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ТЕМАТИЧЕСКИЙ РЕФЕРАТИВНЫЙ СБОРНИК № 6-1

“Radar Doppler Effect”
(«Доплеровский эффект в радиолокации»)

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ТЕМАТИЧЕСКИЙ РЕФЕРАТИВНЫЙ СБОРНИК № 6-1

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Журнальные публикации

"Ground Moving Targets Imaging Algorithm for Synthetic Aperture Radar"

It is well known that the motion of a target induces range migration, especially for high-resolution synthetic aperture radar (SAR) systems. Ground moving target imaging necessitates the correction of the unknown range migration. To finely refocus a moving target, one must accurately obtain the motion parameters for compensating the target trajectory. However, in practice, these parameters usually cannot be precisely estimated. This paper proposes a new imaging approach for ground moving targets without a priori knowledge of their motion parameters. In the devised method, the azimuth compression function is constructed in range frequency domain, which can eliminate the coupling effect between range and azimuth. Theoretical analysis confirms that the methodology can precisely focus targets without interpolation procedure. The effectiveness of the proposed imaging technique is demonstrated by both simulated and real airborne SAR data. [J1]

"Scattering and Doppler Spectral Analysis for Two-Dimensional Linear and Nonlinear Sea Surfaces"

Two-dimensional linear and second-order Creamer [Creamer (2)] nonlinear sea-surface models are combined with the second-order small-slope approximation method to comparatively study the electromagnetic scattering and the Doppler spectral characteristics from sea surfaces. Due to nonlinear hydrodynamics, the bistatic normalized radar cross section (NRCS) calculated from Creamer (2) surfaces is slightly larger than its linear surface counterpart for scattering angles departing from the specular direction, and the Creamer (2) surface backscattering coefficient increases as well for wind direction angles around upwind and downwind, whereas, for the crosswind direction, it is interesting to note that the observations are contrary. However, as was pointed out by Toporkov in a 1-D surface case, the effect of the nonlinear surface model on the average NRCS is minute. In particular, the Doppler spectra of the backscattered echoes are compared for the linear and Creamer (2) surfaces at various incident angles. It is seen, as expected, that the Doppler shifts and spectral widths of 2-D Creamer (2) surfaces exhibit different features compared with those of the linear surfaces, agreeing with the 1-D cases. However, for larger incident angles, the Doppler spectral broadening for Creamer (2) surfaces is not as severe as was reported in previous 1-D studies that used full Creamer model. The reason for this discrepancy appears to be the reduced nature of the Creamer (2) approximation. Moreover, studies of the Doppler characteristics for different wind directions demonstrate that nonlinear effects become weaker as the wind direction varies from upwind to crosswind. [J2]

"Bias Correction and Doppler Measurement for Polarimetric Phased-Array Radar"

This paper discusses ways to avoid and/or mitigate biases in polarimetric variables inherent to agile-beam planar phased-array radars. Two bias-avoiding schemes produce unbiased estimates of the polarimetric backscattering covariance matrix which are then combined into bias-free polarimetric variables. One concerns full polarimetric measurements and calls for adjusting the amplitudes and phases of the array elements so that the transmitted field equals that generated by a mechanically steered polarimetric weather radar antenna; this is followed by an additional adjustment of the received fields. The second scheme is also applicable to full polarimetric measurements but involves adjustments only of the received fields. Crucial to both schemes is decoupling of the Doppler effects from the terms of the covariance matrix. It is a significant part of the bias issue that had not been previously addressed. A scheme to reduce bias applicable to nondepolarizing media (i.e., diagonal backscattering matrix) is also addressed; it calls for multiplication of the fields received by each dipole as opposed to a combination of multiplication and addition required for full correction. The schemes are applied to the alternate transmission and simultaneous reception polarimetric mode and the simultaneous transmission and simultaneous reception mode. [J3]

"Application of a Simple Adaptive Estimator for an Atmospheric Doppler Radar"

A simple method for estimating parameters of the Doppler spectrum of atmospheric signals is described. The

method is based on an adaptive filter processing that has been widely used in telecommunications but rarely applied in measurements using atmospheric radars. The method has been tested using both synthetic and real data obtained by the radar profiler-Transportable Atmospheric Radar (TARA)-and the weather radar-International Research Centre for Telecommunications and Radar (IRCTR) Drizzle Radar (IDRA)-both developed by IRCTR. The method is compared with the traditional pulse-pair method and fast Fourier transform (FFT)-based methods, as well as with the IRCTR FFT-based method implemented in the TARA and IDRA processing including an additional noise clipping stage. The tests have demonstrated high efficiency of the adaptive filtering estimator under low signal-to-noise ratio conditions. The applicability of adaptive estimations in radar meteorology and the limitations associated with a sample length are discussed. [J4]

"Using Doppler Spectra to Separate Hydrometeor Populations and Analyze Ice Precipitation in Multilayered Mixed-Phase Clouds"

Multimodality of cloud radar Doppler spectra is used to partition cloud particle phases and separate distinct ice populations in the radar sample volume, thereby facilitating the analysis of individual ice showers in multilayered mixed-phase clouds. A 35-GHz cloud radar located at Barrow, Alaska, during the Mixed-Phase Arctic Cloud Experiment collected the Doppler spectra. Data from a pair of collocated depolarization lidars confirmed the presence of two liquid cloud layers reported in this letter. Both of these cloud layers were embedded in ice precipitation yet maintained their liquid. The spectral separation of the ice precipitation yielded two distinct ice populations: the ice initiated within the two liquid cloud layers and the ice precipitation formed in the higher cloud layers. The comparisons of ice fall velocity-versus-radar reflectivity relationships derived for distinct showers reveal that a single relationship does not properly represent the ice showers during this period. [J5]

"DOMUS: DOppler MUltiple-Scattering Simulator"

Multiple scattering (MS) strongly affects CloudSat's W-band cloud-profiling radar (CPR) reflectivity when the satellite is overpassing moderate and heavy precipitation systems. With the upcoming deployment of W-band Doppler radars in space-Earth Clouds, Aerosols, and Radiation Explorer's CPR in primis-and the goal of retrieving vertical motions within convective systems, there is an urgent need to assess the impact of MS onto the Doppler signatures. A Monte Carlo code capable of simulating the reflectivity enhancement due to higher orders of scattering has been extended to include the Doppler effects. This paper presents the main guidelines for the inclusion of the Doppler analysis into the Monte Carlo scheme. To our knowledge, this simulator is the first one capable of simulating realistic Doppler signals in the presence of MS. The case studies are first presented in uniform beam-filling conditions for the profiles extracted from a cloud-resolving model simulation of deep convection (i.e., 1-D profiles are used to characterize a stratified atmosphere). The simulations demonstrate that, at ranges where MS contributions affect the overall radar signal, two main features appear as the following: 1) The Doppler spectrum tends to broaden with increasing MS enhancement, adding up to the single-scattering (SS) Doppler fading due to the satellite motion; and 2) the mean Doppler of the backscattered signal departs from the mean Doppler determined by the combined effect of the vertical-wind and hydrometeor-terminal velocities at all range bins below the altitude where the MS contribution significantly overcomes the SS. The simulator can be run in nonuniform-beam-filling conditions as well (i.e., a 3-D field is used to characterize the atmosphere at scales smaller than the radar resolution). With its cutting-edge capabilities, it provides a unique tool for the evaluation of the performances of the upcoming high-frequency spaceborne Doppler radars. [J6]

"Focusing of Medium-Earth-Orbit SAR With Advanced Nonlinear Chirp Scaling Algorithm"

The signal processing of the medium-Earth-orbit synthetic aperture radar (SAR) is more challenging than that of the current low-Earth-orbit SAR because the imaging geometry is more complicated, and the range and azimuth variances are more severe. This paper deals with these imaging problems in three aspects. First, an advanced hyperbolic range equation (AHRE) is proposed for the first time, which is more precise for a spaceborne SAR than the conventional hyperbolic range equation (CHRE). Second, the point target spectrum based on the AHRE is analytically derived, which is useful for developing efficient SAR processing algorithms. Third, the well-known nonlinear chirp scaling (NLCS) algorithm is modified according to this new spectrum, and the so-called AHRE-based advanced NLCS (A-NLCS) algorithm is established. The simulation results validate the correctness of our method for L-band SAR systems at altitudes from 1000 to 10000 km with an azimuth resolution around 3 m. It is also shown that the A-NLCS algorithm has better performance than the CHRE-based algorithms in longer integration time cases. Therefore, we recommend the A-NLCS algorithm for a spaceborne SAR with a lower frequency, finer resolution, and higher satellite altitude. [J7]

"Performance Bounds and Angular Resolution Limit for the Moving Colocated MIMO Radar"

To identify a target, the moving noncoherent colocated multiple-input multiple-output (MIMO) radar system takes advantage of multiple antennas in transmission and reception which are close in space. In this paper, we study the estimation performance and the resolution limit for this scheme in which each array geometry is described by the sample-variance of the sensor distribution. So, our analysis encompasses any sensor distributions, including varying intersensors distances or/and lacunar (missing sensors) configuration. As in the space-time MIMO model considered here the radar is moving, the target Doppler frequency cannot be assumed invariant to the target position/angle. The first part of this paper derives and analyzes closed form (nonmatrix) expressions of the deterministic Cramer-Rao lower bound (CRB) for the direction and the velocity of a moving target contaminated by a structured noise (clutter echoes) and a background noise, including the cases of the clutter-free environment and the high signal-to-noise ratio (SNR) regime. The analysis of the proposed expressions of the CRB allows to better understand the characterization of the target. In particular, we prove the coupling between the direction parameter and the velocity of the target is linear with the radar velocity. In the second part, we focus our study on the analytical (closed form) derivation and the analysis of the angular resolution limit (ARL). Based on the resolution of an equation involving the CRB, the ARL can be interpreted as the minimal separation to resolve two closely spaced targets. Consequently, the ARL is a key quantity to evaluate the performance of a radar system. We show that the ARL is in fact quasi-invariant to the movement of the MIMO radar. [J8]

"Track-before-detect procedures for low pulse repetition frequency surveillance radars"

In this study, the authors present a dynamic programming (DP)-based tracking-before-detect (DP TBD) procedure with reference to a low pulse repetition frequency (PRF) surveillance radar framework. In order to avoid non-linear transformation and meanwhile exploit the ambiguous Doppler information, which is eliminated in most of the literature, the authors model the target dynamics in the measurement coordinates defined by range and apparent Doppler. The target state evolutions in the range-apparent Doppler domain are considered as a hybrid system with the ambiguous number deemed as mode variable. Ambiguity number (or mode) transitions are modelled as state dependent. The authors present a DP TBD method for joint maximum a posteriori(MAP) estimation of the target trajectory in the range-apparent Doppler maps and the corresponding ambiguity sequence, both assumptions of known and unknown nuisance parameters (target power and noise variance) are considered. The detection and tracking performance of the proposed procedure are investigated under several system settings. The effect of the prior uncertainty of the nuisance parameters on the performance is also studied. [J9]

"Analysing and compensating the effects of range and Doppler frequency migrations in linear frequency modulation pulse compression radar"

