the invariance of the Green matrix to the incident field is described. Results of some numerical simulations, assuming a noisy environment, are reported and discussed [J347]

"Recursive T -matrix algorithms for the solution of electromagnetic scattering from strip and patch geometries"

Two recursive T-matrix algorithms are presented and their reduced computational complexities and reduced memory requirements are demonstrated. These algorithms are applied to the problem of electromagnetic scattering from conducting strips and patches with canonical geometries. The geometries are reminiscent of finite-sized frequency selective surfaces. Computational complexities of O(N2) and O(N7/3) and memory requirements of O(N) and O(N4/3) are shown to be feasible for two-dimensional and three-dimensional geometries, respectively. The formulation uses only two components of the electric field. Therefore, the vector electromagnetic problem of scattering from three-dimensional patch geometries can be solved using scalar addition theorems for spherical harmonic wave functions. For a two-dimensional strip problem, both TM and TE polarizations can be solved simultaneously using this formulation. Numerical scattering results in the form of radar cross sections (RCS) are validated by comparison with the method of moments [J348]

"A coding algorithm for the covariance matrix representation of polarimetric radar data"

A coding algorithm for the covariance matrix representation of polarimetric radar data is presented. The goal is to optimize storage requirements and the throughput of computer applications for radar polarimetry, which rely on this kind of representation. The algorithm uses a 10-b quantizer, with gain balance and a nonlinear compressor expander, and achieves a compression factor of 2.5. Some theoretical considerations on the behavior of the quantizer with respect to the input data distribution are discussed. The algorithm performance is characterized using a data set acquired by the NASA JPL AIRSAR sensor [J349]

"An improved pulse-basis conjugate gradient FFT method for the thin conducting plate problem"

A conjugate-gradient fast Fourier transform (CG-FFT) formulation for the scattering by a thin, perfectly conducting plate is presented. Pulse basis functions and a Dirac δ function are used for expansion and testing purposes, respectively. Particular attention is paid to the generation of the terms in the impedance matrix of the resulting matrix equation. Except for the self-coupling terms, all the other terms are computed by explicit

integrations. Comparison with two previously reported pulse-basis CG-FFT formulations shows that the present method is more stable when the error tolerance of the solution is reduced. When sufficient cell discretizations are used, smooth distributions can be obtained which resemble those obtained via rooftop-CG-FFT formulation. The numerical results are further validated by comparing the far-field radar cross section with an analytical technique for a circular plate [J350]

"Symmetrization of cross-polarized responses in polarimetric radar images using reciprocity"

A new method for symmetrizing polarimetric scattering matrices is applied to the polarimetric synthetic aperture radar (SAR) images acquired over Mount Shasta. This method symmetrizes the cross-polarized responses in the polarimetric images using a 2Ч2 matrix derived from the image itself and based on the reciprocal property of natural distributed targets. The covariance parameters of the in-scene trihedral reflectors are presented to demonstrate the effectiveness of this method. The results are also compared with those obtained by the symmetrization technique employed by POLCAL, before and after crosstalk removal. Before crosstalk is removed from the images, there were no significant differences between the results obtained by the POLCAL method and the new method for the covariance parameters of trihedral reflectors. After crosstalk removal, using distributed targets with reflection symmetry, the new symmetrization method outperformed the POLCAL method [J351]

"Statistical properties of the Mueller matrix of distributed targets"

The scattering matrix measured in the backscattering direction by a polarimetric radar system consists of five quantities: |Svv|, |Shh|, and |Shv|, which are the magnitudes of the linearly polarised scattering amplitudes, and φcand φx, which are the co-polarised and crosspolarised phase angles. The co-polarised phase angle φcis shown to exhibit a probability density function (PDF) that is characterised completely by two parameters α and ζ, both of which are related to the elements of the Mueller matrix of the target. The parameter α governs the width of the PDF and ζ governs the mean value of φ c. It is further shown that the three magnitudes |Svv|, |Shh|, and |Shv| and the two parameters α and ζ completely specify the Mueller matrix, and therefore contain all the statistical information available from the polarimetric backscatter response of the target. These results are verified with experimental observations that show that α and ζ are related to the physical and dielectric properties of soil and vegetation targets [J352]

"Accuracy of 3-D radiation boundary conditions for use with the vector Helmholtz equation"

Radiation boundary conditions developed for use with the vector Helmholtz equation in three dimensions are reviewed, including an alternate second-order radiation condition that preserves the symmetry of the matrix operator arising within a numerical implementation. The accuracy of these conditions is systematically tested as a function of the boundary location using outward-propagating spherical harmonics [J353]

"Calibration of wide-band polarimetric measurement system using three perfectly polarization-isolated calibrators"

An improved calibration method for a wideband polarimetric measurement system using three partly unknown, perfectly polarization-isolated calibrators is presented, with experimental results measured from 7 to 17 GHz. The cross-polarized information is provided by rotating the third calibrator to an arbitrary angle with respect to the radar range direction. Only the copolarization terms in the polarimetric scattering matrix (PSM) of the first calibrator are required to be specified. The copolarized scattering properties, including the range information of the other two calibrators and the rotation angle of the third calibrator, can be acquired in the calibration process and used to verify the calibration accuracy [J354]

"The numerical calculation of rough surface scattering by the conjugate gradient method"

The conjugate gradient method has been used to compute the solutions of the magnetic field integral equation for two-dimensional, perfectly conducting, Gaussian, rough surfaces. For surfaces whose roughness is of similar order to the incident wavelength, the rate of convergence of the conjugate gradient method is controlled by the RMS surface slope. In some cases, solutions are obtained with a significant reduction in the computation that direct methods require. Using the solution, the scattered field in the vicinity of the surface was calculated, and it is shown that the scattered field satisfies the extinction theorem to a good approximation [J355]

"Calibration of a polarimetric imaging SAR"

Calibration using point targets is discussed. The fourport network calibration technique is used to describe the radar error model. The processor ambiguity function and the radar distortion matrices are combined to form a generalized polarimetric ambiguity function. The polarimetric ambiguity function of the SAR is found using a

single point target, namely a trihedral corner reflector. Based on the resultant polarimetric ambiguity function, an estimate for the backscattering coefficient of the terrain is found using a modified version of the single target calibration technique (STCT). A radar image recorded by the JPL aircraft SAR, which includes a variety of point targets, is used for verification of the new calibration method. The calibrated responses of the point targets are compared both with theory and responses based on the POLCAL technique [J356]

"Calibration of Stokes and scattering matrix format polarimetric SAR data"

It is shown that the assumptions about the backscatter and the polarimetric radar system for the two approaches described in J.D. Klein's (1992) and J.J. van Zyl's (1990) papers are equivalent. It is demonstrated that, to first order in the radar system crosstalk (i.e. neglecting terms of second order and above), an exact solution to the Stokes matrix format data calibration problem exists. It is shown that van Zyl's approach can give this first-order solution for appropriately symmetrized polarimetric radar data. Then it is shown how, if the data are properly symmetrized, van Zyl's approach can be used to calibrate both scattering matrix and Stokes matrix format data. These conclusions should be generally applicable to polarimetric imaging radar system data [J357]

"Circular polarization for remote sensing of precipitation: polarization diversity work at the National Research Council of Canada"

The precipitation radar work carried out at Ottawa, Ontario, by the National Research Council of Canada (NRC), using dual-channel circularly-polarized radars, is described. This work, and concurrent work by NRC on weather clutter suppression for centimeter-wavelength military radars, included both theory and equipment developments. The discussion covers the early years (1956-66), the NRC Ku-band precipitation radar (1966-80), apparatus built and operated by NRC for scattering-matrix measurements, the NRC X-band precipitation radar (1981-6), and polarization switching and rotation studies [J358]

"Electromagnetic transmission through inhomogeneously filled slots in a thick conducting plane-arbitrary incidence"

The penetration of an arbitrarily incident electromagnetic wave through a slot filled with inhomogeneous material in a thick conducting plane is analyzed. The solution is obtained via a combined finite-element method/method of moments algorithm based on the generalized network formulation. The discretization of the generalized network formulation is performed via the method of moments. The finite-element method is then used to compute the fields within the inhomogeneous interior cavity region, leading to the construction of the interior aperture admittance matrix. It is shown that with the use of entire domain basis functions, the construction of the aperture admittance matrices is computationally efficient. Furthermore, this method is attractive since it preserves the sparsity of the finite-element method matrix, reducing computational memory requirements. Some examples of the penetration of inhomogeneously filled slots of various cross sections are presented [J359]

"On characteristic polarization states in the cross-polarized radar channel"

The characteristic polarization states in the cross-polarized radar channel for the monostatic reciprocal case is derived based on a Stokes vector formulation. The optimization procedure for the channel power leads to an eigenvalue equation which explains the characteristic polarization state properties mathematically and physically. The method is illustrated for a hypothetical target [J360]

"Polarimetric discriminators for SAR images"

A method is developed for optimizing the degree of polarization of a partially polarized wave reflected by a nonstationary scattering object. The method permits, for a scattered wave and a given target characterized by its Mueller matrix, analytic computation of the maximum and minimum values of the degree of polarization, and the corresponding transmitted polarizations. A procedure for the optimization of the scattered wave intensity is also proposed. The degree of polarization and the total scattered intensity extrema are then analyzed experimentally on JPL data. It is shown that several entities such as the received intensity extrema, the coefficient of variation, the fractional polarization and the span, which are currently used for target discrimination, can be deduced from combinations of the maximum and minimum values of the degree of polarization and the scattered wave intensity. Finally, a classification of the San Francisco image, based on these indices, is conducted for a better understanding of the specific physical meaning of each index [J361]

"Measurement and calibration of differential Mueller matrix of distributed targets"

A rigorous method is presented for calibrating polarimetric backscatter measurements of distributed targets. By characterizing the radar distortions over the entire mainlobe of the antenna, the differential Mueller matrix is

derived from the measured scattering matrices with a high degree of accuracy. It is shown that the radar distortions can be determined by measuring the polarimetric response of a metallic sphere over the main lobe of the antenna. The radar distortions are categorized as distortions caused by the active devices or distortions caused by the antenna structure (passive). Since passive distortions are immune to changes once they are determined, they can be used repeatedly. The active distortions can be obtained by measuring the sphere response only at boresight, reducing the time required for calibration under field conditions. The calibration algorithm was applied to backscatter data collected from a rough surface. The results indicate that removal of the radar distortions from the cross products of the scattering matrix elements cannot be accomplished with traditional calibration methods [J362]

"Performance characterization of polarimetric active radar calibrators and a new single antenna design"

Several topics associated with the use of a polarimetric active radar calibrator (PARC), which is a high radar-cross-section transponder with a known scattering matrix, are addressed. The first involves experimental measurements of the magnitudes and phases of the scattering-matrix elements of a pair of PARCs that operate at 1.25 GHz and 5.3 GHz. The measurements were conducted over a wide range of incidence angles (relative to the boresight direction) in the azimuth, elevation, 45°, and 135° planes. The 5.3-GHz PARC, which consisted of two antennas placed several wavelengths apart, exhibited symmetrical patterns with no ripples and excellent isolation between orthogonal polarization channels. The 1.25-GHz PARC, whose antennas were in very close proximity to one another, exhibited unsymmetrical patterns as well as ripples in the phase patterns, thereby introducing errors in the elements of the scattering matrix. To avoid this problem, a single-antenna PARC is designed,, using an orthomode transducer. The single-target calibration technique is extended so that it applies to the use of a PARC as well as reciprocal passive calibration devices such as spheres and trihedral corner reflectors [J363]

"Some limitations on the effectiveness of airborne adaptive radar"

It is shown that internal clutter motion, aircraft crabbing, scattering from near-field obstacles, and channel mismatch can limit the effectiveness of space-time processing in eliminating airborne clutter. An analytical expression is developed to show how each of these effects produces a deterioration in the signal-to-clutter-plus-noise ratio achievable. By studying the spectral decomposition of the covariance matrix, it is found that the effects of both internal clutter motion and crabbing can either be compensated by artificially adding noise or by processing more pulses. A near-field obstacle produces a spread of the clutter into all of sine azimuth-Doppler space. It is shown that the space-time processor attempts to compensate for this effect by placing a near-field null on the obstacle. Thus, adding more elements is much more effective in eliminating this effect than is processing more pulses. Channel mismatch can be alleviated by controlling the dispersive errors more tightly and by increasing the number of receive elements [J364]

"Scattering from a finite array of microstrip patches"

A full-wave solution to the problem of plane wave scattering by a finite array of rectangular microstrip patches printed on a grounded dielectric slab is presented. The electric field integral equation is solved using the spectral-domain Green's function/moment method approach. Derivations for the elements of the impedance and voltage matrices are presented. An efficient massively parallel computer implementation of the moment method solution is described. Computed radar cross section (RCS) data for microstrip patch antenna arrays are presented as a function of incident signal frequency and angle of incidence [J365]

"Numerical solution of integral equations for dielectric objects of prismatic shapes"

A numerical method to investigate scattering from dielectric geometries of prismatic shapes has been developed. The surface integral equations are formulated by Schelkunoff's equivalence principle in terms of equivalent surface electric and magnetic currents. To solve these integral equations for the unknown currents, the object's cross-section is mapped onto a circle. In the transformed space, Fourier type entire-domain basis functions are used in the cross section and triangular subdomain basis functions are selected along the generating curve to represent the currents. A moment method is then used to reduce the integral equations to a matrix equation to compute the current coefficients. It is found that the transformation of the object's surface to a circular shape improves the convergence of the current mode in the cross-section. However, the current modes are coupled on the surface and the matrix equation includes all the modes [J366]

"Polarimetric signatures of a layer of random nonspherical discrete scatterers overlying a homogeneous half-space based on first- and second-order vector radiative transfer theory

[Jgeophysical radar remote sensing]"

Complete polarimetric signatures of a layer of random, nonspherical discrete scatterers overlying a homogeneous half space are studied with the first- and second-order solutions of the vector radiative transfer theory. The vector radiative transfer equation contains a general nondiagonal extinction matrix and a phase matrix that are averaged over particle orientations. The nondiagonal extinction matrix accounts for the difference in propagation constants and the difference in attenuation rates between the two characteristic polarisations. The Mueller matrix based on the first-order and second-order multiple scattering solutions of the vector radiative transfer equation is calculated. The copolarized and depolarized returns are also calculated [J367]

"TE-scattering from dense homogeneous infinite dielectric cylinders of arbitrary cross-section"

A numerical approach to obtain the fields scattered by a homogeneous dielectric cylinder of arbitrary cross section which is illuminated by a TE plane wave is presented. The equivalence theorem is used to transform the problem of solving Maxwell's equations in the whole space, subject to the conditions imposed by the presence of the cylinder and the incident field, into an operator equation for the volume polarization currents in the cylinder. A set of expansion functions is then used to solve the problem using Galerkin's technique. These expansion functions are obtained by dividing the cylinder cross-section into a number of triangular patches and defining, for each node in the mesh of triangles, a basis function which depends on the dimensions of the triangles attached to it. This basis function is divergence-free for all the internal nodes, with surface charges associated to the external nodes only. The computed results include the radar cross sections. Several geometries are studied, and the computed results are compared with exact or numerical results. [J368]

"Scattering from structured slabs having two-dimensional periodicity"

The problem of a plane wave incident on a structured slab is examined. To analyze the problem, an electric field integral equation (EFIE) is derived that has as its unknown the equivalent surface currents on the plates in the unit cell. The integral equation is discretized and solved approximately using the method of moments with subdomain basis and testing functions. The periodic Green's function is efficiently calculated using the Poisson summation formula. The interaction of the structure with the surrounding environment is described in terms of a generalized scattering matrix. Results are presented showing the reflection coefficient as a function of frequency for arrays of zigzagging strips and honeycomb slabs [J369]

"Polarimetric scattering from natural surfaces at 225 GHz"

Polarimetric radar measurement at 225 GHz which demonstrate that the normalized Mueller matrix may be approximated in terms of a single parameter are presented. The depolarization ratio, defined as the ratio of cross-polarized to co-polarized normalized radar cross section, is shown to accurately predict backscatter from vegetation (trees and grass), as well as scattering from terrain at low incidence angles (snowcover and sand). The depolarization ratio also predicts the standard deviation of the scattered field ellipse parameters [J370]

"Data volume reduction for single-look polarimetric imaging radar data"

An 8-b quantization scheme to reduce the data volume for single-look complex scattering matrix data measured by polarimetric imaging radar systems is described. The scattering matrices are not symmetrized before compression, thereby retaining information about background noise and system effects. The data volume is reduced by a factor of 3.2. It is shown, with measured data, that the signal to quantization noise ratio for the compression scheme is more than 35 dB for the cross-polarized channels, and more than 45 dB for the copolarized channels [J371]

"Effects of signal decorrelation on pulse-compressed waveforms for nadir-looking spaceborne radar"

Pulse-compressed waveforms for partially coherent radar return signals are formulated with an incoherent-scatter autocorrelation function, $\rho(\tau)$. Numerical calculations are made for a nadir-looking spaceborne radar with linear FM pulses, and effects of signal decorrelation on the compressed waveforms are qualitatively evaluated. The calculations indicate that the transmitted pulse width should be shorter than half the correlation time, defined as the time at which $\rho(\tau)$ decreases by 0.1, in order to keep signal decorrelation effects negligible [J372]

"Matrix interpretation of the spectral iteration technique for 3D dielectric scatterers in the resonance region"

The matrix interpretation of the spectral iteration technique (MSIT) has recently been shown to provide rapid

convergence for the electromagnetic problems associated with 2D homogeneous dielectric scatterers in the resonance region for both TM and TE incidence. The MSIT is presented in a form suitable for use on 3D homogeneous dielectric and lossy-dielectric scatterers. Rapid convergence on test problems in the resonance region is demonstrated with significantly fewer than 3square root (N) iterations, where N is the number of unknowns, needed for electrically large scatterers. The bistatic RCS computed from the MSIT for spheres with a range of permittivities and diameters up to 2 lambda 0are shown to be in good agreement with analytic solutions. Current distributions from some initial tests on lossy-dielectric thin plates show well-behaved and symmetric results. [J373]

"A new system model for radar polarimeters"

The validity of the 2Ч2 receive Rand transmit Tmodel for radar polarimeter systems, first proposed by H. Zebker et al. (1987), is questioned. The model is found to be invalid for many practical realizations of radar polarimeters, which can lead to significant errors in the calibration of polarimetric radar images. A more general model is put forward, which addresses the system defects which cause the 2Ч2 model to break down. By measuring one simple parameter from a polarimetric active radar calibration (PARC), it is possible to transform the scattering matrix measurements made by a radar polarimeter to a format compatible with a 2Ч2 Rand T matrix model. Alternatively, the PARC can be used to verify the validity of the 2Ч2 model for any polarimetric radar system. Recommendations for the use of PARCs in polarimetric calibration and to measure the orientation angle of the horizontal (H) and vertical (V) coordinate system are also presented [J374]

"Time domain analysis by the point-matched finite element method"

The solution of Maxwell's equations using the point-matched finite-element time-domain approach is presented. The solution scheme is explicit and does not require the solution of any matrix equations. The solution is carried out over a finite domain terminated using appropriate absorbing boundary conditions. Far-field quantities are obtained from the near-field solution by first computing the frequency-domain solutions from the time-domain solution using the fast Fourier transform and then using a near-field to far-field transformation algorithm. [J375]

"A radar backscatter model for discontinuous coniferous forests"

A radar backscattering model for low-to-medium-density woodland in which each tree is treated as an individual backscatterer is described. A forest stand viewed by radar is then an assemblage of scatterers standing on a background in a certain spatial pattern. The backscattering components arising from the various intersections of radar beams with the forest stand are calculated separately, and their Stokes matrices are then added together to achieve the Stokes matrix for total backscattering. Probabilities of radar beams intersecting tree crowns are introduced into the model [J376]

"Physical optics polarization scattering matrix for a top hat reflector"

The polarization scattering matrix for a cylinder on a circular disk is derived subject to the physical optics (PO) approximation. The multiple scattering between the cylinder and the circular disk ground plane is obtained by invoking image theory, and is expressed as a bistatic return from the cylinder and its image, due to the image field. Results for a particular case are evaluated and compared with measurements [J377]

"A general polarimetric radar calibration technique"

A polarimetric radar calibration procedure is introduced and verified with experimental results. The procedure requires measurements of three known targets in order to determine the distortion matrices that characterize the effect of the measurement system on the transmitted and received waves. The scattering matrices for the known targets can be of any form, provided that a limited set of constraints is satisfied. A special case, wherein the transmit and receive distortion matrices are the transpose of each other, is considered. This case is useful for some single antenna systems and has the advantage that only two known targets are required [J378]

"Radar target identification of aircraft using polarization-diverse features"

The characteristics and target identification potential of a representation of the information from two polarization-diverse measurements of the radar backscatter of an unknown target are considered. The locus of these two polarization-diverse waveforms, termed the transient polarization response (TPR), has been shown to be closely related to the geometry of the scattering centers of the target. The polarization-related components of features derived from the TPR concur well with the shape and orientation of the major scattering centers distributed in the downrange profile of the object. This illustrates the intuitively appealing result that the polarization of the backscatter, as represented by the TPR and mapped onto the modified polarization chart, is determined by

target geometry. It is shown that both polarization-related and amplitude-related features derived from the TPR are useful for target identification. By using distance measures that depend on various components, the elliptical parametrization information alone is sufficient to allow satisfactory target identification at SNRs of 0 dB and above. The significance of this result is that the absolute amplitudes of the received horizontally polarized and vertically polarized channels need not be known. However, if amplitude information is known, target identification percentages improve [J379]

"Polarimetric backscatter measurements of deciduous and coniferous trees at 225 GHz"

Polarimetric radar measurements of foliage made in the 220-GHz transmission window are described. A noncoherent, 60-W-peak-power polarimetric radar was used to measure the target Mueller matrix directly by measuring the scattered polarization state for either four or six incident polarizations. Measurements of deciduous trees indicate that waves scattered from erectophil trees (vertically oriented leaves) are more highly polarized than waves scattered from planophil trees (horizontally oriented leaves) for near-grazing incidence angles. White pine trees, which have thin needles, where the least polarized of all trees studied. A comparison of the Mueller matrices of 11 independent footprints taken from seven white pine trees showed a high degree of consistency between measurements [J380]

"On the basic principles of radar polarimetry: the target characteristic polarization state theory of Kennaugh, Huynen's polarization fork concept, and its extension to the partially polarized case"

Basic principles of radar polarimetry are introduced. The target characteristic polarization state theory is developed first for the coherent case using the three stage, the basis transformation, and the power (Mueller) matrix optimization procedures. Kennaugh's and Huynen's theories of radar target polarimetry are verified for the monostatic reciprocal case. It is shown that there exist, in total, five unique pairs of characteristic polarization states for the symmetric scattering matrix of which two pairs, the cross-polarization null and copolarization max pairs, are identical, whereas the cross-pol max and the cross-pol saddlepoint pairs are distinct. The theory is verified by an example for which next to the polarization fork the copolarized and cross-polarized power density plots are also presented. The partially polarized case for completely polarized wave incidence is presented and compared with the results for the coherent and the partially coherent cases, the latter of which is still unresolved [J381]

"Method of moment solutions to scattering problems in a parallel processing environment"

Describes the implementation of a parallelized method of moments (MOM) code into an interactive workstation environment. The workstation allows interactive solid body modeling and mesh generation, MOM analysis, and the graphical display of results. After describing the parallel computing environment, the implementation and results of parallelizing a general MOM code are presented in detail. [J382]

"Analysis of heterogeneous electromagnetic scatterers: research progress of the past decade"

A review of the current status of integral equation and finite element (FEM) (including time domain) modeling as applied particularly to penetrable bodies is provided. The direct numerical solution of the appropriate frequency-domain partial differential equations is an alternative that has recently been the focus of much effort by the research community and appears to offer computational advantages over the integral equation formulations. These frequency-domain approaches require the solution of a matrix equation; the direct time-domain solution of partial differential equations offers a third formulation that does not require a matrix solution and may be more efficient for electrically large structures. The author summarizes the development of these modeling procedures and attempts to identify some of the unresolved issues associated with their development [J383]

"PDE techniques for solving the problem of radar scattering by a body of revolution"

The authors discuss two partial differential equation (PDE) techniques, namely the finite difference (FD) method and the finite element method (FEM), for solving the problem of radar scattering by a body of revolution (BOR). The formulation of the BOR problem is based upon the use of the coupled azimuthal potentials (CAPs), introduced by M.A. Morgan et al. (1977), that allow one to reduce the vector field problem to the solution of two coupled scalar wave equations. An approach to FD/FEM mesh truncation is developed on the basis of a multipole representation for the CAPs in the asymptotic region. Numerical results are presented for some representative geometries to illustrate the application of the PDE methods and some observations regarding the comparative performance of the two methods are included [J384]

СПИСОК ЛИТЕРАТУРЫ

J1. Alvarez-Perez J.L. Coherence, Polarization, and Statistical Independence in Cloude-Pottier's Radar Polarimetry. IEEE Transactions on Geoscience and Remote Sensing. - 2011. - Vol. 49, No. 1. - P. 426-441.

J2. Sharma J.J. Polarimetric Decomposition Over Glacier Ice Using Long-Wavelength Airborne PolSAR. / Sharma J.J., Hajnsek I., Papathanassiou K.P., Moreira A. // IEEE Transactions on Geoscience and Remote Sensing. - 2011. - Vol. 49, No. 1. - P. 519-535.

J3. Lei Zhang. Modeling PSInSAR Time Series Without Phase Unwrapping. / Lei Zhang, Xiaoli Ding, Zhong Lu. // IEEE Transactions on Geoscience and Remote Sensing. - 2011. - Vol. 49, No. 1. - P. 547-556.

J4. Jong-Sen Lee. The Effect of Orientation Angle Compensation on Coherency Matrix and Polarimetric Target Decompositions. / Jong-Sen Lee, Ainsworth T.L. // IEEE Transactions on Geoscience and Remote Sensing. - 2011. - Vol. 49, No. 1. - P. 53-64.

J5. Wei Yang. Electromagnetic Modeling of Breaking Waves at Low Grazing Angles With Adaptive Higher Order Hierarchical Legendre Basis Functions. / Wei Yang, Zhiqin Zhao, Conghui Qi, Zaiping Nie. // IEEE Transactions on Geoscience and Remote Sensing. - 2011. - Vol. 49, No. 1. - P. 346-352.

J6. Heldring A. Multiscale Compressed Block Decomposition for Fast Direct Solution of Method of Moments Linear System. / Heldring A., Rius J.M., Tamayo J.M., Parro,n J., Ubeda E. // IEEE Transactions on Antennas and Propagation. - 2011. - Vol. 59, No. 2. - P. 526-536.

J7. Arii M. Adaptive Model-Based Decomposition of Polarimetric SAR Covariance Matrices. / Arii M., van Zyl J.J., Yunjin Kim. // IEEE Transactions on Geoscience and Remote Sensing. - 2011. - Vol. 49, No. 3. - P. 1104-1113.

J8. Peng-Lang Shui. Range-Spread Target Detection using Consecutive HRRPs. / Peng-Lang Shui, Shu-Wen Xu, Hong-Wei Liu. // IEEE Transactions on Aerospace and Electronic Systems. - 2011. - Vol. 47, No. 1. - P. 647-665.

J9. Sen S. Multiobjective Optimization of OFDM Radar Waveform for Target Detection. / Sen S., Gongguo Tang, Nehorai A. // IEEE Transactions on Signal Processing. - 2011. - Vol. 59, No. 2. - P. 639-652.

J10. Alkan E. Dual-Grid Finite-Difference Frequency-Domain Method for Modeling Chiral Medium. / Alkan E., Demir V., Elsherbeni A.Z., Arvas E. // IEEE Transactions on Antennas and Propagation. - 2010. - Vol. 58, No. 3. - P. 817-823.

J11. Gherboudj I. A Backscatter Modeling for River Ice: Analysis and Numerical Results. / Gherboudj I., Bernier M., Leconte R. // IEEE Transactions on Geoscience and Remote Sensing. - 2010. - Vol. 48, No. 4. - P. 1788-1798.

J12. Asvestas J.S. Calculation of the Impedance Matrix Inner Integral to Prescribed Precision. / Asvestas J.S., Yankovich S.P., Allen O.E. // IEEE Transactions on Antennas and Propagation. - 2010. - Vol. 58, No. 2. - P. 479-487.

J13. Fangyuan Nan. Reconstruction of GPR Signals by Spectral Analysis of the SVD Components of the Data Matrix. / Fangyuan Nan, Siyong Zhou, Yaonan Wang, Fuhai Li, Weifeng Yang. // IEEE Geoscience and Remote Sensing Letters. - 2010. - Vol. 7, No. 1. - P. 200-204.

J14. Gogineni S. Polarimetric MIMO Radar With Distributed Antennas for Target Detection. / Gogineni S., Nehorai A. // IEEE Transactions on Signal Processing. - 2010. - Vol. 58, No. 3. - P. 1689-1697.

J15. Dawei Liu. Three-Dimensional Coherent Radar Backscatter Model and Simulations of Scattering Phase Center of Forest Canopies. / Dawei Liu, Guoqing Sun, Zhifeng Guo, Ranson K.J., Yang Du. // IEEE Transactions on Geoscience and Remote Sensing. - 2010. - Vol. 48, No. 1. - P. 349-357.

J16. Ballester-Berman J.D. Applying the Freeman-Durden Decomposition Concept to Polarimetric SAR

Interferometry. / Ballester-Berman J.D., Lopez-Sanchez J.M. // IEEE Transactions on Geoscience and Remote Sensing. - 2010. - Vol. 48, No. 1. - P. 466-479.

J17. Dufva T. Scattering Model for a Pine Tree Employing VIE With a Broadband MLFMA and Comparison to ICA. / Dufva T., Praks J., Jarvenpaa S., Sarvas J. // IEEE Transactions on Geoscience and Remote Sensing. - 2010. - Vol. 48, No. 3. - P. 1119-1127.

J18. Neumann M. Estimation of Forest Structure, Ground, and Canopy Layer Characteristics From Multibaseline Polarimetric Interferometric SAR Data. / Neumann M., Ferro-Famil L., Reigber A. // IEEE Transactions on Geoscience and Remote Sensing. - 2010. - Vol. 48, No. 3. - P. 1086-1104.

J19. Chen Q. Polarimetric Scattering Similarity Between a Random Scatterer and a Canonical Scatterer. / Chen Q., Jiang Y.M., Zhao L.J., Kuang G.Y. // IEEE Geoscience and Remote Sensing Letters. - 2010. - Vol. 7, No. 4. - P. 866-869.

J20. Orlando D. A Rao Test With Enhanced Selectivity Properties in Homogeneous Scenarios. / Orlando D., Ricci G. // IEEE Transactions on Signal Processing. - 2010. - Vol. 58, No. 10. - P. 5385-5390.

J21. Chen M.S. Fast computation of radar cross-section by fast multipole method in conjunction with lifting wavelet-like transform. / Chen M.S., Sha W.E.I., Wu Q., Huang Z.X., Wu X.L. // IET Microwaves, Antennas & Propagation. - 2010. - Vol. 4, No. 12. - P. 2219-2227.

J22. Sadjadi Firooz A. Finding Underground Targets by Means of Change-Detection Methods in Huynen Spaces. / Sadjadi Firooz A., Sullivan Anders, Gaunaurd Guillermo C. // IEEE Transactions on Aerospace and Electronic Systems. - 2010. - Vol. 46, No. 3. - P. 1404-1421.

J23. Hongwei Gao. Micro-Doppler Signature Extraction from Ballistic Target with Micro-Motions. / Hongwei Gao, Lianggui Xie, Shuliang Wen, Yong Kuang. // IEEE Transactions on Aerospace and Electronic Systems. - 2010. - Vol. 46, No. 4. - P. 1969-1982.