The pulse compression and Doppler processing (PCDP) method has been extensively used to detect low-speed and uniform-speed targets in linear frequency modulation (LFM) pulse compression radar. However, the PCDP method is affected by range migration (RM) and Doppler frequency migration (DFM) when detecting high-speed and accelerating targets. In this paper, the authors analyse and quantify these effects, and obtain the relationships of the optimal number of pulses and the threshold number of pulses with RM and DFM. It shows that when the number of pulses equals its optimal value, the maximum output signal-to-noise ratio can be obtained; when the number of pulses is greater than its threshold value, the migrations should be compensated. Then the authors propose a method based on the scaling processing and the fractional Fourier transform to remove the two migrations. In the end, the authors give a target detection experiment to show that the proposed method can effectively compensate these migrations. [J10]

"Clutter modelling for space-time adaptive processing in airborne radar"

The presence of clutter can be highly detrimental to detection of targets in airborne radar systems. Space-time adaptive processing (STAP) attempts to alleviate the problem by exploiting angle-Doppler inter-relationships to suppress clutter. The requirements for modelling of clutter data that are suitable for the application of STAP are considered in this study. Examples of clutter generated using the ELMBAARC program in bistatic and monostatic applications are provided. Modelling of internal clutter motion is considered, together with its effect on the clutter domain in angle-Doppler space. Modelling of non-homogeneous clutter is also considered. [J11]

"Experimental Determination of the Sea Correlation Time Using GNSS-R Coherent Data"

The feasibility of the Global Navigation Satellite Signal Reflectometry (GNSS-R) techniques has been proven for remote determination of sea state. When using GNSS-R techniques, coherent integration time is limited by the correlation time of the surface under observation which, in the case of the ocean, depends on sea state. In this letter, a new technique to retrieve the sea correlation time at L-band using GNSS-R coherent data is presented

along with experimental results. [J12]

"Maximum Likelihood Angle-Doppler Estimator using Importance Sampling"

A new joint angle-Doppler maximum likelihood estimator (MLE) based on importance sampling (IS) is proposed. The IS method allows one to compute the maximum likelihood estimator in a computationally efficient manner. It is based upon generating random variates using an importance function which approximates the compressed likelihood function. The performance is very close to the Cramer-Rao lower bound (CRLB). The choice of the algorithm parameters, which will affect the estimation performance, is also addressed. With a reasonable parameter choice, even the angles/Dopplers for closely spaced sources can be accurately estimated, whereas conventional subspace methods fail. Comparison with some suboptimal methods demonstrates that the IS method produces better performance at low signal-to-noise (SNR) and/or a small number of snapshots. [J13]

"Electromagnetic scattering from wind blown waves and ripples modulated by longer waves under laboratory conditions"

Laboratory radar measurements at low grazing angle of long waves of different steepness in the presence of wind waves were examined. The radar cross-section (RCS) variation was found to agree closely with the composite model. The effect of the orbital velocity of the long waves was observable in the Doppler spectra and could be used to determine the wave height; however, other aspects of the Doppler spectra could not be satisfactorily explained by the composite model. Electromagnetic (EM) scattering results were also generated using the Forward-backward code in conjunction with a two-dimensional hydrodynamic code that produced time-dependent wave profiles of long waves with wind blown ripples. The numerical results showed close agreement with the normalised RCS calculated from Bragg scattering theory, Г‚Bї0==B|2, but not with the composite model. [J14]

"DataWare: Sea Clutter and Small Boat Radar Reflectivity Databases [JBest of the Web]"

In this issue, "Best of the Web" presents online radar reflectivity databases, which are free of charge to the international research community. Databases such as these are used for the characterization of interference (including noise, sea clutter and land clutter, among others) in radar systems, and the development of signal processing techniques that reduce the detrimental effects of this unwanted interference. The data can also be used for the development and evaluation of signal processing techniques aimed at detecting and tracking man-made objects by separating targets from interference based on Doppler and amplitude characteristics. These signal processing techniques include moving target indication (MTI), pulse-Doppler, space-time adaptive processing, track-before-detect (TkBD), and constant false alarm rate (CFAR) processing. [J15]

"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. [J16]

"A New Slant-Range Velocity Ambiguity Resolving Approach of Fast Moving Targets for SAR System"

This paper describes an ambiguity resolving approach for slant-range velocity estimation which utilizes the wideband characteristic of the transmitted signal (multiple wavelengths). Based on the wavelength dual-wavelength radar data. Then, two effective approaches are introduced to focus the moving target no matter the Doppler ambiguity exists or not. The slant-range velocity is estimated by the number of azimuth cell displacements between the two focused images. Both imaging methods have different properties and advantages. A performance analysis is made, and deleterious factors in practice are analyzed in detail. The

effectiveness of the unambiguous slant-range velocity estimation approach is demonstrated with the use of simulated and real data. [J17]

"On the Doppler Spreading Effect for the Range-Instantaneous-Doppler Technique in Inverse Synthetic Aperture Radar Imagery"

Inverse synthetic aperture radar (ISAR) is an all-weather radar technique which may generate high-resolution images of noncooperative targets. The standard range-Doppler algorithm (RDA) is usually employed for image generation. However, the images obtained with RDA are usually blurred because of the relative motion between radar and target. As a consequence, motion compensation techniques should be used to improve the imagery quality. The range-instantaneous-Doppler (RID) technique based on time-frequency transforms has been proposed for obtaining a sequence of focused ISAR images without the need of using motion compensation techniques. However, in this letter, it is clearly shown that the migration of the target scatterers in slant range indirectly induces Doppler spreading of the scatterers' point spread function in each of the ISAR images obtained by the RID technique. This Doppler spreading means blurring. It is important to highlight that the migration in slant range may be caused not only by the radial component of the translational motion but also by the rotational motion. The application of motion compensation techniques prior to the use of the RID technique allows us to mitigate the Doppler spreading, as shown here both for simulated and live data acquired by a high-resolution coherent radar. [J18]

"Micro-Doppler Effect Analysis and Feature Extraction in ISAR Imaging With Stepped-Frequency Chirp Signals"

The micro-Doppler (m-D) effect induced by the rotating parts or vibrations of the target provides a new approach for target recognition. To obtain high range resolution for the extraction of the fine m-D signatures of an inverse synthetic aperture radar target, the stepped-frequency chirp signal (SFCS) is used to synthesize the ultrabroad bandwidth and reduce the requirement of sample rates. In this paper, the m-D effect in SFCS is analyzed. The analytical expressions of the m-D signatures, which are extracted by an improved Hough transform method associated with time-frequency analysis, are deduced on the range-slow-time plane. The implementation of the algorithm is presented, particularly in those extreme cases of rotating (vibrating) frequencies and radii. The simulations validate the theoretical formulation and robustness of the proposed m-D extraction method. [J19]

"ISAR Imaging for Avian Species Identification With Frequency-Stepped Chirp Signals"

Imaging an avian target by inverse synthesis aperture radar (ISAR) is a novel and important technological approach of solving the problem of avian detection. However, the ISAR images of birds obtained with the conventional range-Doppler algorithm could be contaminated due to serious micro-Doppler effects, which are generated by the birds' flapping wings. In this letter, a novel imaging method of birds is proposed, which is simple to comprehend and operate, and avoids lots of complications and computation burdens. In the method, the moving status of bird is identified first via finding the variety of moving average values of the cross-correlation coefficient of the adjacent high-resolution range profiles. The usage of moving average values is attributed to the characters of the bird's flapping. The parts of respective flapping spectrogram can then be eliminated, and the parts of the residual spectrogram, i.e., the respective gliding spectrogram, can be connected to prepare for the cross-compression. In this letter, the minimum waveform entropy criterion and genetic algorithm are employed in the spectrogram connection to compensate the phase error. Finally, the feasibility and effectiveness of the methods are verified by simulation results. [J20]

"ISAR Imaging of Maneuvering Targets Based on the Range Centroid Doppler Technique"

A new inverse synthetic aperture radar (ISAR) imaging approach is presented for application in situations where the maneuverability of noncooperative target is not too severe and the Doppler variation of subechoes from scatterers can be approximated as a first-order polynomial. The proposed algorithm is referred to as the range centroid Doppler (RCD) ISAR imaging technique and is based on the stretch Keystone-Wigner transform (SKWT). The SKWT introduces a stretch weight factor containing a range of chirp rate into the autocorrelation function of each cross-range profile and uses a 1-D interpolation of the phase history which we call stretch keystone formatting. The processing simultaneously eliminates the effects of linear frequency migration for all signal components regardless of their unknown chirp rate in time-frequency plane, but not for the noise or for the cross terms. By utilizing this novel technique, clear ISAR imaging can be achieved for maneuvering targets without an exhaustive search procedure for the motion parameters. Performance comparison is carried out to evaluate the improvement of the RCD technique versus other methods such as the conventional range Doppler (RD) technique, the range instantaneous Doppler (RID) technique, and adaptive joint time-frequency (AJTF) technique. Examples provided demonstrate the effectiveness of the RCD technique with both simulated and

experimental ISAR data. [J21]

"Equivalence Analysis of Accuracy of Geolocation Models for Spaceborne InSAR"

There are two main geolocation models for spaceborne synthetic aperture radar (SAR) interferometry (InSAR): range Doppler (RD) and direct geocoding (DG) models. The RD model gets the target position by combining and solving the Doppler equation, slant-range equation, and the modified Earth model equation. The DG location model gets the target position through its 3-D coordinates by the Doppler equation and two slant-range equations. Usually, the geolocation accuracy analyses of these two models are discussed separately. It is confused which one is more precise and we should use during InSAR system designing. This paper deduced and compared the geolocation accuracies of these two models in the same frame-matrix. According to the matrix theory, the explicit expressions of the geolocation uncertainty of RD and DG models were deduced through the use of parameters in matrix form. After defining a new slant-range plane coordinate system, the precision of RD geolocation model and that of geocoding location model were compared quantificationally. It was presented that the geolocation uncertainty formulas between RD and DG models were the same. Then, the conclusion that these two models would lead to the same precision in geolocation measurement was obtained. At last, computer simulation results were employed to confirm the mathematical analysis. [J22]

"Simulation and Analysis of Human Micro-Dopplers in Through-Wall Environments"

We present a simulation methodology for generating micro-Doppler radar signatures of humans moving behind walls. The method combines primitive-based modeling of humans with finite-difference time-domain (FDTD) simulation of walls. Realistic motions of humans are generated from computer animation data. The time-varying human radar cross section is simulated using the primitive-based prediction technique. The scattered returns of humans behind walls are then simulated by a hybrid of the human simulation model with the through-wall propagation data generated from FDTD. The resulting simulator is used to investigate the effects of walls of both homogeneous and inhomogeneous types on human micro-Dopplers. It is found that while through-wall propagation affects the magnitude response of the Doppler spectrogram in the form of attenuation and fading, it only introduces very minor distortions on the actual Doppler frequencies from the body parts. This is corroborated by measurement data collected using a Doppler radar, as well as by a point-scatterer analysis of refraction and multipath introduced by walls. [J23]

"An Array Error Estimation Method for Constellation SAR Systems"