J24. Wentao An. Three-Component Model-Based Decomposition for Polarimetric SAR Data. / Wentao An, Yi Cui, Jian Yang. // IEEE Transactions on Geoscience and Remote Sensing. - 2010. - Vol. 48, No. 6. - P. 2732-2739.

J25. Yao Yu. MIMO Radar Using Compressive Sampling. / Yao Yu, Petropulu A.P., Poor H.V. // IEEE Journal of Selected Topics in Signal Processing. - 2010. - Vol. 4, No. 1. - P. 146-163.

J26. Fan Z.H. Preconditioning Matrix Interpolation Technique for Fast Analysis of Scattering Over Broad Frequency Band. / Fan Z.H., Liu Z.W., Ding D.Z., Chen R.S. // IEEE Transactions on Antennas and Propagation. - 2010. - Vol. 58, No. 7. - P. 2484-2487.

J27. Arii M. A General Characterization for Polarimetric Scattering From Vegetation Canopies. / Arii M., van Zyl J.J., Yunjin Kim. // IEEE Transactions on Geoscience and Remote Sensing. - 2010. - Vol. 48, No. 9. - P. 3349-3357.

J28. Ioannidou M.P. EM-Wave Scattering by an Axial Slot on a Circular PEC Cylinder With an Eccentrically Layered Inner Coating: A Dual-Series Solution for TE Polarization. IEEE Transactions on Antennas and Propagation. - 2009. - Vol. 57, No. 11. - P. 3512-3519.

J29. Morio J. A Characterization of Shannon Entropy and Bhattacharyya Measure of Contrast in Polarimetric and Interferometric SAR Image. / Morio J., Refregier P., Goudail F., Dubois-Fernandez P.C., Dupuis X. // Proceedings of the IEEE. - 2009. - Vol. 97, No. 6. - P. 1097-1108.

J30. Liu Tao. Statistics of the Polarimetric Weibull-Distributed Electromagnetic Wave. / Liu Tao, Huang Gao-ming, Wang Xue-song, Xiao Shun-ping. // IEEE Transactions on Antennas and Propagation. - 2009. - Vol. 57, No. 10. - P. 3232-3248.

J31. Anfinsen S.N. Estimation of the Equivalent Number of Looks in Polarimetric Synthetic Aperture Radar Imagery. / Anfinsen S.N., Doulgeris A.P., Eltoft T. // IEEE Transactions on Geoscience and Remote Sensing. - 2009. - Vol. 47, No. 11. - P. 3795-3809.

J32. Jiade Yuan. Efficient Generation of Method of Moments Matrices Using Equivalent Dipole-Moment

Method. / Jiade Yuan, Changqing Gu, Guodong Han. // IEEE Antennas and Wireless Propagation Letters. - 2009. - Vol. 8, {no data available}. - P. 716-719.

J33. Gaobiao Xiao. Generalized Transition Matrix for Arbitrarily Shaped Scatterers With Composite Structures. / Gaobiao Xiao, Jun-Fa Mao. // IEEE Transactions on Electromagnetic Compatibility. - 2009. - Vol. 51, No. 2. - P. 401-405.

J34. Cameron W.L. Polarization Symmetric Scatterer Metric Space. / Cameron W.L., Rais H. // IEEE Transactions on Geoscience and Remote Sensing. - 2009. - Vol. 47, No. 4. - P. 1097-1107.

J35. Praks J. Using Multilook Averaging for Coherently Modeled Scattering From a Pine Tree at L-Band. / Praks J., Sarvas J., Hallikainen M., Pulliainen J. // IEEE Geoscience and Remote Sensing Letters. - 2009. - Vol. 6, No. 1. - P. 162-166.

J36. Jin-Jun Xiao. Joint Transmitter and Receiver Polarization Optimization for Scattering Estimation in Clutter. / Jin-Jun Xiao, Nehorai A. // IEEE Transactions on Signal Processing. - 2009. - Vol. 57, No. 10. - P. 4142-4147.

J37. Mackenzie A.I. Electromagnetic Scattering From Arbitrarily Shaped Dielectric Bodies Using Paired Pulse Vector Basis Functions and Method of Moments. / Mackenzie A.I., Rao S.M., Baginski M.E. // IEEE Transactions on Antennas and Propagation. - 2009. - Vol. 57, No. 7. - P. 2076-2083.

J38. Aldhubaib F.F.H. Characteristic Polarization States Estimation in an Ultrawideband Context: A Frequency Approach. / Aldhubaib F.F.H., Shuley N.V.Z. // IEEE Transactions on Geoscience and Remote Sensing. - 2009. - Vol. 47, No. 8. - P. 2808-2817.

J39. Qiuzhao Dong. Microwave Subsurface Imaging Using Direct Finite-Difference Frequency-Domain-Based Inversion. / Qiuzhao Dong, Rappaport C.M. // IEEE Transactions on Geoscience and Remote Sensing. - 2009. - Vol. 47, No. 11. - P. 3664-3670.

J40. Migliaccio M. The PALSAR Polarimetric Mode for Sea Oil Slick Observation. / Migliaccio M., Gambardella A., Nunziata F., Shimada M., Isoguchi O. // IEEE Transactions on Geoscience and Remote Sensing. - 2009. - Vol. 47, No. 12. - P. 4032-4041.

J41. Guifu Zhang. Phased Array Radar Polarimetry for Weather Sensing: A Theoretical Formulation for Bias Corrections. / Guifu Zhang, Doviak R.J., Zrnic D.S., Crain J., Staiman D., Al-Rashid Y. // IEEE Transactions on Geoscience and Remote Sensing. - 2009. - Vol. 47, No. 11. - P. 3679-3689.

J42. Secmen M. Radar target classification method with reduced aspect dependency and improved noise performance using multiple signal classification algorithm. / Secmen M., Turhan-Sayan G. // IET Radar, Sonar & Navigation. - 2009. - Vol. 3, No. 6. - P. 583-595.

J43. Gladkova I. Analysis of Stepped-Frequency Pulse Train Design. IEEE Transactions on Aerospace and Electronic Systems. - 2009. - Vol. 45, No. 4. - P. 1251-1261.

J44. Martorella M. Automatic Target Recognition by Means of Polarimetric ISAR Images and Neural Networks. / Martorella M., Giusti E., Capria A., Berizzi F., Bates B. // IEEE Transactions on Geoscience and Remote Sensing. - 2009. - Vol. 47, No. 11. - P. 3786-3794.

J45. Qiang Chen. An Optimization Procedure of the Lagrange Multiplier Method for Polarimetric Power Optimization. / Qiang Chen, Yong-Mei Jiang, Ling-Jun Zhao, Gui Gao, Gang-Yao Kuang. // IEEE Geoscience and Remote Sensing Letters. - 2009. - Vol. 6, No. 4. - P. 699-702.

J46. Laviada J. Solution of Electrically Large Problems With Multilevel Characteristic Basis Functions. / Laviada J., Las-Heras F., Pino M.R., Mittra R. // IEEE Transactions on Antennas and Propagation. - 2009. - Vol. 57, No. 10. - P. 3189-3198.

J47. Yonghong Zhang. A New Numerical Method for Calculating Extrema of Received Power for Polarimetric SAR. / Yonghong Zhang, Jixian Zhang, Zhong Lu, Wenyu Gong. // IEEE Geoscience and Remote Sensing Letters. - 2009. - Vol. 6, No. 4. - P. 666-670.

J48. Tebaldini S. Algebraic Synthesis of Forest Scenarios From Multibaseline PolInSAR Data. IEEE Transactions on Geoscience and Remote Sensing. - 2009. - Vol. 47, No. 12. - P. 4132-4142.

J49. De Maio A. Knowledge-aided covariance matrix estimation: a MAXDET approach. / De Maio A., De Nicola S., Landi L., Farina A. // IET Radar, Sonar & Navigation. - 2009. - Vol. 3, No. 4. - P. 341-356.

J50. Chiniard R. Hybrid FEM/Floquet Modes/PO Technique for Multi-Incidence RCS Prediction of Array Antennas. / Chiniard R., Barka A., Pascal O. // IEEE Transactions on Antennas and Propagation. - 2008. - Vol. 56, No. 6. - P. 1679-1686.

J51. Yajima Y. POLSAR Image Analysis of Wetlands Using a Modified Four-Component Scattering Power Decomposition. / Yajima Y., Yamaguchi Y., Sato R., Yamada H., Boerner W.-M. // IEEE Transactions on Geoscience and Remote Sensing. - 2008. - Vol. 46, No. 6. - P. 1667-1673.

J52. Bon N. GLRT subspace detection for range and Doppler distributed targets. / Bon N., Khenchaf A., Garello R. // IEEE Transactions on Aerospace and Electronic Systems. - 2008. - Vol. 44, No. 2. - P. 678-696.

J53. Delgado C. Efficient Multilevel Approach for the Generation of Characteristic Basis Functions for Large Scatters. / Delgado C., Catedra M.F., Mittra R. // IEEE Transactions on Antennas and Propagation. - 2008. - Vol. 56, No. 7. - P. 2134-2137.

J54. Lucente E. An Iteration-Free MoM Approach Based on Excitation Independent Characteristic Basis Functions for Solving Large Multiscale Electromagnetic Scattering Problems. / Lucente E., Monorchio A., Mittra R. // IEEE Transactions on Antennas and Propagation. - 2008. - Vol. 56, No. 4. - P. 999-1007.

J55. Giusti E. Equivalence Between Cameron's Unit Disc and PoincarЙ's Sphere for Symmetric Scattering Characterization and Classification. / Giusti E., Martorella M., Petronio C., Berizzi F. // IEEE Geoscience and Remote Sensing Letters. - 2008. - Vol. 5, No. 2. - P. 152-156.

J56. Medkour T. Statistical Properties of the Estimated Degree of Polarization. / Medkour T., Walden A.T. // IEEE Transactions on Signal Processing. - 2008. - Vol. 56, No. 1. - P. 408-414.

J57. Titin-Schnaider C. Polarimetric Characterization of Bistatic Coherent Mechanisms. IEEE Transactions on Geoscience and Remote Sensing. - 2008. - Vol. 46, No. 5. - P. 1535-1546.

J58. Zhen Peng. A Bandwidth Estimation Approach for the Asymptotic Waveform Evaluation Technique. / Zhen Peng, Xin-Qing Sheng. // IEEE Transactions on Antennas and Propagation. - 2008. - Vol. 56, No. 3. - P. 913-917.

J59. Rodriguez J.L. On the Use of the Singular Value Decomposition in the Fast Multipole Method. / Rodriguez J.L., Taboada J.M., Araujo M.G., Obelleiro Basteiro F., Landesa L., Garcia-Tunon J.I. // IEEE Transactions on Antennas and Propagation. - 2008. - Vol. 56, No. 8. - P. 2325-2334.

J60. Morlaas C. Wind turbine effects on VOR system performance. / Morlaas C., Fares M., Souny B. // IEEE Transactions on Aerospace and Electronic Systems. - 2008. - Vol. 44, No. 4. - P. 1464-1476.

J61. Jun Hu. Fast Solution of Scattering From Conducting Structures by Local MLFMA Based on Improved Electric Field Integral Equation. / Jun Hu, Zaiping Nie, Lin Lei, Li Jun Tian. // IEEE Transactions on Electromagnetic Compatibility. - 2008. - Vol. 50, No. 4. - P. 940-945.

J62. Stupfel B. Frequency Interpolation of the Electromagnetic Surface Currents Via Singular Value Decomposition. Application to High-Frequency Analysis. IEEE Transactions on Antennas and Propagation. - 2008. - Vol. 56, No. 12. - P. 3789-3796.

J63. Lopez-Martinez C. Model-Based Polarimetric SAR Speckle Filter. / Lopez-Martinez C., Fabregas X. // IEEE Transactions on Geoscience and Remote Sensing. - 2008. - Vol. 46, No. 11. - P. 3894-3907.

J64. Nunziata F. On the Mueller Scattering Matrix for SAR Sea Oil Slick Observation. / Nunziata F., Gambardella A., Migliaccio M. // IEEE Geoscience and Remote Sensing Letters. - 2008. - Vol. 5, No. 4. - P. 691-695.

J65. Doulgeris A.P. Classification With a Non-Gaussian Model for PolSAR Data. / Doulgeris A.P., Anfinsen S.N., Eltoft T. // IEEE Transactions on Geoscience and Remote Sensing. - 2008. - Vol. 46, No. 10. - P. 2999-3009.

J66. Demaldent E. Spectral Elements for the Integral Equations of Time-Harmonic Maxwell Problems. / Demaldent E., Levadoux D.P., Cohen G. // IEEE Transactions on Antennas and Propagation. - 2008. - Vol. 56, No. 9. - P. 3001-3010.

J67. Galletti M. Measurement and Characterization of Entropy and Degree of Polarization of Weather Radar Targets. / Galletti M., Bebbington D.H.O., Chandra M., Borner T. // IEEE Transactions on Geoscience and Remote Sensing. - 2008. - Vol. 46, No. 10. - P. 3196-3207.

J68. Dubois-Fernandez P.C. The Compact Polarimetry Alternative for Spaceborne SAR at Low Frequency. / Dubois-Fernandez P.C., Souyris J.-C., Angelliaume S., Garestier F. // IEEE Transactions on Geoscience and Remote Sensing. - 2008. - Vol. 46, No. 10. - P. 3208-3222.

J69. Ren-Yuan Qi. Analysis of the Effects of Faraday Rotation on Spaceborne Polarimetric SAR Observations at -Band. / Ren-Yuan Qi, Ya-Qiu Jin. // IEEE Transactions on Geoscience and Remote Sensing. - 2007. - Vol. 45, No. 5. - P. 1115-1122.

J70. Zhiqin Zhao. Active Learning Applied to RCS Computations With Nonuniform Sampling Using Different Objective Functions. / Zhiqin Zhao, Zaiping Nie, Carin L. // IEEE Transactions on Antennas and Propagation. - 2007. - Vol. 55, No. 4. - P. 1214-1217.

J71. Yang Y. MIMO radar waveform design based on mutual information and minimum mean-square error estimation. / Yang Y., Blum R.S. // IEEE Transactions on Aerospace and Electronic Systems. - 2007. - Vol. 43, No. 1. - P. 330-343.

J72. Sevgi L. Groundwave Modeling and Simulation Strategies and Path Loss Prediction Virtual Tools. IEEE Transactions on Antennas and Propagation. - 2007. - Vol. 55, No. 6. - P. 1591-1598.

J73. Oh Y. Re-examination of analytical models for microwave scattering from deciduous leaves. / Oh Y., Hong J.-Y. // IET Microwaves, Antennas & Propagation. - 2007. - Vol. 1, No. 3. - P. 617-623.

J74. Cloude S.R. Dual-Baseline Coherence Tomography. IEEE Geoscience and Remote Sensing Letters. - 2007. - Vol. 4, No. 1. - P. 127-131.

J75. Touzi R. Target Scattering Decomposition in Terms of Roll-Invariant Target Parameters. IEEE Transactions on Geoscience and Remote Sensing. - 2007. - Vol. 45, No. 1. - P. 73-84.

J76. Ito S. Multiple-Scattering Formulation of Pulsed Beam Waves in Hydrometeors and Its Application to Millimeter-Wave Weather Radar. / Ito S., Kobayashi S., Oguchi T. // IEEE Geoscience and Remote Sensing Letters. - 2007. - Vol. 4, No. 1. - P. 13-17.

J77. Lopez-Martinez C. On the Extension of Multidimensional Speckle Noise Model From Single-Look to Multilook SAR Imagery. / Lopez-Martinez C., Pottier E. // IEEE Transactions on Geoscience and Remote Sensing. - 2007. - Vol. 45, No. 2. - P. 305-320.

J78. Kuo C.-h. Electromagnetic Scattering From Multilayer Rough Surfaces With Arbitrary Dielectric Profiles for Remote Sensing of Subsurface Soil Moisture. / Kuo C.-h., Moghaddam M. // IEEE Transactions on Geoscience and Remote Sensing. - 2007. - Vol. 45, No. 2. - P. 349-366.

J79. Wang D.X. An Efficient Volume Integral Equation Solution to EM Scattering by Complex Bodies With Inhomogeneous Bi-Isotropy. / Wang D.X., Yung E.K.N., Chen R.S., Lau P.Y. // IEEE Transactions on Antennas and Propagation. - 2007. - Vol. 55, No. 7. - P. 1970-1980.

J80. Dechamps N. Electromagnetic Scattering From a Rough Layer: Propagation-Inside-Layer Expansion Method Combined to an Updated BMIA/CAG Approach. / Dechamps N., Bourlier C. // IEEE Transactions on Antennas and Propagation. - 2007. - Vol. 55, No. 10. - P. 2790-2802.

J81. Ping-Liang Rui. A Spectral Multigrid Method Combined With MLFMM for Solving Electromagnetic Wave Scattering Problems. / Ping-Liang Rui, Ru-Shan Chen, Dao-Xiang Wang, Kai-Ning Yung E. // IEEE Transactions on Antennas and Propagation. - 2007. - Vol. 55, No. 9. - P. 2571-2577.

J82. Titin-Schnaider C. Power Optimization for Polarimetric Bistatic Random Mechanisms. IEEE Transactions on Geoscience and Remote Sensing. - 2007. - Vol. 45, No. 11. - P. 3646-3660.

J83. Scharstein R.W. Variational Low Frequency Scattering by a Rectangular Trough in a Hard Ground Plane. / Scharstein R.W., Faircloth D.L., Keen J.M. // IEEE Transactions on Antennas and Propagation. - 2007. - Vol. 55, No. 12. - P. 3656-3667.

J84. De Maio A. Design Principles of MIMO Radar Detectors. / De Maio A., Lops M. // IEEE Transactions on Aerospace and Electronic Systems. - 2007. - Vol. 43, No. 3. - P. 886-898.

J85. Zhou J. Analytic performance bounds on estimates of scattering center parameters. / Zhou J., Zhao H., Shi Z., Fu Q. // IEEE Transactions on Aerospace and Electronic Systems. - 2007. - Vol. 43, No. 2. - P. 813-826.

J86. Ebihara S. MoM Analysis of Dipole Antennas in Crosshole Borehole Radar and Field Experiments. / Ebihara S., Hashimoto Y. // IEEE Transactions on Geoscience and Remote Sensing. - 2007. - Vol. 45, No. 8. - P. 2435-2450.

J87. Ping-Liang Rui. Spectral Two-Step Preconditioning of Multilevel Fast Multipole Algorithm for the Fast Monostatic RCS Calculation. / Ping-Liang Rui, Ru-Shan Chen, Dao-Xiang Wang, Yung E.K.-N. // IEEE Transactions on Antennas and Propagation. - 2007. - Vol. 55, No. 8. - P. 2268-2275.

J88. Souyris J.-C. Polarimetric Analysis of Bistatic SAR Images From Polar Decomposition: A Quaternion Approach. / Souyris J.-C., Tison C. // IEEE Transactions on Geoscience and Remote Sensing. - 2007. - Vol. 45, No. 9. - P. 2701-2714.

J89. Jun-Yi Koay. Paddy Fields as Electrically Dense Media: Theoretical Modeling and Measurement Comparisons. / Jun-Yi Koay, Chue-Poh Tan, Ka-Sing Lim, Saiful Bahari bin Abu Bakar, Hong-Tat Ewe, Hean-Teik Chuah, Jin-Au Kong. // IEEE Transactions on Geoscience and Remote Sensing. - 2007. - Vol. 45, No. 9. - P. 2837-2849.

J90. Briczinski S.J. Robust Voltage Fitting Techniques for Meteor Doppler Speed Determination. / Briczinski S.J., Chun-Hsien Wen, Mathews J.D., Doherty J.F., Zhou Q.N. // IEEE Transactions on Geoscience and Remote Sensing. - 2006. - Vol. 44, No. 12. - P. 3490-3496.

J91. Cameron W.L. Conservative Polarimetric Scatterers and Their Role in Incorrect Extensions of the Cameron Decomposition. / Cameron W.L., Rais H. // IEEE Transactions on Geoscience and Remote Sensing. - 2006. - Vol. 44, No. 12. - P. 3506-3516.

J92. Lucido M. Analysis of the electromagnetic scattering by perfectly conducting convex polygonal cylinders. / Lucido M., Panariello G., Schettino F. // IEEE Transactions on Antennas and Propagation. - 2006. - Vol. 54, No. 4. - P. 1223-1231.

J93. Hobbs S.E. Insect ventral radar cross-section polarisation dependence measurements for radar entomology. / Hobbs S.E., Aldhous A.C. // IEE Proceedings - Radar, Sonar and Navigation. - 2006. - Vol. 153, No. 6. - P. 502-508.

J94. Jong-Sen Lee. Scattering-model-based speckle filtering of polarimetric SAR data. / Jong-Sen Lee, Grunes M.R., Schuler D.L., Pottier E., Ferro-Famil L. // IEEE Transactions on Geoscience and Remote Sensing. - 2006. - Vol. 44, No. 1. - P. 176-187.

J95. Jose Ma Gil. A CAD-oriented method to analyze and design radiating structures based on bodies of revolution by using finite elements and generalized scattering matrix. / Jose Ma Gil, Javier Monge, Rubio J., Zapata J. // IEEE Transactions on Antennas and Propagation. - 2006. - Vol. 54, No. 3. - P. 899-907.

J96. Gurram P.R. Spectral-domain covariance estimation with a priori knowledge. / Gurram P.R., Goodman N.A. // IEEE Transactions on Aerospace and Electronic Systems. - 2006. - Vol. 42, No. 3. - P. 1010-1020.

J97. Jianjun Zhang. Extraction of Ocean Wave Spectra From Simulated Noisy Bistatic High-Frequency Radar Data. / Jianjun Zhang, Eric W. Gill. // IEEE Journal of Oceanic Engineering. - 2006. - Vol. 31, No. 4. - P. 779-796.

J98. Bandiera F. CFAR detection of extended and multiple point-like targets without assignment of secondary data. / Bandiera F., Orlando D., Ricci G. // IEEE Signal Processing Letters. - 2006. - Vol. 13, No. 4. - P. 240-243.

J99. Catedra M.F. Application of matrix pencil to obtain the current modes on electrically large bodies. / Catedra M.F., Rivas F., Delgado C., Gomez J.M., Lozano L. // IEEE Transactions on Antennas and Propagation. - 2006. - Vol. 54, No. 8. - P. 2429-2436.

J100. Pouhe D. RF radiation properties of printed-circuits boards in a GTEM cell. IEEE Transactions on Electromagnetic Compatibility. - 2006. - Vol. 48, No. 3. - P. 468-475.

J101. Yamaguchi Y. A four-component decomposition of POLSAR images based on the coherency matrix. / Yamaguchi Y., Yajima Y., Yamada H. // IEEE Geoscience and Remote Sensing Letters. - 2006. - Vol. 3, No. 3. - P. 292-296.

J102. Jian Yang. On Huynen's decomposition of a Kennaugh matrix. / Jian Yang, Ying-Ning Peng, Yamaguchi Y., Yamada H. // IEEE Geoscience and Remote Sensing Letters. - 2006. - Vol. 3, No. 3. - P. 369-372.

J103. Ainsworth T.L. Orientation angle preserving a posteriori polarimetric SAR calibration. / Ainsworth T.L., Ferro-Famil L., Jong-Sen Lee. // IEEE Transactions on Geoscience and Remote Sensing. - 2006. - Vol. 44, No. 4. - P. 994-1003.

J104. Jinyang Du. A combined method to model microwave scattering from a forest medium. / Jinyang Du, Jiancheng Shi, Tjuatja S., Kun Shan Chen. // IEEE Transactions on Geoscience and Remote Sensing. - 2006. - Vol. 44, No. 4. - P. 815-824.

J105. Tiberi G. A Spectral Domain Integral Equation Method Utilizing Analytically Derived Characteristic Basis Functions for the Scattering From Large Faceted Objects. / Tiberi G., Monorchio A., Manara G., Mittra R. // IEEE Transactions on Antennas and Propagation. - 2006. - Vol. 54, No. 9. - P. 2508-2514.

J106. Kwok Kee Chan. Radar Cross Section Modeling and Measurements of Inlets and Cylinders With Skew Blades. / Kwok Kee Chan, Wong S.K., Riseborough E.S. // IEEE Transactions on Antennas and Propagation. - 2006. - Vol. 54, No. 10. - P. 2930-2939.

J107. Burkholder R.J. Forward-backward iterative physical optics algorithm for computing the RCS of open-ended cavities. / Burkholder R.J., Lundin T. // IEEE Transactions on Antennas and Propagation. - 2005. - Vol. 53, No. 2. - P. 793-799.

J108. Tsalamengas J.L. Diffraction of obliquely incident waves by a strip in a bianisotropic medium. IEEE Transactions on Antennas and Propagation. - 2005. - Vol. 53, No. 1. - P. 260-269.

J109. Peng Liu. Numerical Simulation of the Doppler spectrum of a flying target above dynamic oceanic surface by using the FEM-DDM method. / Peng Liu, Ya-Qiu Jin. // IEEE Transactions on Antennas and Propagation. - 2005. - Vol. 53, No. 2. - P. 825-832.

J110. Hill M.J. Integration of optical and radar classifications for mapping pasture type in Western Australia. / Hill M.J., Ticehurst C.J., Jong-Sen Lee, Grunes M.R., Donald G.E., Henry D. // IEEE Transactions on Geoscience and Remote Sensing. - 2005. - Vol. 43, No. 7. - P. 1665-1681.

J111. Yamaguchi Y. Four-component scattering model for polarimetric SAR image decomposition. / Yamaguchi Y., Moriyama T., Ishido M., Yamada H. // IEEE Transactions on Geoscience and Remote Sensing. - 2005. - Vol. 43, No. 8. - P. 1699-1706.

J112. Davis S.K. Ultrawideband microwave breast cancer detection: a detection-theoretic approach using the generalized likelihood ratio test. / Davis S.K., Tandradinata H., Hagness S.C., Van Veen B.D. // IEEE Transactions on Biomedical Engineering. - 2005. - Vol. 52, No. 7. - P. 1237-1250.

J113. Martin-Herrero J. Computation of longwave electromagnetic response of nonhomogeneous media. / Martin-Herrero J., Peon-Fernandez J.F. // IEEE Transactions on Geoscience and Remote Sensing. - 2005. - Vol. 43, No. 7. - P. 1479-1489.

J114. Pan Liang. Radiative transfer model for microwave bistatic scattering from forest canopies. / Pan Liang, Pierce L.E., Moghaddam M. // IEEE Transactions on Geoscience and Remote Sensing. - 2005. - Vol. 43, No. 11. - P. 2470-2483.

J115. Hsi-Tseng Chou. A discrete-time uniform geometrical theory of diffraction for the fast transient analysis

of scattering from curved wedges. / Hsi-Tseng Chou, Hsien-Kwei Ho, Tsung-Ying Chung. // IEEE Transactions on Antennas and Propagation. - 2005. - Vol. 53, No. 11. - P. 3633-3643.

J116. Borel S. A new well-conditioned Integral formulation for Maxwell equations in three dimensions. / Borel S., Levadoux D.P., Alouges F. // IEEE Transactions on Antennas and Propagation. - 2005. - Vol. 53, No. 9. - P. 2995-3004.

J117. Gope D. Efficient solution of EFIE via low-rank compression of multilevel predetermined interactions. / Gope D., Jandhyala V. // IEEE Transactions on Antennas and Propagation. - 2005. - Vol. 53, No. 10. - P. 3324-3333.

J118. Zheng Lou. Total- and scattered-field decomposition technique for the finite-element time-domain modeling of buried scatterers. / Zheng Lou, Petersson L.E.R., Jian-Ming Jin, Riley D.J. // IEEE Antennas and Wireless Propagation Letters. - 2005. - Vol. 4, {no data available}. - P. 133-137.

J119. Yan Zhang. Mode-expansion method for calculating electromagnetic waves scattered by objects on rough ocean surfaces. / Yan Zhang, Jie Lu, Pacheco J. Jr., Moss C.D., Ao C.O., Grzegorczyk T.M., Kong J.A. // IEEE Transactions on Antennas and Propagation. - 2005. - Vol. 53, No. 5. - P. 1631-1639.

J120. Abramovich Y.I. Bounds on maximum likelihood ratio-Part II: application to antenna array detection-estimation with imperfect wavefront coherence. / Abramovich Y.I., Spencer N.K., Gorokhov A.Y. // IEEE Transactions on Signal Processing. - 2005. - Vol. 53, No. 6. - P. 2046-2058.

J121. Jeonghwa Lee. Sparse inverse preconditioning of multilevel fast multipole algorithm for hybrid Integral equations in electromagnetics. / Jeonghwa Lee, Jun Zhang, Cai-Cheng Lu. // IEEE Transactions on Antennas and Propagation. - 2004. - Vol. 52, No. 9. - P. 2277-2287.

J122. Jing Gu. Speckle filtering in polarimetric SAR data based on the subspace decomposition. / Jing Gu, Jian Yang, Hao Zhang, Yingning Peng, Chao Wang, Hong Zhang. // IEEE Transactions on Geoscience and Remote Sensing. - 2004. - Vol. 42, No. 8. - P. 1635-1641.

J123. Warnick K.F. Error analysis of the moment method. / Warnick K.F., Weng Cho Chew. // IEEE Antennas and Propagation Magazine. - 2004. - Vol. 46, No. 6. - P. 38-53.

J124. Junho Yeo. Efficient generation of method of moments matrices using the characteristic function method. / Junho Yeo, Koksoy S., Prakash V.V.S., Mittra R. // IEEE Transactions on Antennas and Propagation. - 2004. - Vol. 52, No. 12. - P. 3405-3410.

J125. Touzi R. On the use of permanent symmetric scatterers for ship characterization. / Touzi R., Raney R.K., Charbonneau F. // IEEE Transactions on Geoscience and Remote Sensing. - 2004. - Vol. 42, No. 10. - P. 2039-2045.

J126. Kampes B.M. Ambiguity resolution for permanent scatterer interferometry. / Kampes B.M., Hanssen R.F. // IEEE Transactions on Geoscience and Remote Sensing. - 2004. - Vol. 42, No. 11. - P. 2446-2453.

J127. Vouvakis M.N. A symmetric FEM-IE formulation with a single-level IE-QR algorithm for solving electromagnetic radiation and scattering problems. / Vouvakis M.N., Seung-Cheol Lee, Kezhong Zhao, Jin-Fa Lee. // IEEE Transactions on Antennas and Propagation. - 2004. - Vol. 52, No. 11. - P. 3060-3070.

J128. Zhonggui Xiang. A hybrid BEM/WTM/DFT technique for analysis of the EM scattering from open-ended circular cavities with cylindrically periodic terminations. / Zhonggui Xiang, Dongya Shen. // IEEE Transactions on Antennas and Propagation. - 2004. - Vol. 52, No. 9. - P. 2479-2485.

J129. Kim K.T. A memory-reduction scheme for the FFT T-matrix method [EM wave scattering applications]. IEEE Antennas and Wireless Propagation Letters. - 2004. - Vol. 3, No. 1. - P. 193-196.

J130. Alberga V. Volume decorrelation effects in polarimetric SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing. - 2004. - Vol. 42, No. 11. - P. 2467-2478.

J131. Karnychev V. Algorithms for estimating the complete group of polarization invariants of the scattering matrix (SM) based on measuring all SM elements. / Karnychev V., Khlusov V.A., Ligthart L.P., Sharygin G. // IEEE Transactions on Geoscience and Remote Sensing. - 2004. - Vol. 42, No. 3. - P. 529-539.

J132. Hassanien A. A generalized capon estimator for localization of multiple spread sources. / Hassanien A., Shahbazpanahi S., Gershman A.B. // IEEE Transactions on Signal Processing. - 2004. - Vol. 52, No. 1. - P. 280-283.

J133. Wei X.C. The hybridization of fast multipole method with asymptotic waveform evaluation for the fast monostatic RCS computation. / Wei X.C., Zhang Y.J., Li E.P. // IEEE Transactions on Antennas and Propagation. - 2004. - Vol. 52, No. 2. - P. 605-607.