In practice, unavoidable array errors, consisting of phase and position errors, significantly degrade the performance of constellation synthetic aperture radar (SAR) systems. Therefore, methods are required to estimate these errors. In constellation SAR systems, the clutter spectrum components within a Doppler bin can be used as calibration sources with known directions. In this letter, it is observed that the steering vectors of the spectrum components in one Doppler bin are conjugate with those of the spectrum components in its contrary Doppler bin on condition that each SAR operates in side-looking mode and its nominal left coordinate is zero, which is easy to realize. We obtain a new phase error estimation method based on this observation. An array error estimation method, which estimates phase and position errors simultaneously, is proposed via combining the new phase error estimation method with the least squares method for estimating position errors. The advantages of the proposed method include its capability to directly estimate phase and position errors without joint iteration between the estimations of phase and position errors; thus, it performs well, while the conventional method behaves unstably because it may converge to a local optimal solution, when position errors are large. Furthermore, mathematical analysis indicates that the proposed method has less computational load. In addition, computer simulations show that it performs better than the conventional method. The only cost is that it employs twice as many Doppler bins as the conventional method does, which is endurable because there are numerous Doppler bins. [J24]

"Generating Large-Scale High-Quality SAR Mosaic Datasets: Application to PALSAR Data for Global Monitoring"

This paper proposes a mosaicking algorithm to produce large-scale radiometrically and geometrically calibrated Synthetic Aperture Radar (SAR) datasets as a base for environmental monitoring of terrestrial biospheric and cryospheric changes. Features of the proposed method are thematic inclusion of a) long-strip processing of the SAR data, b) ortho-rectification and slope correction using a digital elevation model, c) suppression of differences in intensity between neighboring strips, and d) preparation of metadata (e.g., dates from launch, local incidence angle, radar shadow, layover, and valid/invalid data) to support dataset interpretation. The performance of the proposed method is evaluated using Advanced Land Observing Satellite (ALOS) Phased Array type L-band SAR (PALSAR) mosaics for Southeast Asia, Australia, and Africa. [J25]

"Ortho-Rectification and Slope Correction of SAR Data Using DEM and Its Accuracy Evaluation"

This paper proposes an accurate ortho-rectification and slope correction method for Synthetic Aperture Radar (SAR) images using a digital elevation model (DEM). Since SAR observation is performed in the squint condition, the image is distorted both geometrically and radiometrically (e.g., through foreshortening, range and azimuth shift, layover, radiometric modulation associated with slope, and shadowing). Furthermore, the pixel height cannot be retrieved directly even when orbital data are accurate. The proposed method calculates the geometric and radiometric distortion components from a comparative process between the DEM-based Simulated SAR Image (DSSI) and the SAR slant range image. When applied to Advanced Land Observing Satellite (ALOS) Phased Array Type L-band SAR (PALSAR) data, the geometric accuracy of the ortho-rectified SAR image at the off-nadir angle of 34.3° was high, with a Root Mean Square Error (RMSE) of 11.9 m when evaluated against Ground Control Points (GCPs) deployed globally. The slope correction effectively reduced the radiometric variation caused by the terrain height variation. The proposed method can be applied to a range of SAR data to support a diversity of applications. [J26]

"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. [J27]

"L-band array for ground-based remote sensing of volcanic eruptions"

In this study, an L-band array for ground-based remote sensing of volcanic eruptions will be presented. The proposed array configuration was created using a particular class of microstrip elements, namely shorted rectangular patch (SRP) antennas, with improved directivity arranged in a 6Ч6 array with high inter-element spacing. This solution allowed high directivity, while grating lobe effects were mitigated by the element factor. The array was developed for use with volcano Doppler radar (Voldorad), a volcanological Doppler radar used to remotely sense summit eruptions of Mt. Etna in Sicily, where the prototype Voldorad is now located. The main features of the SRP and the design principles of the array will be presented, along with simulated and measured results. [J28]

"An Experimental Study of WiMAX-Based Passive Radar"

Passive radars using illuminators of opportunity have attracted much attention in recent years. The worldwide inter-operability for microwave access (WiMAX) signal is a new illumination source for passive radar. This paper presents a study to understand and to demonstrate the feasibility of using WiMAX signals for passive radar. The study includes WiMAX signal analysis, the design and implementation of a WiMAX-based passive radar demonstrator, the associated radar signal processing scheme, and the field measurements. Results based on field measurements for various moving targets provide some useful references about the performance and potential capability of using WiMAX signals for passive radar applications. [J29]

"Resolving Velocity Ambiguity in Multifrequency, Pulse-to-Pulse Coherent Doppler Sonar"

Coherent Doppler sonar allows noninvasive velocity measurements and is suitable for both laboratory and field applications. The approach is particularly attractive in those environments where optical techniques are not suitable either because of power requirements or more critically, water turbidity. Notably, the technique has been employed successfully in oceanic and river boundary layer studies. However, the occurrence of range and velocity ambiguities limit the more general application of the technique. This paper introduces a method to overcome speed ambiguities by acquiring acoustic backscatter at two (or more) frequencies simultaneously with a broadband transmit pulse. The different frequencies have distinct velocity ambiguities allowing disambiguation of the velocity measurements. The approach is conceptually similar to the use of multiple transmit pulse rates but has the advantage that the data can be acquired simultaneously and so there is no loss in data rate. In addition, system geometry often restricts the allowed pulse repetition rate so that disambiguation using

frequency is more flexible and more generally applicable. Theoretically, the effective ambiguity velocity of a dual-frequency system can be extended arbitrarily but phase noise in a practical system restricts the method to about a fivefold increase in ambiguity velocity. [J30]

"GMTI Tracking via the Gaussian Mixture Cardinalized Probability Hypothesis Density Filter"

The cardinalized probability hypothesis density (CPHD) filter is a recursive Bayesian algorithm for estimating multiple target states with a varying target number in clutter. In particular the Gaussian mixture variant (GMCPHD), which provides closed-form prediction and update equations for the filter in the case of linear Gaussian systems, is a candidate for real time multi-target tracking. The following three issues are addressed. First we show the equivalence between the GMCPHD filter and the standard multi hypothesis tracker (MHT) in the case of a single target. Second by using a Gaussian sum approach, we extend the GMCPHD filter to incorporate digital road maps for road constrained targets. The use of such external information leads to more precise tracks and faster and more reliable target number estimates. Third we model the effect of Doppler blindness by a target state-dependent detection probability, which leads to a more stable target-number estimation in the case of low-Doppler targets. [J31]

"The First-Order High Frequency Radar Ocean Surface Cross Section for an Antenna on a Floating Platform"

The first-order high frequency surface wave radar (HFSWR) cross section of the ocean surface is derived for the case of the transmitting and receiving antenna being mounted on a floating, but otherwise fixed, ocean platform. It is assumed that the sway component of the platform or barge motion is responsible for observed differences in the cross section compared to that for the fixed antenna case. Based on earlier work, a general expression for the bistatically received first-order electric field, which consists of a two-dimensional spatial convolution, is presented and reduced to integral form. Then, it is assumed that the surface can be described by a Fourier series whose coefficients are zero-mean Gaussian random variables, and from there the analysis proceeds for the backscatter case. The integrals are taken to the time domain, with the source field being that of a barge-mounted omnidirectional vertically polarized pulsed dipole antenna. Subsequently, the first-order monostatic radar cross section is developed and found to consist of Bessel functions. Simulation results for the new cross section are also provided to show the effects of barge motion under different sea states and operating frequencies. It is seen that the results have important implications in the application of HFSWR technology to ocean remote sensing. [J32]

"Multistatic micro-Doppler radar signatures of personnel targets"

This study extends the theory of the micro-Doppler effect into the multistatic domain, and considers how the multistatic micro-Doppler signature (μ-DS) will affect radar automatic target recognition (ATR). Real multistatic μ-DS of personnel targets are examined and their nature compared with theory and simulated results. It is demonstrated that the use of multistatic μ-DSs would increase the robustness of radar ATR systems to the problem of self-occlusion, where the target obscures itself. Redundancy in the multistatic μ-DS is identified, and how this may reduce the data fusion demands of multi-aspect classifiers is discussed. Also, information theory is used to demonstrate that the multistatic μ-DS contains more target information than the monostatic case. This result leads to the prediction that multi-aspect μ-DS-based radar ATR would have improved performance compared to single-aspect solutions. [J33]

"HFSW Radar Model: Simulation and Measurement"

High-frequency surface-wave (HFSW) radars are usually used to remotely measure oceanographic parameters. These systems can also potentially detect targets beyond the conventional microwave radar coverage. In this paper, the backscattered Doppler spectrum made up of the sea clutter, ship echoes, and the background noise has been modeled. Taking into account the propagation and the signal-processing effects, a range-Doppler image has been generated. This model can be used for different purposes like the (theoretical) evaluation of detection performance. This paper gives an overview of the theoretical elements for modeling the backscatter signal. The processing effects on the range-Doppler image and the time-evolving target signature are also introduced. Some of the simulated elements and the obtained range-Doppler images are compared with real data. Finally, from this model, the detection capabilities of HFSW radars are evaluated. [J34]

"Investigation of Doppler Features From Wind Turbine Scattering"

We examine the Doppler features from wind turbine scattering through a series of model measurements. Both backscattered and forward-scattered data are collected in the laboratory at Ku-band from various wind turbine models undergoing rotation. The tested models include a 1:160 scale model turbine, a three-arm wire model,

and a small wind turbine from Bergey Windpower with 2' blades. The findings from the wire turbine model are corroborated by simulations performed using the Numerical Electromagnetics Code (NEC). Detailed accounts of the physics behind the observed Doppler features due to multiple scattering, near-field effects, and blade-shape effects are reported. [J35]

"Formulation of Doppler and cross-ambiguity processes based on delay only"

The author addresses the problem of estimating the time varying delay of a signal observed by two or more receivers, and develop accurate and computationally efficient methods for processing these signals. The effectiveness of these methods is demonstrated on signals whose parameters are consistent with airborne receivers and a stationary ground emitter. The author proposes a solution to the time varying delay problem that is based on the phase of the short time cross-correlation function. This model is based on the exact signal model in which received signal differs from the transmitted signal by a time varying delay function. The process presented is based on previous work and provides enough accuracy in the estimated delay function that accurate Doppler velocity may be estimated from the estimated delay function. Moreover, the process is computationally efficient since it is based on the conventional correlation function and does not require estimation of a cross-ambiguity function or scale cross-ambiguity function surfaces on a fine Doppler lattice. [J36]

"Analysis of Wind Turbines Blockage on Doppler Weather Radar Beams"

The split-step solution to the parabolic wave equation describing beam propagation permits examination of the signal degradation in a Doppler weather radar caused by wind turbines blockage under general atmospheric conditions and at arbitrary transmitter and receiver configurations. At radar wavelengths, an understanding of turbine and terrain obscuration effects is essential for deciding the reliability of radar measurements affected by blockage. [J37]

"Phase-Coded Interrupted CW Signals and Processors"

High resolution radars require signals with large time-bandwidth product such as CW signal and coherent pulse train (CPT). We discuss a phase-coded interrupted CW (ICW) signal which is the combination of CW signal and CPT. Phase codes used here are with perfect periodic autocorrelation. The periodic ambiguity function of ICW signals is studied including single-carrier signal and multi-carrier signal. It is interesting that the gate function has different effects on two signals and contributes to a multi-carrier ICW signal which yields nearly perfect autocorrelation. Meanwhile we also suggest an efficient receiver approach to ICW signals, which can reduce the computational burden of the processor and utilize the good properties of P3 and P4 codes. [J38]