J134. Jian-Ying Li. Electromagnetic scattering by a mixture of conducting and dielectric objects: analysis using method of moments. / Jian-Ying Li, Li L.-W. // IEEE Transactions on Vehicular Technology. - 2004. - Vol. 53, No. 2. - P. 514-520.

J135. El-Shenawee M. Polarimetric scattering from two-layered two-dimensional random rough surfaces with and without buried objects. IEEE Transactions on Geoscience and Remote Sensing. - 2004. - Vol. 42, No. 1. - P. 67-76.

J136. Monakov A. Direction finding for an extended target with possibly non-symmetric spatial spectrum. / Monakov A., Besson O. // IEEE Transactions on Signal Processing. - 2004. - Vol. 52, No. 1. - P. 283-287.

J137. Shahbazpanahi S. A covariance fitting approach to parametric localization of multiple incoherently distributed sources. / Shahbazpanahi S., Valaee S., Gershman A.B. // IEEE Transactions on Signal Processing. - 2004. - Vol. 52, No. 3. - P. 592-600.

J138. Ya-Qiu Jin. Retrievals of underlying surface roughness and moisture from polarimetric pulse echoes in the specular direction through stratified vegetation canopy. / Ya-Qiu Jin, Fei Chen, Mei Chang. // IEEE Transactions on Geoscience and Remote Sensing. - 2004. - Vol. 42, No. 2. - P. 426-433.

J139. Jian Yang. Generalized optimization of polarimetric contrast enhancement. / Jian Yang, Guiwei Dong, Yingning Peng, Yamaguchi Y., Yamada H. // IEEE Geoscience and Remote Sensing Letters. - 2004. - Vol. 1, No. 3. - P. 171-174.

J140. Alfano G. Polarization diversity detection of distributed targets in compound-Gaussian clutter. / Alfano G., De Maio A., Conte E. // IEEE Transactions on Aerospace and Electronic Systems. - 2004. - Vol. 40, No. 2. - P. 755-765.

J141. Meincke P. Plane-wave characterization of antennas close to a planar interface. / Meincke P., Hansen T.B. // IEEE Transactions on Geoscience and Remote Sensing. - 2004. - Vol. 42, No. 6. - P. 1222-1232.

J142. Carr M. A procedure for modeling material junctions in 3-D surface integral equation approaches. / Carr M., Topsakal E., Volakis J.L. // IEEE Transactions on Antennas and Propagation. - 2004. - Vol. 52, No. 5. - P. 1374-1378.

J143. Freeman A. Calibration of linearly polarized polarimetric SAR data subject to Faraday rotation. IEEE Transactions on Geoscience and Remote Sensing. - 2004. - Vol. 42, No. 8. - P. 1617-1624.

J144. Lech R. Propagation in rectangular waveguides periodically loaded with cylindrical posts. / Lech R., Mazur J. // IEEE Microwave and Wireless Components Letters. - 2004. - Vol. 14, No. 4. - P. 177-179.

J145. Fujita M. Target decomposition analysis of SIR-C imagery for characterization of scattering mechanisms and their dependence on observation parameters. / Fujita M., Nakamura S. // IEEE Transactions on Geoscience and Remote Sensing. - 2003. - Vol. 41, No. 12. - P. 2721-2724.

J146. Juan Yang. Two-dimensional scattering by a periodic array of gyrotropic cylinders embedded in a dielectric slab. / Juan Yang, Le-Wei Li, Chang-Hong Liang. // IEEE Antennas and Wireless Propagation Letters. - 2003. - Vol. 2, {no data available}. - P. 18-21.

J147. Conte E. Distributed target detection in compound-Gaussian noise with Rao and Wald tests. / Conte E., De Maio A. // IEEE Transactions on Aerospace and Electronic Systems. - 2003. - Vol. 39, No. 2. - P. 568-582.

J148. Mei Chang. Temporal Mueller matrix solution for polarimetric scattering from inhomogeneous random media of nonspherical scatterers. / Mei Chang, Ya-Qiu Jin. // IEEE Transactions on Antennas and Propagation. -

2003. - Vol. 51, No. 4. - P. 820-832.

J149. Boerner W.-M. Recent advances in extra-wide-band polarimetry, interferometry and polarimetric interferometry in synthetic aperture remote sensing and its applications. IEE Proceedings - Radar, Sonar and Navigation. - 2003. - Vol. 150, No. 3. - P. 113-124.

J150. Jong-Sen Lee. Speckle filtering and coherence estimation of polarimetric SAR interferometry data for forest applications. / Jong-Sen Lee, Cloude S.R., Papathanassiou K.P., Grunes M.R., Woodhouse I.H. // IEEE Transactions on Geoscience and Remote Sensing. - 2003. - Vol. 41, No. 10. - P. 2254-2263.

J151. Fujita M. Development of a retrodirective PARC for ALOS/PALSAR calibration. IEEE Transactions on Geoscience and Remote Sensing. - 2003. - Vol. 41, No. 10. - P. 2177-2186.

J152. Hajnsek I. Inversion of surface parameters from polarimetric SAR. / Hajnsek I., Pottier E., Cloude S.R. // IEEE Transactions on Geoscience and Remote Sensing. - 2003. - Vol. 41, No. 4. - P. 727-744.

J153. Yun Ji. A numerical investigation of interior resonances in the hybrid FEM/MoM method. / Yun Ji, Hao Wang, Hubing T.H. // IEEE Transactions on Antennas and Propagation. - 2003. - Vol. 51, No. 2. - P. 347-349.

J154. Conradsen K. A test statistic in the complex Wishart distribution and its application to change detection in polarimetric SAR data. / Conradsen K., Nielsen A.A., Schou J., Skriver H. // IEEE Transactions on Geoscience and Remote Sensing. - 2003. - Vol. 41, No. 1. - P. 4-19.

J155. Ling Li. Scalable multilevel fast multipole method for multiple targets in the vicinity of a half space. / Ling Li, Zhijun Liu, Xiaolong Dong, Thompson J.A., Carin L. // IEEE Transactions on Geoscience and Remote Sensing. - 2003. - Vol. 41, No. 4. - P. 791-802.

J156. del Rio V.S. Maximum-likelihood estimation of specific differential phase and attenuation in rain. / del Rio V.S., Antar Y.M.M., Fabregas X. // IEEE Transactions on Geoscience and Remote Sensing. - 2003. - Vol. 41, No. 12. - P. 2771-2782.

J157. Velamparambil S. 10 million unknowns: is it that big? [computational electromagnetics]. / Velamparambil S., Weng Cho Chew, Jiming Song. // IEEE Antennas and Propagation Magazine. - 2003. - Vol. 45, No. 2. - P. 43-58.

J158. Koo Voon Chet. Development of a ground-based radar for scattering measurements. / Koo Voon Chet, Chung Boon Kuan, Chuah Hean Teik. // IEEE Antennas and Propagation Magazine. - 2003. - Vol. 45, No. 2. - P. 36-42.

J159. Conte E. CFAR detection of distributed targets in non-Gaussian disturbance. / Conte E., De Maio A., Ricci G. // IEEE Transactions on Aerospace and Electronic Systems. - 2002. - Vol. 38, No. 2. - P. 612-621.

J160. El-Shenawee M. The multiple interaction model for nonshallow scatterers buried beneath 2-d random rough surfaces. IEEE Transactions on Geoscience and Remote Sensing. - 2002. - Vol. 40, No. 4. - P. 982-987.

J161. {no data available}. Low altitude target model for radar simulation. IEEE Transactions on Aerospace and Electronic Systems. - 2002. - Vol. 38, No. 2. - P. 668-675.

J162. Touzi R. Characterization of target symmetric scattering using polarimetric SARs. / Touzi R., Charbonneau F. // IEEE Transactions on Geoscience and Remote Sensing. - 2002. - Vol. 40, No. 11. - P. 2507-2516.

J163. Ya-Qiu Jin. Polarimetric scattering indexes and information entropy of the SAR imagery for surface monitoring. / Ya-Qiu Jin, Fei Chen. // IEEE Transactions on Geoscience and Remote Sensing. - 2002. - Vol. 40, No. 11. - P. 2502-2506.

J164. Xiao-Long Zhu. Adaptive RLS algorithm for blind source separation using a natural gradient. / Xiao-Long Zhu, Xian-Da Zhang. // IEEE Signal Processing Letters. - 2002. - Vol. 9, No. 12. - P. 432-435.

J165. Muhtar Qong. A new scattering mechanism enhancement scheme for polarimetric SAR images. IEEE Transactions on Geoscience and Remote Sensing. - 2002. - Vol. 40, No. 12. - P. 2582-2592.

J166. Garmatyuk D.S. Ultra-wideband continuous-wave random noise arc-SAR. / Garmatyuk D.S., Narayanan R.M. // IEEE Transactions on Geoscience and Remote Sensing. - 2002. - Vol. 40, No. 12. - P. 2543-2552.

J167. Yaich M.I. The far-zone scattering calculation of frequency-dependent materials objects using the TLM method. / Yaich M.I., Khalladi M. // IEEE Transactions on Antennas and Propagation. - 2002. - Vol. 50, No. 11. - P. 1605-1608.

J168. Waller M.L. Application of adaptive basis functions for a diagonal moment matrix solution of arbitrarily shaped three-dimensional conducting body problems. / Waller M.L., Rao S.A. // IEEE Transactions on Antennas and Propagation. - 2002. - Vol. 50, No. 10. - P. 1445-1452.

J169. Oh Y. Semi-empirical model of the ensemble-averaged differential Mueller matrix for microwave backscattering from bare soil surfaces. / Oh Y., Sarabandi K., Ulaby F.T. // IEEE Transactions on Geoscience and Remote Sensing. - 2002. - Vol. 40, No. 6. - P. 1348-1355.

J170. Xu J.-Y. Using cross-entropy for polarimetric radar discrimination problem. / Xu J.-Y., Yang J., Peng Y.-N., Wang C. // Electronics Letters. - 2002. - Vol. 38, No. 12. - P. 593-594.

J171. Santalla V. A comparison between different polarimetric measurement schemes. / Santalla V., Antar Y.M.M. // IEEE Transactions on Geoscience and Remote Sensing. - 2002. - Vol. 40, No. 5. - P. 1007-1017.

J172. Nashashibi A.Y. An ultrafast wide-band millimeter-wave (MMW) polarimetric radar for remote sensing applications. / Nashashibi A.Y., Sarabandi K., Frantzis P., De Roo R.D., Ulaby F.T. // IEEE Transactions on Geoscience and Remote Sensing. - 2002. - Vol. 40, No. 8. - P. 1777-1786.

J173. Shuley N.V. On the fast approximation of Green's functions in MPIE formulations for planar layered media. / Shuley N.V., Boix R.R., Medina F., Horno M. // IEEE Transactions on Microwave Theory and Techniques. - 2002. - Vol. 50, No. 9. - P. 2185-2192.

J174. De Maio A. Polarimetric adaptive detection of range-distributed targets. IEEE Transactions on Signal Processing. - 2002. - Vol. 50, No. 9. - P. 2152-2159.

J175. Sadjadi F. Improved target classification using optimum polarimetric SAR signatures. IEEE Transactions on Aerospace and Electronic Systems. - 2002. - Vol. 38, No. 1. - P. 38-49.

J176. Jian Yang. The characteristic polarization states and the equi-power curves. / Jian Yang, Yamaguchi Y., Yamada H., Czyz Z.H., Boerner W.-M., Mott H., Luneburg E., Yingning Peng. // IEEE Transactions on Geoscience and Remote Sensing. - 2002. - Vol. 40, No. 2. - P. 305-313.

J177. McLaughlin D.J. Fully polarimetric bistatic radar scattering behavior of forested hills. / McLaughlin D.J., Yuliang Wu, Stevens W.G., Xuehu Zhang, Sowa M.J., Weijers B. // IEEE Transactions on Antennas and Propagation. - 2002. - Vol. 50, No. 2. - P. 101-110.

J178. Heldring A. New block ILU preconditioner scheme for numerical analysis of very large electromagnetic problems. / Heldring A., Rius J.M., Ligthart L. // IEEE Transactions on Magnetics. - 2002. - Vol. 38, No. 2. - P. 337-340.

J179. Chen S.Y. Analysis of low frequency scattering from penetrable scatterers. / Chen S.Y., Weng Cho Chew, Song J.M., Jun-Sheng Zhao. // IEEE Transactions on Geoscience and Remote Sensing. - 2001. - Vol. 39, No. 4. - P. 726-735.

J180. Xia M.Y. Wavelet-based simulations of electromagnetic scattering from large-scale two-dimensional perfectly conducting random rough surfaces. / Xia M.Y., Chan C.H., Shu-Qing Li, Jin-Lin Hu, Leung Tsang. // IEEE Transactions on Geoscience and Remote Sensing. - 2001. - Vol. 39, No. 4. - P. 718-725.

J181. Yong Wang. Complex natural resonances of conducting planar objects buried in a dielectric half-space. / Yong Wang, Longstaff I.D., Leat C.J., Shauley N.V. // IEEE Transactions on Geoscience and Remote Sensing. - 2001. - Vol. 39, No. 6. - P. 1183-1189.

J182. Johnson J.T. Coupled canonical grid/discrete dipole approach for computing scattering from objects above or below a rough interface. / Johnson J.T., Burkholder R.J. // IEEE Transactions on Geoscience and Remote Sensing. - 2001. - Vol. 39, No. 6. - P. 1214-1220.

J183. Stoyanov Aleksandr J. Effective medium theory for large particulate size composites. / Stoyanov Aleksandr J., Fischer Eugene C., Uberall Herbert. // Journal of Applied Physics. - 2001. - Vol. 89, No. 8. - P. 4486-4490.

J184. Jian Yang. Similarity between two scattering matrices. / Jian Yang, Ying-Ning Peng, Shi-Ming Lin. // Electronics Letters. - 2001. - Vol. 37, No. 3. - P. 193-194.

J185. Rouquette S. Estimation of frequencies and damping factors by two-dimensional ESPRIT type methods. / Rouquette S., Najim M. // IEEE Transactions on Signal Processing. - 2001. - Vol. 49, No. 1. - P. 237-245.

J186. Jian Yang. Development of target null theory. / Jian Yang, Yamaguchi Y., Yamada H., Boerner W.-M., Mott H., Yingning Peng. // IEEE Transactions on Geoscience and Remote Sensing. - 2001. - Vol. 39, No. 2. - P. 330-338.

J187. Jones G. III. Recognizing occluded objects in SAR images. / Jones G. III, Bhanu B. // IEEE Transactions on Aerospace and Electronic Systems. - 2001. - Vol. 37, No. 1. - P. 316-328.

J188. O'Sullivan J.A. SAR ATR performance using a conditionally Gaussian model. / O'Sullivan J.A., DeVore M.D., Kedia V., Miller M.I. // IEEE Transactions on Aerospace and Electronic Systems. - 2001. - Vol. 37, No. 1. - P. 91-108.

J189. Ferro-Famil L. Unsupervised classification of multifrequency and fully polarimetric SAR images based on the H/A/Alpha-Wishart classifier. / Ferro-Famil L., Pottier E., Jong-Sen Lee. // IEEE Transactions on Geoscience and Remote Sensing. - 2001. - Vol. 39, No. 11. - P. 2332-2342.

J190. Kim K.-T. Radar target identification using one-dimensional scattering centres. / Kim K.-T., Seo D.-K., Kim H.-T. // IEE Proceedings - Radar, Sonar and Navigation. - 2001. - Vol. 148, No. 5. - P. 285-296.

J191. Jong-Sen Lee. Quantitative comparison of classification capability: fully polarimetric versus dual and single-polarization SAR. / Jong-Sen Lee, Grunes M.R., Pottier E. // IEEE Transactions on Geoscience and Remote Sensing. - 2001. - Vol. 39, No. 11. - P. 2343-2351.

J192. Lazarov A.D. Iterative MMSE method and recurrent Kalman procedure for ISAR image reconstruction. IEEE Transactions on Aerospace and Electronic Systems. - 2001. - Vol. 37, No. 4. - P. 1432-1441.

J193. Morgenthaler A.W. Scattering from lossy dielectric objects buried beneath randomly rough ground: validating the semi-analytic mode matching algorithm with 2-D FDFD. / Morgenthaler A.W., Rappaport C.M. // IEEE Transactions on Geoscience and Remote Sensing. - 2001. - Vol. 39, No. 11. - P. 2421-2428.

J194. Ghogho M. Estimation of directions of arrival of multiple scattered sources. / Ghogho M., Besson O., Swami A. // IEEE Transactions on Signal Processing. - 2001. - Vol. 49, No. 11. - P. 2467-2480.

J195. Reinert J. Theoretical and experimental waveguide characterization of small wire scatterers. / Reinert J., Jacob A.F. // IEEE Transactions on Microwave Theory and Techniques. - 2001. - Vol. 49, No. 7. - P. 1266-1269.

J196. Conte E. GLRT-based adaptive detection algorithms for range-spread targets. / Conte E., De Maio A., Ricci G. // IEEE Transactions on Signal Processing. - 2001. - Vol. 49, No. 7. - P. 1336-1348.

J197. Poirier J.-R. A macro-element compression for the moment method. / Poirier J.-R., Bendali A., Borderies P. // IEEE Transactions on Antennas and Propagation. - 2001. - Vol. 49, No. 10. - P. 1485-1490.

J198. Mayhan J.T. High resolution 3D “snapshot” ISAR imaging and feature extraction. / Mayhan J.T., Burrows M.L., Cuomo K.M., Piou J.E. // IEEE Transactions on Aerospace and Electronic Systems. - 2001. - Vol. 37, No. 2. - P. 630-642.

J199. Jian Yang. Numerical methods for solving the optimal problem of contrast enhancement. / Jian Yang, Yamaguchi Y., Boerner W.-M., Shiming Lin. // IEEE Transactions on Geoscience and Remote Sensing. - 2000. - Vol. 38, No. 2. - P. 965-971.

J200. De Doncker P. The use of the transfinite interpolation in the method of moments applied to electromagnetic scattering by dielectric cylinders. IEEE Transactions on Antennas and Propagation. - 2000. - Vol.

48, No. 5. - P. 661-670.

J201. Coutts S.D. Passive localization of moving emitters using out-of-plane multipath. IEEE Transactions on Aerospace and Electronic Systems. - 2000. - Vol. 36, No. 2. - P. 584-595.

J202. Monakov A.A. Observation of extended targets with antenna arrays. IEEE Transactions on Aerospace and Electronic Systems. - 2000. - Vol. 36, No. 1. - P. 297-302.

J203. Adve R.S. Compensation for the effects of mutual coupling on direct data domain adaptive algorithms. / Adve R.S., Sarkar T.K. // IEEE Transactions on Antennas and Propagation. - 2000. - Vol. 48, No. 1. - P. 86-94.

J204. Zahn D. Numerical simulation of scattering from rough surfaces: a wavelet-based approach. / Zahn D., Sarabandi K., Sabet K.F., Harvey J.F. // IEEE Transactions on Antennas and Propagation. - 2000. - Vol. 48, No. 2. - P. 246-253.

J205. Jong-Sen Lee. Polarimetric SAR data compensation for terrain azimuth slope variation. / Jong-Sen Lee, Schuler D.L., Ainsworth T.L. // IEEE Transactions on Geoscience and Remote Sensing. - 2000. - Vol. 38, No. 5. - P. 2153-2163.

J206. Miwa T. Enhancement of reflected waves in single-hole polarimetric borehole radar measurement. / Miwa T., Sato M., Niitsuma H. // IEEE Transactions on Antennas and Propagation. - 2000. - Vol. 48, No. 9. - P. 1430-1437.

J207. Ewe H.T. Electromagnetic scattering from an electrically dense vegetation medium. / Ewe H.T., Chuah H.T. // IEEE Transactions on Geoscience and Remote Sensing. - 2000. - Vol. 38, No. 5. - P. 2093-2105.

J208. Barka A. Scattering from 3-D cavities with a plug and play numerical scheme combining IE, PDE, and modal techniques. / Barka A., Soudais P., Volpert D. // IEEE Transactions on Antennas and Propagation. - 2000. - Vol. 48, No. 5. - P. 704-712.

J209. Gerlach K. Fast converging adaptive detection of Doppler-shifted, range-distributed targets. / Gerlach K., Steiner M.J. // IEEE Transactions on Signal Processing. - 2000. - Vol. 48, No. 9. - P. 2686-2690.

J210. Komisarek K.S. An investigation of new FETD/ABC methods of computation of scattering from three-dimensional material objects. / Komisarek K.S., Wang N.N., Dominek A.K., Hann R. // IEEE Transactions on Antennas and Propagation. - 1999. - Vol. 47, No. 10. - P. 1579-1585.

J211. Fante R.L. Adaptive nulling of SAR sidelobe discretes. IEEE Transactions on Aerospace and Electronic Systems. - 1999. - Vol. 35, No. 4. - P. 1212-1218.

J212. Cui T.J. Fast algorithm for electromagnetic scattering by buried 3-D dielectric objects of large size. / Cui T.J., Chew W.C. // IEEE Transactions on Geoscience and Remote Sensing. - 1999. - Vol. 37, No. 5. - P. 2597-2608.

J213. Stoyanov Aleksandr J. Effective-medium model dependence of the radar reflectivity of conducting particle films. / Stoyanov Aleksandr J., Howell Barbara F., Fischer Eugene C., Uberall Herbert, Chouffani Khalid. // Journal of Applied Physics. - 1999. - Vol. 86, No. 6. - P. 3110-3119.

J214. Zaporozhets A.A. Bistatic RCS calculations with the vector parabolic equation method. / Zaporozhets A.A., Levy M.F. // IEEE Transactions on Antennas and Propagation. - 1999. - Vol. 47, No. 11. - P. 1688-1696.

J215. Bendali A. A boundary-element solution of the Leontovitch problem. / Bendali A., Fares M.B., Gay J. // IEEE Transactions on Antennas and Propagation. - 1999. - Vol. 47, No. 10. - P. 1597-1605.

J216. Greenwood A.D. A novel efficient algorithm for scattering from a complex BOR using mixed finite elements and cylindrical PML. / Greenwood A.D., Jian-Ming Jin. // IEEE Transactions on Antennas and Propagation. - 1999. - Vol. 47, No. 4. - P. 620-629.

J217. Marchand R.T. On the use of finite surfaces in the numerical prediction of rough surface scattering. / Marchand R.T., Brown G.S. // IEEE Transactions on Antennas and Propagation. - 1999. - Vol. 47, No. 4. - P. 600-604.

J218. Gerlach K. Adaptive detection of range distributed targets. / Gerlach K., Steiner M.J. // IEEE Transactions on Signal Processing. - 1999. - Vol. 47, No. 7. - P. 1844-1851.

J219. Santalla V. Optimal polarizations and application to meteorological targets. / Santalla V., McCormick G., Antar Y.M.M. // IEEE Transactions on Antennas and Propagation. - 1999. - Vol. 47, No. 4. - P. 767-769.

J220. Miwa T. Subsurface fracture measurement with polarimetric borehole radar. / Miwa T., Sato M., Niitsuma H. // IEEE Transactions on Geoscience and Remote Sensing. - 1999. - Vol. 37, No. 2. - P. 828-837.

J221. Kendra J.R. A hybrid experimental/theoretical scattering model for dense random media. / Kendra J.R., Sarabandi K. // IEEE Transactions on Geoscience and Remote Sensing. - 1999. - Vol. 37, No. 1. - P. 21-35.

J222. Goldstein J.S. Multistage partially adaptive STAP CFAR detection algorithm. / Goldstein J.S., Reed I.S., Zulch P.A. // IEEE Transactions on Aerospace and Electronic Systems. - 1999. - Vol. 35, No. 2. - P. 645-661.

J223. Tarng J.H. A novel 3-D scattering model of 1.8-GHz radio propagation in microcellular urban environment. / Tarng J.H., Ju K.M. // IEEE Transactions on Electromagnetic Compatibility. - 1999. - Vol. 41, No. 2. - P. 100-106.

J224. Li E.S. Low grazing incidence millimeter-wave scattering models and measurements for various road surfaces. / Li E.S., Sarabandi K. // IEEE Transactions on Antennas and Propagation. - 1999. - Vol. 47, No. 5. - P. 851-861.

J225. Yang J. Co-null of targets and co-null Abelian group. / Yang J., Yamaguchi Y., Yamada H. // Electronics Letters. - 1999. - Vol. 35, No. 12. - P. 1017-1019.

J226. Jong-Sen Lee. Unsupervised classification using polarimetric decomposition and the complex Wishart classifier. / Jong-Sen Lee, Grunes M.R., Ainsworth T.L., Li-Jen Du, Schuler D.L., Cloude S.R. // IEEE Transactions on Geoscience and Remote Sensing. - 1999. - Vol. 37, No. 5. - P. 2249-2258.

J227. Chien-Min Lin. Monte Carlo simulations of scattering and emission from lossy dielectric random rough surfaces using the wavelet transform method. / Chien-Min Lin, Chi Hou Chan, Leung Tsang. // IEEE Transactions on Geoscience and Remote Sensing. - 1999. - Vol. 37, No. 5. - P. 2295-2304.

J228. Mitchell R.A. Robust statistical feature based aircraft identification. / Mitchell R.A., Westerkamp J.J. // IEEE Transactions on Aerospace and Electronic Systems. - 1999. - Vol. 35, No. 3. - P. 1077-1094.

J229. Gerlach K. Spatially distributed target detection in non-Gaussian clutter. IEEE Transactions on Aerospace and Electronic Systems. - 1999. - Vol. 35, No. 3. - P. 926-934.

J230. Song J.M. Fast Illinois solver code (FISC). / Song J.M., Lu C.C., Chew W.C., Lee S.W. // IEEE Antennas and Propagation Magazine. - 1998. - Vol. 40, No. 3. - P. 27-34.

J231. Anastassiu H.T. Integral equation modeling of cylindrically periodic scatterers in the interior of a cylindrical waveguide. / Anastassiu H.T., Volakis J.L., Filipovic D.S. // IEEE Transactions on Microwave Theory and Techniques. - 1998. - Vol. 46, No. 11. - P. 1713-1720.

J232. Prakash V.V.S. Sidewall inclined slot in a rectangular waveguide: theory and experiment. / Prakash V.V.S., Christopher S., Balakrishnan N. // IEE Proceedings - Microwaves, Antennas and Propagation. - 1998. - Vol. 145, No. 3. - P. 233-238.

J233. Theron I.P. Compact range radar cross-section measurements using a noise radar. / Theron I.P., Walton E.K., Gunawan S. // IEEE Transactions on Antennas and Propagation. - 1998. - Vol. 46, No. 9. - P. 1285-1288.

J234. Chao-Fu Wang. A fast full-wave analysis of scattering and radiation from large finite arrays of microstrip antennas. / Chao-Fu Wang, Feng Ling, Jian-Ming Jin. // IEEE Transactions on Antennas and Propagation. - 1998. - Vol. 46, No. 10. - P. 1467-1474.

J235. Jean-Fu Kiang. Scattering properties of circular cylinders with periodical corrugations in the azimuthal direction. IEEE Transactions on Antennas and Propagation. - 1998. - Vol. 46, No. 10. - P. 1589-1590.

J236. Jiming Song. The Fast Illinois Solver Code: requirements and scaling properties. / Jiming Song, Weng

Cho Chew. // IEEE Computational Science & Engineering. - 1998. - Vol. 5, No. 3. - P. 19-23.

J237. Wiesbeck W. Wide-band multiport antenna characterization by polarimetric RCS measurements. / Wiesbeck W., Heidrich E. // IEEE Transactions on Antennas and Propagation. - 1998. - Vol. 46, No. 3. - P. 341-350.

J238. Donohue D.J. Application of iterative moment-method solutions to ocean surface radar scattering. / Donohue D.J., Ku H.-C., Thompson D.R. // IEEE Transactions on Antennas and Propagation. - 1998. - Vol. 46, No. 1. - P. 121-132.

J239. Jean-Fu Kiang. Backscattering of TE waves by periodical surface with dielectric cover. IEEE Transactions on Antennas and Propagation. - 1998. - Vol. 46, No. 2. - P. 176-180.

J240. Nakamura M. Real-time and full polarimetric FM-CW radar and its application to the classification of targets. / Nakamura M., Yamaguchi Y., Yamada H. // IEEE Transactions on Instrumentation and Measurement. - 1998. - Vol. 47, No. 2. - P. 572-577.

J241. Yang J. Simple method for obtaining characteristic polarisation states. / Yang J., Yamaguchi Y., Yamada H., Sengoku M., Lin S.M. // Electronics Letters. - 1998. - Vol. 34, No. 5. - P. 441-443.

J242. Yunhan Dong. A new decomposition of radar polarization signatures. / Yunhan Dong, Forster B.C., Ticehurst C. // IEEE Transactions on Geoscience and Remote Sensing. - 1998. - Vol. 36, No. 3. - P. 933-939.

J243. Sarabandi K. Modeling and measurements of scattering from road surfaces at millimeter-wave frequencies. / Sarabandi K., Li E.S., Nashashibi A. // IEEE Transactions on Antennas and Propagation. - 1997. - Vol. 45, No. 11. - P. 1679-1688.

J244. Luneburg E. Comments on “The specular null polarization theory” (and Reply). / Luneburg E., Hubbert J. // IEEE Transactions on Geoscience and Remote Sensing. - 1997. - Vol. 35, No. 4. - P. 1070-1072.

J245. Rosloniec S. Novel microstrip-line directional filters. / Rosloniec S., Habib T. // IEEE Transactions on Microwave Theory and Techniques. - 1997. - Vol. 45, No. 9. - P. 1633-1637.

J246. Hean-Teik Chuah. Radar backscatter from a dense discrete random medium. / Hean-Teik Chuah, Tjuatja S., Fung A.K., Bredow J.W. // IEEE Transactions on Geoscience and Remote Sensing. - 1997. - Vol. 35, No. 4. - P. 892-900.

J247. Guo-Xin Fan. Scattering from a cylindrically conformal slotted waveguide array antenna. / Guo-Xin Fan, Jian-Ming Jin. // IEEE Transactions on Antennas and Propagation. - 1997. - Vol. 45, No. 7. - P. 1150-1159.

J248. Frolik J.L. Forward and inverse scattering for discrete layered lossy and absorbing media. / Frolik J.L., Yagle A.E. // IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing. - 1997. - Vol. 44, No. 9. - P. 710-722.

J249. Song J. Multilevel fast multipole algorithm for electromagnetic scattering by large complex objects. / Song J., Cai-Cheng Lu, Weng Cho Chew. // IEEE Transactions on Antennas and Propagation. - 1997. - Vol. 45, No. 10. - P. 1488-1493.

J250. Tzong-Jyh Chen. Calibration and measurement of a wideband six-port polarimetric measurement system. / Tzong-Jyh Chen, Tah-Hsiung Chu. // IEEE Transactions on Antennas and Propagation. - 1997. - Vol. 45, No. 7. - P. 1080-1085.

J251. Pillai R.S. A frequency-domain approach to shallow-water depth measurement. / Pillai R.S., Antoniou A. // IEEE Transactions on Geoscience and Remote Sensing. - 1997. - Vol. 35, No. 3. - P. 540-545.

J252. Cloude S.R. An entropy based classification scheme for land applications of polarimetric SAR. / Cloude S.R., Pottier E. // IEEE Transactions on Geoscience and Remote Sensing. - 1997. - Vol. 35, No. 1. - P. 68-78.

J253. Hirosawa H. Degree of polarization of radar backscatters from a mixed target. IEEE Transactions on Geoscience and Remote Sensing. - 1997. - Vol. 35, No. 2. - P. 466-470.

J254. Weng Cho Chew. Fast solution methods in electromagnetics. / Weng Cho Chew, Jian-Ming Jin, Cai-

Cheng Lu, Michielssen E., Song J.M. // IEEE Transactions on Antennas and Propagation. - 1997. - Vol. 45, No. 3. - P. 533-543.