"Motion-Compensation Improvement for Widebeam, Multiple-Receiver SAS Systems"

The effect that uncompensated motion errors have on synthetic aperture sonar (SAS) imagery can be severe. Time-domain beamforming SAS reconstruction is able to compensate arbitrary track errors, but the more efficient frequency-domain reconstruction algorithms, such as the range-Doppler, chirp-scaling, and wave number (akarange migration or Stolt-mapping) algorithms do not allow for simple compensation, especially for widebeam sonars. Data processed via these block algorithms is usually compensated before azimuth compression in a computationally inexpensive preprocessing step. Unfortunately, this compensation assumes a narrowbeam geometry, causing blurring in high-resolution images collected with widebeam sonars. In this paper, we demonstrate a new technique for compensation of large, but known, motion errors in data collected with widebeam geometry sonars. The technique relies on obtaining angle-of-arrival information from the multiple-receiver array configuration typical in high-resolution SAS systems. The new method of compensating for motion errors was found to significantly outperform the previous techniques in a simulation of point-reflector imagery. [J39]

"Noninvasive Biosignal Detection Radar System Using Circular Polarization"

This paper proposes an integrated hypersensitive Doppler radar system through a circular polarization characteristic. Through the idea of a reverse sense of rotation when the reflecting surface is perfectly conducting, it is shown that the detecting property of the system can be effectively improved by using antennas that have a reverse polarization. This bistatic radar system can be used in noninvasively sensing biosignals such as respiration and heart rates with the periodic movement of skin and muscle near the heart. The operating frequency of the system is in the X-band and the radar size is 95 times 50 times 13 mm3. [J40]

"Injection Heights of Biomass Burning Debris Estimated From WSR-88D Radar Observations"

Understanding the vertical distribution of aerosols is critical to accurately determining their effects on air quality. Since current tools for obtaining this information have limited spatial and temporal coverage, we explore the use of Doppler radar data for obtaining the injection heights of biomass burning debris (BBD) produced from large fires in southern Georgia during Spring 2007. Due to their submicrometer sizes, the smoke aerosols are not detected by the radar. Therefore, we use BBD as a possible surrogate for aerosol height since smoke aerosols are often collocated with the debris. Using 32 h of Weather Surveillance Radar-1988 Doppler (WSR-88D) radar data from Jacksonville, FL, between May 23 and 25, 2007, the injection heights of BBD (D ~ 1mm) are calculated. Our analysis indicates that the maximum injection height is ~5 km for the strongest fire, with a mean injection height of 3 plusmn 1.0 km. Maximum injection heights are present between 1800 and 0000 UTC, during the late afternoon periods when both the intensity of the fire (based on radar information) and the convective mixing are greatest. The injection heights estimated from this approach represent the first step at providing inputs for future air-quality forecasting applications within numerical simulations, particularly ones that require diurnal information. [J41]

"Prolog to On the Complexity of the Verification of the Costas Property"

This is an introduction to the above titled paper. [J42]

"In-band interference reduction in FMCW channel data using Prony modelling"

He is shown that Prony modelling can be used to reduce the effect of in-band interference in frequency modulated continuous-wave (FMCW) channel data. Results of the modelling are examined by comparing average power delay profiles and Doppler spectra with those obtained from FFT processing. [J43]

"Improvement of high-frequency surface waves radar performances by use of multiple-input multiple-output configurations"

A multiple-input multiple-output (MIMO) configuration has been studied for communication applications, offering a lot of advantages to mitigate propagation effects because of multipath and fading environments. More recently, MIMO techniques in radar have been proposed. MIMO is discussed in the context of high-frequency surface waves radar (HFSWR). After a short introduction to the MIMO radar technique (a technique which is not new; the RIAS developed by ONERA was probably the first MIMO radar), explores two different applications are explored. The first application aims at improving the resolution and accuracy of a coastal radar, proposed here in a bistatic configuration. Such a radar operates with a wide sparse frequency band and with an equivalent wide aperture, taking advantage of the MIMO configuration. Simulation over a congested area of targets demonstrates the benefit of MIMO over the conventional HFSWR radar, especially in terms of separation of targets. The second application consists in a more practical ship-borne HFWSR configuration compatible with space time adaptive processing (STAP) to improve the detection of slow targets. In this case, a limited number of receiving channels is considered whereas STAP uses the degrees of freedom offered by the transmitting array. The MIMO-STAP is compared with a conventional STAP, showing that theoretical performances should not be affected by the MIMO configuration even if the signals are no longer perfectly orthogonal, because of Doppler shift, once scattered by moving targets. [J44]

"Application of the radon transform to detect small-targets in sea clutter"

The authors present a novel and heuristic approach for the detection of low radar cross-section targets in high-resolution sea clutter. The proposed technique is based on the application of the Radon transform to range-time matrices formed by column-wise storage of consecutive range profiles. The objective of this paper is 2-fold: to analyse the effect of the transform on real high-resolution sea clutter and to describe a detection scheme based on the insight obtained. The proposed technique emulates the behaviour of traditional motion target detection algorithms without the need for reliable Doppler information. It also constitutes a powerful non-coherent integration strategy of the target-s energy along its specific path on the range-time plot. The performance of the detection technique has been tested against real high-resolution sea clutter data, acquired at the south coast of Spain with an in-house developed continuous wave linear frequency modulated millimetre-wave radar system. Monte Carlo simulations show a significant improvement over the conventional cell averaging constant false alarm rate schemes. [J45]

"Phase-Coded Waveforms and Their Design"

The design of radar waveforms has received considerable attention since the 1950s. In 1953, P.M. Woodward (1953; 1953) defined the narrowband radar ambiguity function or, simply, ambiguity function. It is a device formulated to describe the effects of range and Doppler on matched filter receivers. Woodward acknowledged the influence that Shannon's communication theory from 1948 had on his ideas; and he explained the relevance

of ambiguity in radar signal processing, perhaps best conceived in terms of a form of the uncertainty principle (see the sections "Motivation" and "Ambiguity Functions"). However, in the 50 or so years since Woodward's book was published, radar signal processing has used the ambiguity function as an intricate and flexible tool in the design of waveforms to solve diverse problems in radar. In the process, substantial connections were established in mathematics, physics, and other areas of signal processing. As such, we are introducing two new methods, discussed in sections "CAZAC Sequences" and "Aperiodic Simulations". [J46]

"Radar Signature of a Helicopter Illuminated by a Long LFM Signal"

Helicopters exhibit a very particular Doppler radar signature caused by the movement of rotor blades. This signature can easily be derived using a short-time approximation: the blades are assumed to be static during each pulse. In wideband linear frequency modulated (LFM) radars, however, this assumption cannot be made. The work presented here describes the echo of rotary blades illuminated by LFM radars without the short-time assumption and provides useful information for detection and recognition purposes. [J47]

"Adaptive ground clutter suppression for conformal array radar systems"

Conformal arrays (CFAs) possess certain desirable characteristics for deployment on unmanned aerial vehicles and other payload-limited platforms. However, the CFA non-planar geometry induces clutter non-stationarity, resulting in elevated signal-to-interference-plus-noise ratio (SINR) loss when applying conventional space-time adaptive processing (STAP) algorithms. Non-stationary clutter leads to covariance matrix estimation error and, consequently, an erroneous STAP frequency response. In this study, the authors examine two practical conformal antenna configurations: a belly-mounted canoe and a nose-mounted, chined shape. Using high-fidelity signal models, the authors show traditional STAP losses in excess of 10-dB because of the effects of clutter non-stationarity. The authors then investigate a number of ameliorating techniques compatible with standard STAP implementation, including localised processing, localised processing with time-varying weights, equivalent uniform linear array transformation, angle-Doppler warping and higher-order angle-Doppler warping. The authors demonstrate very good performance for the higher-order angle-Doppler warping method applied to the chined radome shape, with peak adaptive SINR losses reduced from nearly 16-dB for the uncompensated case to 3-dB of loss consistent with performance attainable in a homogeneous clutter environment. The authors also find good performance for three-dimensional angle-Doppler warping over azimuth, elevation and Doppler when applied to the tapered canoe shape, with uncompensated losses of roughly 14-dB reduced to 3-dB, again a level compatible with STAP applied in a homogeneous clutter environment. The authors thus show that CFA STAP can yield performance similar to that of a conventional planar array when using appropriate compensation methods. [J48]

"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. [J49]

"Modeling and performance analysis of SAW reader systems for delay-line sensors"

In this contribution, we present a comprehensive modeling approach for delay line-based surface acoustic wave (SAW) sensor reader systems, which provides valuable insight into the interaction of the individual system parameters. A parametric analysis of signal strength, noise, and quantization effects and consideration of important signal processing parameters, such as data windows and averaging, allows prediction of the achievable statistical measurement accuracy by closed-form solutions. The performance and capabilities of the derived model are verified on system design examples as well as multiple practical measurement scenarios, using a prototype 2.45-GHz frequency-stepped continuous-wave SAW reader system. [J50]

"Orbit Accuracy Requirement for ABYSS: The Space Station Radar Altimeter to Map Global Bathymetry"

The Altimetric Bathymetry from Surface Slopes (ABYSS), which is the proposed science payload on the International Space Station (ISS), is a Johns Hopkins University Applied Physics Laboratory-developed flight-proved delay-Doppler phase-monopulse radar altimeter capable of measuring ocean surface slope in the 6-200-

km half-wavelength frequency band range with an accuracy of 0.5 mu rad, with autonomous gimbal control to compensate for the ISS structural motions. This measurement allows an improved mapping of the global bathymetry, enabling a wide range of scientific research works and applications. The nonrepeat ISS orbital ground track is ideal for ABYSS. This letter describes a simulation study on the effects of the Earth's gravity field and other errors, including thermal bending of the ISS, on the orbit determination of the altimeter instrument antenna phase center location, fulfilling the science objectives of ABYSS. Our study concluded that the error due to mean gravity field is no longer limiting due primarily to the recent Gravity Recovery and Climate Experiment gravity modeling and that the ABYSS/ISS radial orbit slope error budget in the presence of various force and measurement model errors is estimated at the 0.2-mu rad root-sum-squared (RSS) level, which satisfies the ABYSS orbit accuracy science requirement to provide an improved mapping of global bathymetry. [J51]

"Through-Wall Human Tracking With Multiple Doppler Sensors Using an Artificial Neural Network"

An artificial neural network is proposed to track a human using the Doppler information measured by a set of spatially distributed sensors. The neural network estimates the target position and velocity given the observed Doppler data from multiple sensors. It is trained using data from a simple point scatterer model in free space. The minimum required number of sensors is investigated for the robust target tracking. The effect of sensor position on the estimation error is studied. For the verification of the proposed method, a toy car and a human moving in a circular track are measured in line-of-sight and through-wall environments. The resulting normalized estimation errors on the target parameters are less than 5%. [J52]

"Effects of Non-Uniform Motion in Through-the-Wall SAR Imaging"