J255. Pocock M.D. The complex bi-conjugate gradient solver applied to large electromagnetic scattering problems, computational costs, and cost scalings. / Pocock M.D., Walker S.P. // IEEE Transactions on Antennas and Propagation. - 1997. - Vol. 45, No. 1. - P. 140-146.

J256. Yong Up Lee. Distributed source modeling and direction-of-arrival estimation techniques. / Yong Up Lee, Jinho Choi, Iickho Song, Seong Ro Lee. // IEEE Transactions on Signal Processing. - 1997. - Vol. 45, No. 4. - P. 960-969.

J257. Cugiani C. Full-wave investigation of a corner reflector proposed as reference line target for automotive applications. / Cugiani C., Orta R., Savi P., Tascone R. // IEEE Transactions on Antennas and Propagation. - 1997. - Vol. 45, No. 12. - P. 1823-1829.

J258. Walker S.P. Parallel computation of time-domain integral equation analyses of electromagnetic scattering and RCS. / Walker S.P., Leung C.Y. // IEEE Transactions on Antennas and Propagation. - 1997. - Vol. 45, No. 4. - P. 614-619.

J259. Hean-Teik Chuah. A phase matrix for a dense discrete random medium: evaluation of volume scattering coefficient. / Hean-Teik Chuah, Tjuatja S., Fung A.K., Bredow J.W. // IEEE Transactions on Geoscience and Remote Sensing. - 1996. - Vol. 34, No. 5. - P. 1137-1143.

J260. Ufimtsev P.Y. Proceedings of Second International Workshop on Active Matrix Liquid Crystal Displays. Proceedings of the IEEE. - 1996. - Vol. 84, No. 12. - {no data available}.

J261. Yamaguchi Y. Polarimetric detection of objects buried in snowpack by a synthetic aperture FM-CW radar. / Yamaguchi Y., Moriyama T. // IEEE Transactions on Geoscience and Remote Sensing. - 1996. - Vol. 34, No. 1. - P. 45-51.

J262. Cloude S.R. A review of target decomposition theorems in radar polarimetry. / Cloude S.R., Pottier E. // IEEE Transactions on Geoscience and Remote Sensing. - 1996. - Vol. 34, No. 2. - P. 498-518.

J263. Hsiao-Chang Chu. Shielding and reflection properties of periodic fiber-matrix composite structures. / Hsiao-Chang Chu, Chun Hsiung Chen. // IEEE Transactions on Electromagnetic Compatibility. - 1996. - Vol. 38, No. 1. - P. 1-6.

J264. Sarabandi K. A novel bistatic scattering matrix measurement technique using a monostatic radar. / Sarabandi K., Nashashibi A. // IEEE Transactions on Antennas and Propagation. - 1996. - Vol. 44, No. 1. - P. 41-50.

J265. Chang P.S. Polarimetric backscatter from fresh and metamorphic snowcover at millimeter wavelengths. / Chang P.S., Mead J.B., Knapp E.J., Sadowy G.A., Davis R.E., McIntosh R.E. // IEEE Transactions on Antennas and Propagation. - 1996. - Vol. 44, No. 1. - P. 58-73.

J266. Jenn D.C. In-band scattering from arrays with parallel feed networks. / Jenn D.C., Flokas V. // IEEE Transactions on Antennas and Propagation. - 1996. - Vol. 44, No. 2. - P. 172-178.

J267. Heidary K. Scattering from an infinite conducting cylinder covered with a finite two-layer dielectric coating (modal approach). IEEE Transactions on Electromagnetic Compatibility. - 1996. - Vol. 38, No. 1. - P. 70-77.

J268. Cameron W.L. Simulated polarimetric signatures of primitive geometrical shapes. / Cameron W.L., Youssef N.N., Leung L.K. // IEEE Transactions on Geoscience and Remote Sensing. - 1996. - Vol. 34, No. 3. - P. 793-803.

J269. ZhiNing Chen. Electromagnetic scattering from a chiral cylinder-general case. / ZhiNing Chen, Wei Hong, WenXun Zhang. // IEEE Transactions on Antennas and Propagation. - 1996. - Vol. 44, No. 7. - P. 912-917.

J270. Hubbert J.C. Specular null polarization theory: applications to radar meteorology. / Hubbert J.C., Bringi V.N. // IEEE Transactions on Geoscience and Remote Sensing. - 1996. - Vol. 34, No. 4. - P. 859-873.

J271. Lindsay R.W. The discrete wavelet transform and the scale analysis of the surface properties of sea ice. / Lindsay R.W., Percival D.B., Rothrock D.A. // IEEE Transactions on Geoscience and Remote Sensing. - 1996. - Vol. 34, No. 3. - P. 771-787.

J272. Rihaczek A.W. Radar resolution of ideal point scatterers. IEEE Transactions on Aerospace and Electronic Systems. - 1996. - Vol. 32, No. 2. - P. 842-845.

J273. Guoqing Sun. A three-dimensional radar backscatter model of forest canopies. / Guoqing Sun, Ranson K.J. // IEEE Transactions on Geoscience and Remote Sensing. - 1995. - Vol. 33, No. 2. - P. 372-382.

J274. Yamaguchi Y. Two-dimensional and full polarimetric imaging by a synthetic aperture FM-CW radar. / Yamaguchi Y., Nishikawa T., Sengoku M., Boerner W.-M. // IEEE Transactions on Geoscience and Remote Sensing. - 1995. - Vol. 33, No. 2. - P. 421-427.

J275. Ferrazzoli P. Radar sensitivity to tree geometry and woody volume: a model analysis. / Ferrazzoli P., Guerriero L. // IEEE Transactions on Geoscience and Remote Sensing. - 1995. - Vol. 33, No. 2. - P. 360-371.

J276. Stjernman A. Dual-channel and multifrequency radar system calibration. / Stjernman A., Vivekanandan J., Nystrom A. // IEEE Transactions on Geoscience and Remote Sensing. - 1995. - Vol. 33, No. 2. - P. 325-330.

J277. Raghavan R.S. CFAR detection in clutter with unknown correlation properties. / Raghavan R.S., Qiu H.F., McLaughlin D.J. // IEEE Transactions on Aerospace and Electronic Systems. - 1995. - Vol. 31, No. 2. - P. 647-657.

J278. Jenn D.C. Inband scattering from arrays with series feed networks. / Jenn D.C., Seunghoon Lee. // IEEE Transactions on Antennas and Propagation. - 1995. - Vol. 43, No. 8. - P. 867-873.

J279. McLaughlin D.J. High resolution polarimetric radar scattering measurements of low grazing angle sea clutter. / McLaughlin D.J., Allan N., Twarog E.M., Trizna D.B. // IEEE Journal of Oceanic Engineering. - 1995. - Vol. 20, No. 3. - P. 166-178.

J280. Ellis G.A. An analysis technique for buried inhomogeneous dielectric objects in the presence of an air-Earth interface. / Ellis G.A., Peden I.C. // IEEE Transactions on Geoscience and Remote Sensing. - 1995. - Vol. 33, No. 3. - P. 535-540.

J281. McLaughlin D.J. A bistatic polarimeter calibration technique. / McLaughlin D.J., Ren Z., Wu Y. // IEEE Transactions on Geoscience and Remote Sensing. - 1995. - Vol. 33, No. 3. - P. 796-799.

J282. Sarkar T.K. Using the matrix pencil method to estimate the parameters of a sum of complex exponentials. / Sarkar T.K., Pereira O. // IEEE Antennas and Propagation Magazine. - 1995. - Vol. 37, No. 1. - P. 48-55.

J283. Ross D.C. Hybrid finite element-modal analysis of jet engine inlet scattering. / Ross D.C., Volakis J.L., Anastassiu H.T. // IEEE Transactions on Antennas and Propagation. - 1995. - Vol. 43, No. 3. - P. 277-285.

J284. Tang C. Scattering from ice crystals at 94 and 220 GHz millimeter wave frequencies. / Tang C., Aydin K. // IEEE Transactions on Geoscience and Remote Sensing. - 1995. - Vol. 33, No. 1. - P. 93-99.

J285. Gau J.-R.J. New polarimetric calibration technique using a single calibration dihedral. / Gau J.-R.J., Burnside W.D. // IEE Proceedings - Microwaves, Antennas and Propagation. - 1995. - Vol. 142, No. 1. - P. 19-25.

J286. Soumya Nag. Electromagnetic plane wave scattering by a system of two uniformly lossy dielectric prolate spheroids in arbitrary orientation. / Soumya Nag, Sinha B.P. // IEEE Transactions on Antennas and Propagation. - 1995. - Vol. 43, No. 3. - P. 322-327.

J287. de Daran F. Modeling of electromagnetic waves scattered by a system of spherical particles. / de Daran F., Vigneras-Lefebvre V., Parneix J.P. // IEEE Transactions on Magnetics. - 1995. - Vol. 31, No. 3. - P. 1598-1601.

J288. Nag S.K. Electromagnetic scattering by a system of two parallel uniformly lossy dielectric prolate spheroids. / Nag S.K., Sinha B.P. // IEEE Transactions on Magnetics. - 1995. - Vol. 31, No. 3. - P. 1662-1665.

J289. Obelleiro-Basteiro F. An iterative physical optics approach for analyzing the electromagnetic scattering by large open-ended cavities. / Obelleiro-Basteiro F., Luis Rodriguez J., Burkholder R.J. // IEEE Transactions on Antennas and Propagation. - 1995. - Vol. 43, No. 4. - P. 356-361.

J290. Nashashibi A. A calibration technique for polarimetric coherent-on-receive radar systems. / Nashashibi A., Sarabandi K., Ulaby F.T. // IEEE Transactions on Antennas and Propagation. - 1995. - Vol. 43, No. 4. - P. 396-404.

J291. Tse-Tong Chia. The application of FDTD in hybrid methods for cavity scattering analysis. / Tse-Tong Chia, Burkholder R.J., Lee R. // IEEE Transactions on Antennas and Propagation. - 1995. - Vol. 43, No. 10. - P. 1082-1090.

J292. Rousseau P.R. A hybrid approach for calculating the scattering from obstacles within large, open cavities. / Rousseau P.R., Burkholder R.J. // IEEE Transactions on Antennas and Propagation. - 1995. - Vol. 43, No. 10. - P. 1068-1075.

J293. Fabregas X. Target spinor calibration (TSC) for polarimetric radar cross-section measurements. / Fabregas X., Romeu J., Broquetas A., Jofre L. // Electronics Letters. - 1995. - Vol. 31, No. 19. - P. 1694-1695.

J294. Leviatan Y. Analysis of electromagnetic scattering using arrays of fictitious sources. / Leviatan Y., Baharav Z., Heyman E. // IEEE Transactions on Antennas and Propagation. - 1995. - Vol. 43, No. 10. - P. 1091-1098.

J295. Taflove A. Reinventing electromagnetics: emerging applications for FD-TD computation. IEEE Computational Science & Engineering. - 1995. - Vol. 2, No. 4. - P. 24-34.

J296. Chen R. Analysis of scattering from rough surfaces at large incidence angles using a periodic-surface moment method. / Chen R., West J.C. // IEEE Transactions on Geoscience and Remote Sensing. - 1995. - Vol. 33, No. 5. - P. 1206-1213.

J297. Ross D.C. Overlapping modal and geometric symmetries for computing jet-engine inlet scattering. / Ross D.C., Volakis J.L., Anastassiu H.T. // IEEE Transactions on Antennas and Propagation. - 1995. - Vol. 43, No. 10. - P. 1159-1163.

J298. Jin Ya . Polarimetric scattering from heterogeneous particulate media. / Jin Ya ,Qiu. // Journal of Applied Physics. - 1995. - Vol. 78, No. 8. - P. 4835-4839.

J299. Fargues M.P. Investigations in the numerical behavior of the adaptive rank-revealing QR factorization. / Fargues M.P., Ferreira M.P. // IEEE Transactions on Signal Processing. - 1995. - Vol. 43, No. 11. - P. 2787-2791.

J300. Khalladi M. RCS of arbitrarily-shaped targets with the TLM method. / Khalladi M., Morente J.A., Porti J.A. // IEEE Transactions on Antennas and Propagation. - 1994. - Vol. 42, No. 6. - P. 891-893.

J301. Touzi R. The principle of speckle filtering in polarimetric SAR imagery. / Touzi R., Lopes A. // IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 5. - P. 1110-1114.

J302. Tomiyasu K. Image processing of synthetic aperture radar range ambiguous signals. IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 5. - P. 1114-1117.

J303. Blanchard J.L. Integral equation analysis of artificial media. / Blanchard J.L., Newman E.H., Peters M.E. // IEEE Transactions on Antennas and Propagation. - 1994. - Vol. 42, No. 5. - P. 727-731.

J304. Soudais P. Iterative solution of a 3-D scattering problem from arbitrary shaped multidielectric and multiconducting bodies. IEEE Transactions on Antennas and Propagation. - 1994. - Vol. 42, No. 7. - P. 954-959.

J305. Elshafiey I. Scattering from two-dimensional objects embedded in multilayered media. / Elshafiey I., Udpa L., Udpa S.S. // IEEE Transactions on Magnetics. - 1994. - Vol. 30, No. 5. - P. 3160-3163.

J306. Ya-Qin Jin. Polarimetric scattering from a layer of random clusters of small spheroids. IEEE Transactions on Antennas and Propagation. - 1994. - Vol. 42, No. 8. - P. 1138-1144.

J307. Goggans P.M. Electromagnetic scattering from objects composed of multiple homogeneous regions using a region-by-region solution. / Goggans P.M., Kishk A.A., Glisson A.W. // IEEE Transactions on Antennas and Propagation. - 1994. - Vol. 42, No. 6. - P. 865-871.

J308. Jong-Sen Lee. Intensity and phase statistics of multilook polarimetric and interferometric SAR imagery. / Jong-Sen Lee, Hoppel K.W., Mango S.A., Miller A.R. // IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 5. - P. 1017-1028.

J309. Fung A.K. Numerical simulation of scattering from three-dimensional randomly rough surfaces. / Fung A.K., Shah M.R., Tjuatja S. // IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 5. - P. 986-994.

J310. Quegan S. A unified algorithm for phase and cross-talk calibration of polarimetric data-theory and observations. IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 1. - P. 89-99.

J311. Jay Kyoon Lee. Optimum polarizations in the bistatic scattering from layered random media. / Jay Kyoon Lee, Mudaliar S. // IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 1. - P. 169-176.

J312. Kwok R. Polarization signatures of frozen and thawed forests of varying environmental state. / Kwok R., Rignot E.J.M., Way J., Freeman A., Holt J. // IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 2. - P. 371-381.

J313. Monakov A.A. Estimation of the covariance matrix for dependent signal samples: polarization diversity systems. IEEE Transactions on Aerospace and Electronic Systems. - 1994. - Vol. 30, No. 2. - P. 484-492.

J314. Sarabandi K. Power lines: radar measurements and detection algorithm for polarimetric SAR images. / Sarabandi K., Pierce L., Oh Y., Ulaby F.T. // IEEE Transactions on Aerospace and Electronic Systems. - 1994. - Vol. 30, No. 2. - P. 632-643.

J315. Porti J.A. Wire-junction matrix model for the TLM method. / Porti J.A., Khalladi M., Morente J.A., Gimenez G., Carrion M.C. // IEEE Transactions on Antennas and Propagation. - 1994. - Vol. 42, No. 2. - P. 282-285.

J316. Joughin I.R. Probability density functions for multilook polarimetric signatures. / Joughin I.R., Winebrenner D.P., Percival D.B. // IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 3. - P. 562-574.

J317. Sarabandi K. Calibration of a polarimetric synthetic aperture radar using a known distributed target. IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 3. - P. 575-582.

J318. Unal C.M.H. Calibration of a polarimetric radar using a rotatable dihedral corner reflector. / Unal C.M.H., Niemeijer R.J., van Sinttruyen J.S., Ligthart L.P. // IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 4. - P. 837-845.