Synthetic aperture radar (SAR) provides high resolution images that are well suited for through-the-wall target detection and recognition. As targets behind-the-wall undergo non-uniform motions, such as vibration, rotation and acceleration, their patterns can be recognized. To understand these signatures in through-the-wall SAR, we model and analyze the non-uniform motion-induced Doppler effect as well as the focused target SAR image. In particular, the wall effects on the focused SAR image and the micro-Doppler are formulated and analyzed. These analyses facilitate improving the target recognition performance by quantitatively estimating the parameters of the micro-Doppler signatures as well as the SAR imaging. We further analyze the detection performance of the non-uniform motion-induced target based on the generalized likelihood ratio test (GLRT) technique. The relationship between motion parameters and the detection performance allows us to evaluate the performance bound and the minimum detectable parameters. [J53]

"Doppler Compensation & Single Pulse Imaging using Adaptive Pulse Compression"

The effects of target Doppler are addressed in relation to adaptive receive processing for radar pulse compression. To correct for Doppler-induced filter mismatch over a single pulse, the Doppler-compensated adaptive pulse compression (DC-APC) algorithm is presented whereby the respective Doppler shifts for large target returns are jointly estimated with the illuminated range profile and subsequently incorporated into the original APC adaptive receive filter formulation. As a result, the Doppler-mismatch-induced range sidelobes can be suppressed thereby regaining a significant portion of the sensitivity improvement that is possible when applying adaptive pulse compression (APC) without the existence of significant Doppler mismatch. In contrast, instead of compensating for Doppler mismatch, the single pulse imaging (SPI) algorithm generalizes the APC formulation for a bank of Doppler-shifted matched filters thereby producing a sidelobe-suppressed range-Doppler image from the return signal of a single radar pulse which is applicable for targets with substantial variation in Doppler. Both techniques are based on the recently proposed APC algorithm and its generalization, the multistatic adaptive pulse compression (MAPC) algorithm, which have been shown to be effective for the suppression of pulse compression range sidelobes thus dramatically increasing the sensitivity of pulse compression radar. [J54]

"UWB in Millimeter Wave Band With Pulsed ILO"

A simple but efficient transmitter for ultra-wide-band impulse radio wavelet generator in millimeter-wave band is presented. It is suitable for RADAR, gigabit wireless personal area network, and localization applications. This front-end involves a subharmonic injection-locked oscillator driven by a pulse generator (PG) with fast transition time (<25 ps). Its frequency oscillation is locked on one of the numerous harmonic components generated by the PG around 30 GHz. This allows to obtain a stable pulse-to-pulse phase condition and a very low phase noise (<-110 dBc/Hz@100 kHz). Two monolithic microwave integrated circuits have been designed using a commercial pseudomorphic high-electron mobility transistor foundry process (ft = 100 GHz). The first one is a PG with position and width modulation capabilities, and the second one is an oscillator with a 30-GHz free-running output frequency. The start of the oscillations is studied, using the external quality factor as main factor. [J55]

"Azimuth dependence of Doppler spectra of sea clutter at low grazing angle"

The effect of varying the azimuth angle of a cliff-top radar on the Doppler spectra of low grazing angle sea clutter has been investigated. The peak of the horizontally polarised Doppler spectra was found to depend on the component of the phase velocity of the breaking waves in the line of sight of the radar. The analysis was presented in terms of two main scattering components, one slow and one fast, which could explain the Doppler spectra as well as the higher moments of the spectra. The connection to the amplitude statistics for the two components was also discussed. The slow component was present all the time and had amplitude statistics that were Rayleigh-distributed. The fast component was present only intermittently and had amplitude statistics that were spikier than the Rayleigh distribution. The width of the spectra varied with azimuth in a way unrelated to the direction relative to the wind. A wave tank experiment with long wavelength mechanical waves and wind-generated waves illustrated that the cause of the broadening of the spectra was probably due to the effect of swell waves. [J56]

"Application of Subarray Averaging and Entropy Minimization Algorithm to Stepped-Frequency ISAR Autofocus"

Subarray averaging and entropy minimization (SAEM) algorithm is applied to stepped-frequency ISAR autofocus to compensate for the phase error along the down-range due to high target speed and low pulse repetition frequency (PRF) of radar systems. In stepped-frequency radar systems, the phase error due to target motion in each burst make range profiles blur. Thus, the stepped-frequency ISAR often adopts a high PRF radar system in order to suppress the effect of target motion in each burst. However, it inevitably leads to loss of many advantages by adopting low PRF radars in stepped-frequency ISAR imaging. In order to take advantage of a low PRF radar in stepped-frequency ISAR imaging, this paper makes use of a method called SAEM (subarray averaging and entropy minimization) that uses a subarray averaging concept in conjunction with the entropy cost function in order to find the target's motion parameters. Well-focused ISAR images also can be provided from the combination of the SAEM and a traditional autofocus algorithm, even when low PRF stepped-frequency waveform is used. The effectiveness of this method is illustrated and analyzed with simulated targets comprised of point scatters and measured Boeing-737 data. [J57]

"Focusing Azimuth-Invariant Bistatic SAR Data With Chirp Scaling"

This letter presents a bistatic chirp scaling algorithm to processing the azimuth-invariant bistatic synthetic aperture radar data. Two methods are used to derive the different parts of the range-Doppler expression of the point target. Compared with the method relying on the two-order expansion of the bistatic range model, the new algorithm can give the close-form azimuth modulation. Through the introduction of the fractional Fourier transform into the range processing, the resolutions are enhanced further. [J58]

"Reply to "Comments on 'Discrete Frequency-Coding Waveform Design for Netted Radar Systems'""

For original paper see H. Deng, ibid., vol.11, no.2, p.179-182, (2004). This paper presents reply to "comments on 'discrete frequency-coding waveform design for netted radar systems'". [J59]

"Sea-Surface Current Features Observed by Doppler Radar"

A coherent X-band radar was operated from the shore to measure velocities at the sea surface. The test site at a tidal inlet (Lister Tief) in the German Bight lay protected from swell and long wind waves. A vertical-vertical antenna was used to obtain the backscattered radar signal caused by Bragg scattering. To cover a sector of the circle, the antenna was rotated in 1Dstroksteps. At each step, the data acquisition was performed to obtain a time series of the backscattered radar signal. The maximum range is 1905 m with a range resolution of 7.5 m and an azimuthal resolution of 3.5diam. Maps of the averaged backscattered radar power and radial Doppler velocities are obtained. The radar backscatter maps show the modulation of the radar cross section due to changes in the surface roughness. The radar Doppler velocity maps show the modulations of the surface scatterer speed. The maps show many features, for example, the impact of subsurface sand waves, eddies, current shears, slicks, ship wakes, atmospheric effects, and small-scale current changes behind sheet pile walls. As the radar backscatter is caused by short wind waves, the wind influence on the Doppler signal was calculated for a first attempt to obtain true current motions. The results were compared with in situ current measurements. By subsequently measuring the surfaces current from two radar positions and performing the wind correction, the current vector fields are assessed. [J60]

"A Systematic Construction for Radar Arrays"

The radar array problem arises from the need to design frequency hopping sequences with small out-of-phase autocorrelations. It assumes the reflected signals have negligible Doppler shifts, so the correlations are calculated along the time axis only. In this correspondence, a systematic construction for radar arrays is provided by means of homogeneous uniform difference matrices. A systematic construction for properly centered permutation matrices, a special kind of homogeneous uniform difference matrices, is also provided, which partially solves the open problems posed by Zhang and Tu. [J61]

"The Effect of the Bistatic Scattering Angle on the High-Frequency Radar Cross Sections of the Ocean Surface"

High-frequency (HF) bistatic Doppler cross sections of the ocean surface are examined with respect to their dependency on the bistatic angle. Previously derived results which incorporate a pulsed dipole source and two orders of scatter are considered. It is trivially seen that the first-order result has a linear dependence on the cosine of the bistatic angle. The second-order echo accounts for a double scatter of incident radiation from first-order surface waves-the so-called electromagnetic term-and a single scatter from a second-order ocean wave. The latter, generally referred to as the second-order hydrodynamic term because it originates from coupling between first-order ocean waves, predominates the Doppler continuum in most regions of interest. The analysis presented here verifies that in addition to a cosine-dependent reduction in cross section magnitude with increasing bistatic angle, both components of the second-order scatter tend to zero under the condition of near-forward scatter for bistatic HF radar operation. Of course, this imposes practical limitations on the region over which a bistatically configured HF radar system may be used to remotely sense ocean surface parameters. [J62]

"Assessment of Radar Signal Attenuation Caused by the Melting Hydrometeor Layer"

Attenuation of radar signals by melting hydrometeors is studied using modeling approaches and comparisons of simulated and observed results. In spite that the melting layer in precipitating systems is usually relatively thin (~ 500 m), this attenuation can be substantial at X-band frequencies for low elevation angles and at millimeter-wavelength frequencies that are used by the U.S. Department of Energy's Atmospheric Radiation Measurement Program and CloudSat radars operating at vertical/nadir incidence. Melting layer attenuation is stronger than the attenuation in the resultant rain at comparable path lengths and needs to be accounted for in remote sensing methods that use radar reflectivity measurements for retrieving cloud and precipitation parameters if the radar beam penetrates this layer. The choice of the mixing rule for calculating dielectric constants of melting hydrometeors determines, to a significant degree, the magnitude of the modeled attenuation values. A relatively simple Wiener mixing rule provides results that are consistent with melting layer reflectivity enhancements and attenuation estimates from the X-band radar observations. The total melting layer attenuation Ais related to the resultant rain rate Rin an approximately linear manner at X- and Kalpha-band frequencies, whereas at W-band, the melting layer attenuation increase with rain rate is slower due to strong non-Rayleigh scattering effects. Typical A-Rrelations are suggested, and the variability of these relations is discussed. This paper is mostly concerned with precipitating systems associated with snowflakes that are unrimed or only slightly rimed above the freezing level, as indicated by relatively low values of vertical Doppler velocities. [J63]

"Polarimetric Detection of Targets in Heavy Inhomogeneous Clutter"

Polarization diversity has proved to be a useful tool for radar detection, especially when discrimination by Doppler effect is not possible. In this paper, we address the problem of improving the performance of polarimetric detectors for targets in heavy inhomogeneous clutter. First, we introduce a new polarimetric radar model that includes the realistic dependence of the clutter reflections on the transmitted signal. Then, we develop a polarimetric detection test that is robust to inhomogeneous clutter. We run this polarimetric test against synthetic and real data to assess its performance in comparison with existing polarimetric detectors. Finally, we propose a polarimetric waveform-design algorithm to further improve the target-detection performance. A numerical analysis is presented to demonstrate the potential performance improvement that can be achieved with this algorithm. [J64]

"Dynamic Radar Cross Section and Radar Doppler Measurements of Commercial General Electric Windmill Power Turbines Part 1: Predicted and Measured Radar Signatures"

Commercial windmill-driven power turbines ("wind turbines") are expanding in popularity and use in the commercial power industry, since they can generate significant electricity without using fuel or emitting carbon-dioxide ldquogreenhouse gasrdquo. In-country and near-off-shore wind turbines are becoming more common on the European continent. The United States has recently set long-term goals to generate 10% of national electric power using renewable sources. In order to make such turbines efficient, current 1.5 MW wind-turbine towers and rotors are very large, with blades exceeding 67 m in diameter, and tower heights exceeding 55 m. Newer