J319. Weimin Sun. Edge-based FEM solution of scattering from inhomogeneous and anisotropic objects. / Weimin Sun, Balanis C.A. // IEEE Transactions on Antennas and Propagation. - 1994. - Vol. 42, No. 5. - P. 627-632.

J320. Guissard A. Mueller and Kennaugh matrices in radar polarimetry. IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 3. - P. 590-597.

J321. Hubbert J.C. A comparison of radar, optic, and specular null polarization theories. IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 3. - P. 658-671.

J322. Guissard A. Phase calibration of polarimetric radars from slightly rough surfaces. IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 3. - P. 712-715.

J323. Ya-Qiu Jin. Numerical eigenanalysis of the coherency matrix for a layer of random nonspherical scatterers. / Ya-Qiu Jin, Cloude S.R. // IEEE Transactions on Geoscience and Remote Sensing. - 1994. - Vol. 32, No. 6. - P. 1179-1185.

J324. Sletten M.A. An ultrawideband, polarimetric radar for the study of sea scatter. / Sletten M.A., Trizna D.B. // IEEE Transactions on Antennas and Propagation. - 1994. - Vol. 42, No. 11. - P. 1461-1466.

J325. Hoppe D.J. Higher order impedance boundary conditions applied to scattering by coated bodies of revolution. / Hoppe D.J., Rahmat-Samii Y. // IEEE Transactions on Antennas and Propagation. - 1994. - Vol. 42, No. 12. - P. 1600-1611.

J326. Pazmany A.L. The use of estimation techniques to reduce noncoherent polarimetric measurement errors. / Pazmany A.L., McIntosh R.E. // IEEE Transactions on Antennas and Propagation. - 1994. - Vol. 42, No. 9. - P. 1325-1328.

J327. Hanson G.W. The RCS of a microstrip dipole deduced from an expansion of pole singularities. / Hanson G.W., Nyquist D.P. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 3. - P. 376-379.

J328. Wigneron J.-P. Microwave emission of vegetation: sensitivity to leaf characteristics. / Wigneron J.-P., Calvet J.-C., Kerr Y., Chanzy A., Lopes A. // IEEE Transactions on Geoscience and Remote Sensing. - 1993. - Vol. 31, No. 3. - P. 716-726.

J329. Wong Y. A new clustering algorithm applicable to multispectral and polarimetric SAR images. / Wong Y., Posner E.C. // IEEE Transactions on Geoscience and Remote Sensing. - 1993. - Vol. 31, No. 3. - P. 634-644.

J330. Lo K.W. Comments on a “A neural network approach to MVDR beamforming problem”. / Lo K.W., Chang P.R., Yang W.H., Chan K.K. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 9. - P. 1344-1346.

J331. Russchenberg H.W.J. Deriving the linear depolarisation ratio of precipitation from copolar radar measurements. / Russchenberg H.W.J., Ligthart L.P. // Electronics Letters. - 1993. - Vol. 29, No. 12. - P. 1051-1053.

J332. Sarabandi K. Monte Carlo simulation of scattering from a layer of vertical cylinders. / Sarabandi K., Polatin P.F., Ulaby F.T. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 4. - P. 465-475.

J333. Hua Y. Imaging of point scatterers from step-frequency ISAR data. / Hua Y., Baqai F.A., Zhu Y., Heilbronn D.J. // IEEE Transactions on Aerospace and Electronic Systems. - 1993. - Vol. 29, No. 1. - P. 195-205.

J334. Towers M.S. Electromagnetic scattering from an arbitrary, inhomogeneous 2-D object-a finite and infinite element solution. / Towers M.S., McCowen A., Macnab J.A.R. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 6. - P. 770-777.

J335. Vivekanandan J. Polarimetric radar modeling of mixtures of precipitation particles. / Vivekanandan J., Raghavan R., Bringi V.N. // IEEE Transactions on Geoscience and Remote Sensing. - 1993. - Vol. 31, No. 5. - P. 1017-1030.

J336. Giuli D. Radar target scattering matrix measurement through orthogonal signals. / Giuli D., Fossi M., Facheris L. // IEE Proceedings F Radar and Signal Processing. - 1993. - Vol. 140, No. 4. - P. 233-242.

J337. Kalbasi K. A multilevel formulation of the method of moments [EM scattering]. / Kalbasi K., Demarest K.R. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 5. - P. 589-599.

J338. Khalladi M. Two near-to far-zone approaches for scattering problems using the TLM method. / Khalladi M., Morenta J.A., Porti J.A., Gimenez G. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 4. - P. 502-505.

J339. Lam C.M. Calculation of Mueller matrices and polarization signatures for a slab of random medium using vector radiative transfer. / Lam C.M., Ishimaru A. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 7. - P. 851-862.

J340. Chien-Chang Huang. Analysis of wire scatterers with nonlinear or time-harmonic loads in the frequency domain. / Chien-Chang Huang, Tah-Hsiung Chu. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 1. - P. 25-30.

J341. Mead J.B. Polarimetric observations and theory of millimeter-wave backscatter from snow cover. / Mead J.B., Chang P.S., Lohmeier S.P., Langlois P.M., McIntosh R. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 1. - P. 38-46.

J342. Chufo R.L. A radar coal thickness sensor. / Chufo R.L., Johnson W.J. // IEEE Transactions on Industry Applications. - 1993. - Vol. 29, No. 5. - P. 834-840.

J343. He S. Electromagnetic scattering from a stratified bi-isotropic (nonreciprocal chiral) slab: numerical computations. / He S., Hu Y. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 8. - P. 1057-1062.

J344. Hong W. Radar cross-section of dielectric-coated conducting cylinder loaded with periodic metallic strips using mixed SDM, CGM and FFT:TE incidence. / Hong W., Zhu Z. // IEE Proceedings H Microwaves, Antennas and Propagation. - 1993. - Vol. 140, No. 5. - P. 373-377.

J345. Schneider J. Detection of tunnels in low loss media illuminated by a transient pulse. / Schneider J., Peden I.C. // IEEE Transactions on Geoscience and Remote Sensing. - 1993. - Vol. 31, No. 2. - P. 503-506.

J346. Howell R. Measurement of ocean wave spectra using narrow-beam HE radar. / Howell R., Walsh J. // IEEE Journal of Oceanic Engineering. - 1993. - Vol. 18, No. 3. - P. 296-305.

J347. Caorsi S. Numerical electromagnetic inverse-scattering solutions for two-dimensional infinite dielectric cylinders buried in a lossy half-space. / Caorsi S., Gragnani G.L., Pastorino M. // IEEE Transactions on Microwave Theory and Techniques. - 1993. - Vol. 41, No. 2. - P. 352-357.

J348. Gurel L. Recursive T -matrix algorithms for the solution of electromagnetic scattering from strip and patch geometries. / Gurel L., Chew W.C. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 1. - P. 91-99.

J349. De Grandi G. A coding algorithm for the covariance matrix representation of polarimetric radar data. / De Grandi G., Lavalle C., Sieber A.J. // IEEE Transactions on Geoscience and Remote Sensing. - 1993. - Vol. 31, No. 1. - P. 292-295.

J350. Tran T.V. An improved pulse-basis conjugate gradient FFT method for the thin conducting plate problem. / Tran T.V., McCowen A. // IEEE Transactions on Antennas and Propagation. - 1993. - Vol. 41, No. 2. - P. 185-190.

J351. Yueh S.H. Symmetrization of cross-polarized responses in polarimetric radar images using reciprocity. / Yueh S.H., Nghiem S.V., Kwok R. // IEEE Transactions on Geoscience and Remote Sensing. - 1993. - Vol. 31, No. 6. - P. 1180-1185.

J352. Ulaby F.T. Statistical properties of the Mueller matrix of distributed targets. / Ulaby F.T., Sarabandi K., Nashashibi A. // IEE Proceedings F Radar and Signal Processing. - 1992. - Vol. 139, No. 2. - P. 136-146.

J353. Peterson A.F. Accuracy of 3-D radiation boundary conditions for use with the vector Helmholtz equation. IEEE Transactions on Antennas and Propagation. - 1992. - Vol. 40, No. 3. - P. 351-355.

J354. Tzong-Jyh Chen. Calibration of wide-band polarimetric measurement system using three perfectly polarization-isolated calibrators. / Tzong-Jyh Chen, Tah-Hsiung Chu. // IEEE Transactions on Antennas and Propagation. - 1992. - Vol. 40, No. 12. - P. 1573-1577.

J355. Devayya R. The numerical calculation of rough surface scattering by the conjugate gradient method. / Devayya R., Wingham D.J. // IEEE Transactions on Geoscience and Remote Sensing. - 1992. - Vol. 30, No. 3. - P. 645-648.

J356. Sarabandi K. Calibration of a polarimetric imaging SAR. / Sarabandi K., Pierce L.E., Ulaby F.T. // IEEE Transactions on Geoscience and Remote Sensing. - 1992. - Vol. 30, No. 3. - P. 540-549.

J357. Freeman A. Calibration of Stokes and scattering matrix format polarimetric SAR data. / Freeman A., van Zyl J.J., Klein J.D., Zebker H.A., Shen Y. // IEEE Transactions on Geoscience and Remote Sensing. - 1992. - Vol. 30, No. 3. - P. 531-539.

J358. Antar Y.M.M. Circular polarization for remote sensing of precipitation: polarization diversity work at the National Research Council of Canada. / Antar Y.M.M., Hendry A., McCormick G.C. // IEEE Antennas and Propagation Magazine. - 1992. - Vol. 34, No. 6. - P. 7-16.

J359. Gedney S.D. Electromagnetic transmission through inhomogeneously filled slots in a thick conducting plane-arbitrary incidence. / Gedney S.D., Mittra R. // IEEE Transactions on Electromagnetic Compatibility. - 1992. - Vol. 34, No. 4. - P. 404-415.

J360. Yamaguchi Y. On characteristic polarization states in the cross-polarized radar channel. / Yamaguchi Y., Boerner W.-M., Eom H.J., Sengoku M., Motooka S., Abe T. // IEEE Transactions on Geoscience and Remote Sensing. - 1992. - Vol. 30, No. 5. - P. 1078-1080.

J361. Touzi R. Polarimetric discriminators for SAR images. / Touzi R., Goze S., Le Toan T., Lopes A., Mougin E. // IEEE Transactions on Geoscience and Remote Sensing. - 1992. - Vol. 30, No. 5. - P. 973-980.

J362. Sarabandi K. Measurement and calibration of differential Mueller matrix of distributed targets. / Sarabandi K., Oh Y., Ulaby F.T. // IEEE Transactions on Antennas and Propagation. - 1992. - Vol. 40, No. 12. - P. 1524-1532.

J363. Sarabandi K. Performance characterization of polarimetric active radar calibrators and a new single antenna design. / Sarabandi K., Oh Y., Ulaby F.T. // IEEE Transactions on Antennas and Propagation. - 1992. - Vol. 40, No. 10. - P. 1147-1154.

J364. Barile E.C. Some limitations on the effectiveness of airborne adaptive radar. / Barile E.C., Fante R.L., Torres J.A. // IEEE Transactions on Aerospace and Electronic Systems. - 1992. - Vol. 28, No. 4. - P. 1015-1032.

J365. King A.S. Scattering from a finite array of microstrip patches. / King A.S., Bow W.J. // IEEE Transactions on Antennas and Propagation. - 1992. - Vol. 40, No. 7. - P. 770-774.

J366. Moheb H. Numerical solution of integral equations for dielectric objects of prismatic shapes. / Moheb H., Shafai L. // IEEE Transactions on Antennas and Propagation. - 1991. - Vol. 39, No. 6. - P. 758-766.

J367. Tsang L. Polarimetric signatures of a layer of random nonspherical discrete scatterers overlying a homogeneous half-space based on first- and second-order vector radiative transfer theory [geophysical radar remote sensing]. / Tsang L., Ding K.-H. // IEEE Transactions on Geoscience and Remote Sensing. - 1991. - Vol. 29, No. 2. - P. 242-253.

J368. Mendes L. TE-scattering from dense homogeneous infinite dielectric cylinders of arbitrary cross-section. / Mendes L., Arvas E. // IEEE Transactions on Magnetics. - 1991. - Vol. 27, No. 5. - P. 4295-4298.

J369. Jorgenson R.E. Scattering from structured slabs having two-dimensional periodicity. / Jorgenson R.E., Mittra R. // IEEE Transactions on Antennas and Propagation. - 1991. - Vol. 39, No. 2. - P. 151-157.

J370. Mead J.B. Polarimetric scattering from natural surfaces at 225 GHz. / Mead J.B., Langlois P.M., Chang P.S., McIntosh R.E. // IEEE Transactions on Antennas and Propagation. - 1991. - Vol. 39, No. 9. - P. 1405-1411.

J371. van Zyl J.J. Data volume reduction for single-look polarimetric imaging radar data. / van Zyl J.J., Burnette C.F. // IEEE Transactions on Geoscience and Remote Sensing. - 1991. - Vol. 29, No. 5. - P. 784-786.

J372. Kozu T. Effects of signal decorrelation on pulse-compressed waveforms for nadir-looking spaceborne radar. IEEE Transactions on Geoscience and Remote Sensing. - 1991. - Vol. 29, No. 5. - P. 786-790.

J373. McCowen A. Matrix interpretation of the spectral iteration technique for 3D dielectric scatterers in the resonance region. / McCowen A., Tran T.V. // IEE Proceedings H Microwaves, Antennas and Propagation. - 1991. - Vol. 138, No. 3. - P. 219-224.

J374. Freeman A. A new system model for radar polarimeters. IEEE Transactions on Geoscience and Remote Sensing. - 1991. - Vol. 29, No. 5. - P. 761-767.

J375. Joseph J. Time domain analysis by the point-matched finite element method. / Joseph J., Sober T.J.,

Gohn K.J., Konrad A. // IEEE Transactions on Magnetics. - 1991. - Vol. 27, No. 5. - P. 3852-3855.

J376. Sun G. A radar backscatter model for discontinuous coniferous forests. / Sun G., Simonett D.S., Strahler A.H. // IEEE Transactions on Geoscience and Remote Sensing. - 1991. - Vol. 29, No. 4. - P. 639-650.

J377. Blejer D.J. Physical optics polarization scattering matrix for a top hat reflector. IEEE Transactions on Antennas and Propagation. - 1991. - Vol. 39, No. 6. - P. 857-859.

J378. Whitt M.W. A general polarimetric radar calibration technique. / Whitt M.W., Ulaby F.T., Polatin P., Liepa V.V. // IEEE Transactions on Antennas and Propagation. - 1991. - Vol. 39, No. 1. - P. 62-67.

J379. Chamberlain N.E. Radar target identification of aircraft using polarization-diverse features. / Chamberlain N.E., Walton E.K., Garber F.D. // IEEE Transactions on Aerospace and Electronic Systems. - 1991. - Vol. 27, No. 1. - P. 58-67.

J380. Mead J.B. Polarimetric backscatter measurements of deciduous and coniferous trees at 225 GHz. / Mead J.B., McIntosh R.E. // IEEE Transactions on Geoscience and Remote Sensing. - 1991. - Vol. 29, No. 1. - P. 21-28.

J381. Boerner W.-M. On the basic principles of radar polarimetry: the target characteristic polarization state theory of Kennaugh, Huynen's polarization fork concept, and its extension to the partially polarized case. / Boerner W.-M., Yan W.-L., Xi A.-Q., Yamaguchi Y. // Proceedings of the IEEE. - 1991. - Vol. 79, No. 10. - P. 1538-1550.

J382. Cwik T. Method of moment solutions to scattering problems in a parallel processing environment. / Cwik T., Partee J., Patterson J. // IEEE Transactions on Magnetics. - 1991. - Vol. 27, No. 5. - P. 3837-3840.

J383. Peterson A.F. Analysis of heterogeneous electromagnetic scatterers: research progress of the past decade. Proceedings of the IEEE. - 1991. - Vol. 79, No. 10. - P. 1431-1441.

J384. Gordon R.K. PDE techniques for solving the problem of radar scattering by a body of revolution. / Gordon R.K., Mittra R. // Proceedings of the IEEE. - 1991. - Vol. 79, No. 10. - P. 1449-1458.

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