4.5 MW designs are expected to be even larger. The problem with such large, moving, metallic devices is the potential interference such structures present to an array of civilian air-traffic-control radars. A recent study by the Undersecretary of Defense for Space and Sensor Technology acknowledged the potential performance impact wind turbines introduce when located within line of site of air-traffic-control or air-route radars [Report to the Congressional Defense Committees on The Effect of Windmill Farms On Military Readiness, 2006]. In the spring of 2006, the Air Force Research Laboratory embarked on a rigorous measurement and prediction program to provide credible data to national decision makers on the magnitude of the signatures, so that the interference issues could be credibly studied. This paper, the first of two parts, will discuss the calibrated RCS measurement of the turbines, and compare this data (with its uncertainty) to modeled data. [J65]

"Comparison of Processing Algorithms for a Delay/Doppler Altimeter"

The use of a radar altimeter is to measure the height of the reflecting surface when the instrument passes overhead. A delay/Doppler altimeter (DDA) reduces the along-track resolution cell using correlation of pulses within burst, as in a synthetic aperture radar, with the net effect of synthesizing an array with a narrower lobe. The processing of DDA data therefore implies the correction of the phase delay of pulses, which is said to be Dopplerbeamsharpeningsince it can be reduced to a DFT in the along-track direction. The noise term on Doppler echoes is decreased by incoherent summing of contributions of different bursts. Summation of these contributions requires that pointing of each beam is directed toward a given output grid of samples on ground, and this can be a nontrivial task, depending on the topography profile. In this letter, a comparison between different beam sharpening algorithms is presented: Two of them are similar in their basic idea even if with different implementations; the third one can be considered as reference since no approximations are needed in principle, but is computationally inefficient. What results is that the first couple can be considered basically equivalent in terms of precision and computational efficiency, with little differences at the change of the environmental conditions. Results based on simulated data of simple and complex scenarios are presented as support of the reasoning. [J66]

"Correction of the Sea State Impact in the L-Band Brightness Temperature by Means of Delay-Doppler Maps of Global Navigation Satellite Signals Reflected Over the Sea Surface"

This paper presents an efficient procedure based on 2-D convolutions to obtain delay-Doppler maps (DDMs) of Global Navigation Satellite Signals reflected (GNSS-R) over the sea surface and collected by a spaceborne receiver. Two DDM-derived observables (area and volume) are proposed to link the sea-state-induced brightness temperature to the measured normalized DDM. Finally, the requirements to use Global Positioning System reflectometry to accurately correct for the sea state impact on the L-band brightness temperature (quantization levels, decimation, truncation, and noise impact) are analyzed in view of its implementation in the Passive Advanced Unit instrument of the Spanish Earth Observation Satellite (SeoSAT/INGENIO) project. [J67]

"Cramer-Rao bounds for target parameters in space-based radar applications"

The Cramer-Rao (CR) bounds for target Doppler and power are presented when detecting targets using a space-based radar (SBR) platform. The target in noise-only case is considered first and the results are compared with those obtained for a centro-symmetric uniform linear pulse array. When clutter is also present, the effect of the Earth's rotation and range foldover becomes significant; and they must be taken into consideration. The CR bounds are computed for target Doppler and power, and compared with their variance estimates obtained from simulation results corresponding to various airborne and SBR situations. From the simulation results, the Earth's rotation together with range foldover significantly increase the CR bounds for both target Doppler and power. This is in agreement with other results that show the Earth's rotation and range foldover together degrade the clutter suppression performance of adaptive processing algorithms. It is shown that when both the Earth's rotation effect and range foldover effect are present in the data, target detection is difficult, and it is necessary to introduce waveform diversity into the transmit design to minimize the effect of clutter and other interference. In this context, using waveform diversity on transmit, it is possible to compensate the degradation in terms of the CR bounds and achieve performance close to the ideal case. [J68]

"Robust measurement of group delay in the presence of density fluctuations by means of ultrafast swept reflectometry"

It is well known that reflectometric measurements can be seriously disturbed by density fluctuations. In this paper the basic mechanisms that critically affect the measurements are outlined with the help of a simplified two-dimensional model which simultaneously mimics the dynamic of the plasma turbulence and the frequency sweep. It turns out that an adequate modulation rate can easily overcome the adverse effect of wave scattering produced by short wavelength fluctuations even when measurements taken at a single frequency would fail.

Nevertheless the Doppler effect caused by long wavelength fluctuations can produce a substantial shift in the group delay, which accounts for nonmonotonous density profile reconstructions. In turn this effect can be corrected using a very fast ascending and descending frequency modulation, similarly to what is done in FM radars. The technical feasibility of such a system is demonstrated using the Kaband reflectometer of RFX, where a triangular modulation of 2.5 MHz, with a bidirectional modulation rate up to 4 GHz/200 ns, has been obtained. [J69]

"Random Body Movement Cancellation in Doppler Radar Vital Sign Detection"

The complex signal demodulation and the arctangent demodulation are studied for random body movement cancellation in quadrature Doppler radar noncontact vital sign detection. This technique can be used in sleep apnea monitor, lie detector, and baby monitor to eliminate the false alarm caused by random body movement. It is shown that if the dc offset of the baseband signal is accurately calibrated, both demodulation techniques can be used for random body movement cancellation. While the complex signal demodulation is less likely to be affected by a dc offset, the arctangent demodulation has the advantage of eliminating harmonic and intermodulation interference at high carrier frequencies. When the dc offset cannot be accurately calibrated, the complex signal demodulation is more favorable. Ray-tracing model is used to show the effects of constellation deformation and optimum/null detection ambiguity caused by the phase offset due to finite antenna directivity. Experiments have been performed using 4-7 GHz radar to verify the theory. [J70]

"Urban RF multipath mitigation"

Sensing in urban environments is of growing interest to the surveillance community, as is observation of targets with micro-Doppler features-elements of the target structure with independent range-Doppler behaviour about some target centroid. Multipath effects unique in character to urban sensing can conceal important features in the range-Doppler response of a target with micro-Doppler behaviour. The range-Doppler smearing because of multipath is analysed, and this analysis serves as the basis for a prominent point multipath mitigation algorithm. The effectiveness of this technique is evaluated with simulated micro-Doppler data with artificial multipath effects. [J71]

"Stretch processing for masking effect removal in noise radar"

A method of removing the masking effect caused by strong target echoes in a noise radar is presented. Signal processing in noise radar is based on the calculation of the correlation between transmitted and received signals. Strong echoes of nearby targets produce relatively high sidelobes in the correlation function, thus masking weak echoes of far targets. The classical method of masking effect removal, taking into consideration only the Doppler shift of target echoes, does not remove the strong target echo completely when targets migrate between range resolution cells in the integration time. The method proposed, based on signal stretch processing and a point target model, shows an improvement over existing methods and allows for the detection of weak targets also in the presence of the fast and strong ones. [J72]

"Motion compensation in ISAR imaging using the registration-restoration-fusion approach"

The distortion in the inverse synthetic aperture radar (ISAR) image of a target is a result of small time-varying perturbed motion experienced by the target during the image integration period and is attributed to a phase modulation effect of the radar return from the target. Large distortion in ISAR images of a moving target has been investigated and demonstrated under controlled experiments and simulation. Results from the analysis suggest that severe distortion is attributed to the phase modulation effect where a time-varying Doppler frequency provides the smearing mechanism. For applications of target identification, the registration-restoration-fusion method has been developed to refocus the distorted ISAR images. This method has been applied to both the experimental and simulated ISAR data. Results demonstrate that the registration-restoration-fusion motion compensation approach can improve the distorted ISAR image better than what can be achieved by conventional Fourier transform methods. This study also adds insight into the distortion mechanisms that affect the ISAR images of a target in motion. [J73]

"Principle and Methods on Bistatic SAR Signal Processing via Time Correlation"

In this paper, we discuss the mapping between the 3-D scene space and the bistatic synthetic aperture radar (SAR) image space and show that when the direction of the angular velocity of the bistatic SAR remains constant, the process of bistatic SAR imaging can be approximately modeled as a perspective operator from the 3-D scene space to the 2-D image space, and the perspective line is perpendicular to the plane determined by the composition direction of the T/R line of sight and the composition direction of the angular velocity of the T/R platform. Then, we show that the 2-D point spread function of the bistatic SAR is determined not only by the

range and ldquoazimuthrdquo resolutions but also by the geometry of the bistatic SAR and the bases of the SAR image space, and the concept ldquoambiguity regionrdquo is introduced to describe the ambiguity problem in the 3-D scene space. Then, the range-Doppler algorithm is discussed, and a new translational-variant bistatic SAR imaging method is proposed, which uses the scaled inverse fast Fourier transform (IFFT) technique to eliminate the translational-variant feature of the SAR space resolution. The space truncation error of this new algorithm is discussed to analyze the depth of focus of the scaled IFFT bistatic SAR imaging algorithms, and we find that the upper bounce of the space truncation error is proportional to the square of the distance from the scatterer to the T/R platforms. Last, the effects of motion measurement errors are discussed in detail, and, through theoretical analysis and numerical experiments, we show that the absolute position measurement error, the baseline measurement error, the perpendicular (vertical) component of the absolute velocity measurement error (AVME), and the perpendicular component of the relative velocity measurement error (RVME) cause SAR image shifting in the image space mainly, and the parallel component of the AVME and the parallel component of the RVME cause the SAR image to s--everely defocus. [J74]

"Micro-Doppler analysis of wheels and pedestrians in ISAR imaging"

In radar imaging, it is well known that relative motion or deformations of parts of illuminated objects induce additional features in the Doppler frequency spectrum. These features are called micro-Doppler effect and appear as sidebands around the central Doppler frequency. They can provide valuable information about the structure of the moving parts and may be used for identification purposes. Previous papers have mostly focused on 1D micro-Doppler analysis. The authors propose to emphasise the analysis of such `non-stationary targets` using a 2D imaging space, using both the micro-Doppler and a high-range resolution analysis. As in 2D-ISAR imaging, range separation enables to better discriminate the various effects caused by the time-varying reflectors. The study is focused on two different common examples: rotating wheels and human motion. With the help of micro-Doppler signature, information on the geometrical features of wheels (position, orientation) and on the gait of pedestrians can be extracted. Examples will be shown with simulated and experimental data. [J75]

"Pulse Compression Sidelobe Reduction by Minimization of Lp -Norms"

Most modern radar systems make extensive use of pulse compression techniques. This paper presents a technique for the design of mismatched receive finite impulse response (FIR) filters based on the minimization of Lp-norms of the sidelobes. The goal of the minimization process is to reduce the range sidelobe levels of the convolution of the transmit pulse and the receive filter. A closed-form solution is derived for the least-squares case (which is equivalent to the L2-norm) and an expression for the optimization of the higher order norms is developed. The solutions for the higher order norms have to be obtained by means of iterative numerical methods. The effect of using receive filters which are longer than the transmit pulses is also investigated. Results are presented for linear FM transmit waveforms having time-bandwidth products ranging from 10 to 100 in combination with selected values of the norm order ranging from 2 to 200. Receive filter lengths up to three times the transmit pulse lengths are investigated. Results are presented which highlight the tradeoffs between sidelobe level, mismatch loss and mainlobe width. The effect of Doppler shift on the sidelobe response of these receive filters is also investigated. [J76]

"Waveform Selection for Maneuvering Targets Within an IMM Framework"

We consider radar waveform selection algorithms for tracking accelerating targets. Tracking is handled within an interacting multiple model (IMM) framework, which produces a number of potential cost functions for minimization. The waveform library is obtained by implementing a fractional Fourier transform on a base waveform, thereby rotating its ambiguity function around its peak. This has the effect of rotating the lower bound of measurement covariance in the range-Doppler plane. Simulation results consider a number of potential cost functions, and show robustness to cases in which the target modes are not precisely known. [J77]

"Radar Pulse Compression Repair"

This correspondence presents an adaptive approach for range sidelobe mitigation for use by future radar systems as well as in-service radar systems in which the precompressed received signal may not be readily available or it may not be feasible to replace the current pulse compression system. The approach, denoted as pulse compression repair (PCR), utilizes a previously developed adaptive technique to operate on the match filtered output treating the resulting waveform autocorrelation as if it were the transmitted waveform thus "repairing" the effects of range-sidelobe masking that are induced by matched filtering. Illustrative results are presented comparing PCR with the matched filter and the CLEAN algorithm which demonstrate significant performance advantages for PCR as well as robustness to Doppler mismatch and system errors. [J78]

"Random Noise Radar/Sodar With Ultrawideband Waveforms"

Random noise waveforms with ultrawide bandwidth improve the range resolution and reduces the probability of intercept in radar/sodar. As a result of the nonperiodic waveform, the range ambiguity is removed as well. By transmitting a sine signal that is phase or frequency modulated by random noise, autocorrelation functions with improved side lobe suppression in range can be formed. There are great similarities in the signal-processing algorithms applied in noise radar and sodar. The much slower propagation velocity of sound compared to light reduces the signal bandwidth but increases the time of measurement, however. In both sodar and radar, the range resolution is determined by the wavelength band occupied by the transmitted waveform, while the velocity resolution is controlled by the ratio of wavelength and time of measurement. The slower sound velocity also enhances the range/Doppler ambiguity problem in sodar when periodic waveforms are applied. This ambiguity could be suppressed if nonperiodic waveforms are introduced, such as random noise. In this paper, fundamental similarities and differences on system level between sodar and radar are first discussed, and signal-processing algorithms applied in random noise radar/sodar are reviewed. In particular, the noise floor of the ambiguity function and its relationship to spectrum width and time of measurement are analyzed, including improved side lobe suppression using mismatched filtering. The signal-processing algorithms were tested on raw data from sodar measurements on moving targets, buildings, vegetation, and water surfaces. An adaptive filter algorithm for suppression of the increased noise floor from dominant reflectors was derived and successfully applied to both sodar and stepped frequency radar data [J79]

"A GPS-Reflections Receiver That Computes Doppler/Delay Maps in Real Time"

This paper describes a new instrument that was specially designed and developed to gather Global Positioning System (GPS) signals after they have been reflected from suitable surfaces (sea, ice, and ground), for Earth remote sensing. The device has been called the GPS open-loop differential real-time receiver (GOLD-RTR). Its main and most innovative feature is its computation and storage, in real time, of complex-valued (I and Q) cross correlations (waveforms) between GPS L1-C/A signals-received directly and after reflection-and the corresponding models of these signals. Particularly, the GOLD-RTR schedules consecutive coherent integration time slots of 1 ms over which ten parallel correlation channels, with 64 lags each, work simultaneously and continuously with the input raw data sampled at 40 MHz. The total throughput is 10 000 waveforms per second, each waveform being 64 lags long. These real-time correlation resources can be flexibly distributed in several configurations according to the observational requirements, for instance: Doppler/delay maps or up to ten simultaneous reflected waveforms for ten different GPS satellites are examples of what can be done. The further processing of the real-time computed 1-ms waveforms in a flight campaign over the ocean, ice, or ground can be used to obtain geophysical parameters such as sea level and tides, sea surface mean-square slopes, ice roughness and thickness, soil moisture and biomass, or future applications. This paper covers the GOLD-RTR architecture and hardware, signal processing and data storage issues, machine-user interface, laboratory readiness tests, and waveform data samples from the first two jet aircraft campaigns at 9300 m over the sea [J80]

"Adding Sensitivity to the MLBF Doppler Centroid Estimator"

The multilook beat frequency (MLBF) algorithm is the Doppler centroid estimator most commonly used in practice to solve the Doppler ambiguity. However, it still makes errors, notably in medium- or low-contrast scenes. In this paper, we present two ways in which the estimation sensitivity of the MLBF algorithm can be improved. First, we give a more thorough frequency-domain explanation of how the MLBF algorithm works and explain how cross beating and range migration cause estimation difficulties. The first improvement to the algorithm replaces the fast Fourier transform (FFT)-based beat frequency estimator with a more accurate one that uses phase increments. It avoids the FFT limitations of resolution and quantization, especially when the signal is discontinuous in one range cell due to range cell migration or burst mode operation (ScanSAR). A second improvement uses range cell migration correction to straighten the target trajectories before the beat frequency estimator is applied. This has the effect of narrowing the bandwidth of the beat signal and reducing the effect of cross beating. Finally, experiments with RADARSAT-1 data are used to illustrate the improved estimation accuracy of the modified algorithm [J81]

"Vibration and Rotation in Millimeter-Wave SAR"

Synthetic aperture radar (SAR) provides high-resolution images of static ground scenes, whereas processing of data containing ground object motion results in varying focusing effects. Special cases of such motion are vibration and rotation, which are closely related to each other. Their patterns may be distinctly recognizable in focused SAR intensity images as well as in a time-frequency analysis. Millimeter-wave (mmW) SAR is well suited to image vibration because its wavelength is close to typical vibration amplitudes. Through a thorough motion analysis in a standard SAR system model, we show the effects of rotation and vibration in mmW SAR

theoretically and in simulated and real data [J82]

"Least Squares Estimation of Doppler and Polarimetric Parameters for Weather Targets"

Doppler and polarimetric parameters have shown to be of great utility in weather radar applications. Different measurement schemes have been proposed and implemented to obtain Doppler and polarimetric information of the sensed weather target. To date, none of these methods is capable of providing all polarimetric and Doppler parameters of interest for the whole range of temporal correlation conditions. To obtain all parameters, some of the systems require to assume different hypotheses about the Doppler or polarimetric characteristics of the targets. Failure of the assumed hypotheses leads to unacceptable bias and loss of performance of the estimated parameters. Other methods reach a tradeoff, reducing either the number of polarimetric parameters to be estimated or the maximum measurable range of Doppler parameters. With respect to polarimetric parameter estimation, it has already been shown that alternate transmission of three different polarizations improves polarimetric parameter estimation through decoupling of temporal and polarimetric effects. In this paper, this measurement system is generalized by means of a new data processing algorithm and a least squares estimation to provide joint estimates of all Doppler and polarimetric parameters for all temporal correlation conditions. No hypotheses are required. In fact, this method provides minimum variance unbiased linear estimates of all elements of the polarimetric covariance matrix. It also allows Doppler parameter estimation within their corresponding maximum measurable ranges, which are determined by the radar base pulse repetition frequency. The performance of Doppler parameter estimates is comparable to that reached by nonpolarimetric systems. Implementation of the method requires transmitting three known polarizations. Moreover, phase shifts between them should be either known or measured. [J83]

"MIMO Radar Ambiguity Functions"

Multiple-Input Multiple-Output (MIMO) radar has been shown to provide enhanced performance in theory and in practice. MIMO radars are equipped with the ability to choose freely their transmitted waveforms at each aperture. In conventional radar systems Woodward's ambiguity function is used to characterize waveform resolution performance. In this paper we extend the idea of waveform ambiguity functions to MIMO radars. MIMO ambiguity functions are developed that simultaneously characterize the effects of array geometry and transmitted waveforms on resolution performance. Overall resolution performance is shown to be governed by a space-time covariance function that can be controlled by the system on transmit using waveform diversity. Visual examples are provided to illustrate the resolution enhancement possible using MIMO technology [J84]

"Doppler aliasing reduction in SAR imagery using stepped-frequency waveforms"

A new technique for eliminating Doppler aliasing artifacts in synthetic aperture radar (SAR) imagery is presented. The technique uses continuous transmission of stepped-frequency (SF) waveforms to generate a simple, but effective, approximation of a two-dimensional |sinc|2 ambiguity function. This approach ensures aliasing artifacts are placed at nulls in a Doppler filter, effectively removing them from the imagery. Various methods of generating SF waveforms are introduced and their performance is quantified. Finally, simulated SAR imagery shows elimination of more than 99% of the aliased energy [J85]

"Mathematics of Synthesizing Range Profile"

The mathematics of synthesizing a high-range resolution profile (HRRP) is discussed. With a generalized model of synthetic wideband signal and its echo signal, stretch processing technique is extended and refined. Then, an investigation on the mathematic principle of synthesizing a range profile demonstrates that quadratic phase error criterion does not exactly represent the effect of motion on a synthetic range profile (SRP). Therefore, a least-mean-square error criterion is proposed, and several conclusions about the new criterion are derived. In addition, specific conclusions about the distortion for a stepped-frequency waveform (SFW) are investigated with some simulations [J86]

"High-Resolution Estimation of Ranges Using Multiple-Frequency CW Radar"

The problem of ranging multiple vehicles traveling at similar speeds using multiple-frequency continuous-wave (CW) radar is considered. A new method based on the compensation of vehicle movement and MUSIC-based time delay estimator is presented. The method is tested using a commercially available multiple-frequency CW radar sensor in real traffic situations. Test results show that the proposed method makes it possible to estimate the positions of two vehicles moving at similar speeds. Test results also demonstrate that under a given bandwidth, the multiple-frequency CW radar can provide about ten times higher resolution as compared with the coherent spread spectrum radar [J87]

"Optimum and decentralized detection for multistatic airborne radar"

The likelihood ratio test (LRT) for multistatic detection detection is derived for the case where each sensor platform is a coherent space-time radar. Due to the geometric separation of the platforms, target statistics are modeled as independent from platform to platform but constant over the local data on a single platform. Clutter statistics are also assumed independent from platform to platform but have a local space-time correlation structure typical of monostatic space-time adaptive processing (STAP). Moreover, the target Doppler hypothesis varies from platform to platform due to multiple viewing perspectives. Previous published work has investigated the detection improvement obtained by multiple input, multiple output (MIMO) radar. This prior work, however, has only considered white noise. When clutter is considered, the diversity benefit of a MIMO or multistatic radar system is strongly dependent on geometry. We investigate the relationship between geometry and diversity gain for multistatic airborne space-time radar and the effects of this relationship on decentralized and centralized detection. [J88]

"Template-Based Target Identification and Confusion Matrices [JAESS Tutorial IV]"

One-dimensional high-range-resolution (HRR) and two-dimensional range-Doppler-imaging (RDI) radar represent possible sensor technologies where template-based techniques can be applied to perform combat identification (CID). The majority of the research reported in these areas consists of empirical studies. This article provides a theoretical basis for understanding some of the fundamental trade-offs associated with these CID techniques, such as the following: What are the relative advantages of RDI over HRR radar or of finer versus coarser resolution in the HRR process? What is the relative advantage of coherent over noncoherent processing? How do target correlations, signal-to-noise ratio (SNR), and target scintillation affect the ability to identify targets? Because confusion matrices are often used to characterize the performance of CID systems, we provide analytical methods for calculating the entries in confusion matrices as a function of the issues cited above. These formulations provide analytical bases to guide system trade-off decisions. The organization of this paper is as follows. We begin with a short overview of HRR and RDI and then explore a number of ways to process the associated target templates that range from an ideal, theoretical approach to an approach that would be more feasible to implement within current-day radars. We first develop analytic template-based methodologies for constructing confusion matrix entries for nonscintillating targets for both coherent and noncoherent processing assumptions. The confusion matrix entries in these cases are conditional probabilities obtained from a simple rule: find the probability that among m (in general, correlated) random variables, each associated with a possible target, that any one is the largest. For the noncoherent case, the successful application of this rule requires the target template values to explicitly include the effects of thermal noise (noise-adjusted templates). We conclude by showing h--ow to calculate theoretically optimum results (e.g., using maximum likelihood techniques) for noncoherent processing of targets that exhibit uncorrelated Swerling 1 scintillation in ail resolution bins as a function of the SNR. This approach allows us to include overall target intensity (e.g., total radar cross section (RCS)) as a further factor in the target decision process. [J89]

"A Chirp Transform Algorithm for Processing Squint Mode FMCW SAR Data"

Frequency-modulated continuous-wave (FMCW) synthetic aperture radar (SAR) is a lightweight cost-effective high-resolution airborne imaging radar. In squint case, the frequency scaling algorithm, which is suitable for processing nonchirped raw data, cannot be used directly in FMCW SAR data processing because of low system sampling frequency. On the other hand, the continuous antenna motion of FMCW SAR can cause serious distortions in the reconstructed images. In this letter, an improved algorithm called the chirp transform algorithm is proposed. When the effects of the residual video phase are negligible, the algorithm uses a chirp transform to perform the time scaling operation to alleviate the sampling frequency problem. It requires only fast Fourier transforms and multiplications. The range cell migration introduced by the continuous motion is also compensated completely in range-Doppler domain. The algorithm performances are analyzed and are supported by point target simulation experiments. [J90]

"A new approach for synthesizing the range profile of moving targets via stepped-frequency waveforms"

In radar target imaging, motion induces a range-Doppler coupling effect, which results in distortion in synthesizing a range profile for a moving target. To eliminate or suppress the distortion of the synthetic range profile, conventional technology such as motion compensation requires velocity estimation. Unfortunately, for a high-speed moving target, it is difficult to achieve real-time accurate estimation of the velocity of the target. Based on phase cancellation, a new technology is proposed to achieve a motion target range profile via stepped-frequency waveform. The new technology does not need the estimation of the velocity. Hence, its computational cost can be minimized. It is also easier to use. The simulation result confirms the effect of the new

technology [J91]

"Performance of correlation-based frequency estimation methods in the presence of multiplicative noise"

This paper provides a comprehensive performance evaluation of a correlation-based frequency estimator under different fading channel conditions. The efficiency of the estimator in terms of the Cramer-Rao lower bound (CRB) is investigated for different fading conditions, i.e., slow fading, fast fading, Rayleigh fading, and Ricean fading. The asymptotic CRB, which provides an insight to the frequency estimation in fading channels, has been evaluated via a frequency-domain approach. The optimal correlation lag value suitable for frequency estimation under different fading conditions is determined, and closed-form expressions for the variance of the estimates are provided. For proper implementation of the estimator, the Doppler spread of the signal is also estimated. It is shown that using the Doppler spread information, frequency estimation accuracy at low signal-to-noise ratios can be improved using multiple lags of correlations [J92]

"Doppler Spectra From a Two-Dimensional Ocean Surface at L-Band"

An approximate time-harmonic three-dimensional electromagnetic boundary-integral method, the small-slope integral equation, is combined with a series expansion of the Creamer surface representation at second order with respect to the height, denoted by Creamer (2). The resulting model provides at low numerical cost simulations of the nonlinear ocean surface Doppler spectrum at L-band. As a result of approximations, the model is designed for a low-wind speed, typically up to 5 m/s. It is shown that applying directly a second-order model such as Creamer (2) to a semiempirical sea surface spectrum induces an unrealistic magnification of small-scale roughness that is involved in the scattering process at microwave frequencies. This paper thus proposes an undressed version of the Pierson-Moskowitz spectrum that corrects this artifact. Full-polarized Doppler simulations at L-band and 70deg incidence are presented. Effects of the surface nonlinearities are outlined, and the simulated Doppler spectra show correct variations with respect to wind speed and direction [J93]

"Performance improvement for constellation SAR using signal processing techniques"

A new concept of spaceborne synthetic aperture radar (SAR) implementation has recently been proposed-the constellation of small spaceborne SAR systems. In this implementation, several formation-flying small satellites cooperate to perform multiple space missions. We investigate the possibility to produce high-resolution wide-area SAR images and fine ground moving-target indicator (GMTI) performance with constellation of small spaceborne SAR systems. In particular, we focus on the problems introduced by this particular SAR system, such as Doppler ambiguities, high sparseness of the satellite array, and array element errors. A space-time adaptive processing (STAP) approach combined with conventional SAR imaging algorithms is proposed which can solve these problems to some extent. The main idea of the approach is to use a STAP-based method to properly overcome the aliasing effect caused by the lower pulse-repetition frequency (PRF) and thereby retrieve the unambiguous azimuth wide (full) spectrum signals from the received echoes. Following this operation, conventional SAR data processing tools can be applied to focus the SAR images fully. The proposed approach can simultaneously achieve both high-resolution SAR mapping of wide ground scenes and GMTI with high efficiency. To obtain array element errors, an array auto-calibration technique is proposed to estimate them based on the angular and Doppler ambiguity analysis of the clutter echo. The optimizing of satellite formations is also analyzed, and a platform velocity/PRF criterion for array configurations is presented. An approach is given to make it possible that almost any given sparse array configuration can satisfy the criterion by slightly adjusting the PRF. Simulated results are presented to verify the effectiveness of the proposed approaches. [J94]

"Micro-Doppler effect in radar: phenomenon, model, and simulation study"

When, in addition to the constant Doppler frequency shift induced by the bulk motion of a radar target, the target or any structure on the target undergoes micro-motion dynamics, such as mechanical vibrations or rotations, the micro-motion dynamics induce Doppler modulations on the returned signal, referred to as the micro-Doppler effect. We introduce the micro-Doppler phenomenon in radar, develop a model of Doppler modulations, derive formulas of micro-Doppler induced by targets with vibration, rotation, tumbling and coning motions, and verify them by simulation studies, analyze time-varying micro-Doppler features using high-resolution time-frequency transforms, and demonstrate the micro-Doppler effect observed in real radar data. [J95]

"Modified range-Doppler processing for FM-CW synthetic aperture radar"

The combination of compact frequency-modulated continuous-wave (FM-CW) technology and high-resolution synthetic aperture radar (SAR) processing techniques should pave the way for the development of a lightweight, cost-effective, high-resolution, airborne imaging radar. Regarding FM-CW SAR signal processing, the motion

during the transmission of a sweep and the reception of the corresponding echo were expected to be one of the major problems. In FM-CW SAR, the so-called stop-and-go approximation is no longer valid due to the relatively long sweeps that FM-CW radars transmit. The main effect of the continuous motion is a Doppler frequency shift throughout the SAR observation time. This Doppler frequency shift can be compensated for by modifying the range migration compensation. [J96]

"Image feature-based space-time processing for ground moving target detection"

An image feature-based space time processing (IFSTP) algorithm is introduced to effectively detect ground moving targets in clutter and jamming via airborne radar. This new approach exploits the distinct image features of targets and interference signals in the angle-Doppler domain. An image segmentation algorithm, referred to as region growing, extracts targets and interference features in the angle-Doppler domain, and an innovative block-size detection algorithm discriminates between moving targets and interference based on the extracted image features. The proposed IFSTP algorithm is particularly suitable for detecting ground moving targets in highly nonhomogeneous clutter environments, without any requirement for clutter covariance estimation. [J97]

"Training strategies for joint domain localised-space-time adaptive processing in a bistatic environment"

Optimum space-time adaptive processing (STAP) requires knowledge of the true interference covariance matrix. In practice, this matrix is not known and must be estimated from training data, which must be target free and statistically homogeneous with respect to the range gate under test. These conditions are often not satisfied, which degrades the detection performance. Particularly for bistatic ground moving target indication radar, the clutter Doppler frequency depends on range for all array geometries. This range dependency leads to problems in clutter suppression through STAP techniques. The main aim in this paper is to access the relative merits of several strategies associated with STAP weight training for bistatic airborne radar applications. In particular, the issues associated with applying reduced-dimension conventional STAP and in-the-gate processing are studied. Simulation results show that, for a bistatic radar environment, in-the-gate processing approach performs better than conventional STAP approaches [J98]

"Characterizing Observed Environmental Variability With HF Doppler Radar Surface Current Mappers and Acoustic Doppler Current Profilers: Environmental Variability in the Coastal Ocean"

A network of high-frequency (HF) radars is deployed along the New Jersey coast providing synoptic current maps across the entire shelf. These data serve a variety of user groups from scientific research to Coast Guard search and rescue. In addition, model forecasts have been shown to improve with surface current assimilation. In all applications, there is a need for better definitions and assessment of the measurement uncertainty. During a summer coastal predictive skill experiment in 2001, an array of in situ current profilers was deployed near two HF radar sites, one long-range and one standard-range system. Comparison statistics were calculated between different vertical bins on the same current profiler, between different current profilers, and between the current profilers and the different HF radars. The velocity difference in the vertical and horizontal directions were then characterized using the observed root-mean-square (rms) differences. We further focused on two cases, one with relatively high vertical variability, and the second with relatively low vertical variability. Observed differences between the top bin of the current profiler and the HF radar were influenced by both system accuracy and the environment. Using the in situ current profilers, the environmental variability over scales based on the HF radar sampling was quantified. HF radar comparisons with the current profilers were on the same order as the observed environmental difference over the same scales, indicating that the environment has a significant influence on the observed differences. Velocity variability in the vertical and horizontal directions both contribute to these differences. When the potential effects of the vertical variability could be minimized, the remaining difference between the current profiler and the HF radar was similar to the measured horizontal velocity difference (~2.5 cm/s) and below the resolution of the raw radial data at the time of the deployment [J99]

"Separation of target rigid body and micro-doppler effects in ISAR imaging"

Micro-Doppler (m-D) effect is caused by moving parts of the radar target. It can cover rigid parts of a target and degrade the inverse synthetic aperture radar (ISAR) image. Separation of the patterns caused by stationary parts of the target from those caused by moving (rotating or vibrating) parts is the topic of this paper. Two techniques for separation of the rigid part from the rotating parts have been proposed. The first technique is based on time-frequency (TF) representation with sliding window and order statistics techniques. The first step in this technique is recognition of rigid parts in the range/cross-range plane. In the second step, reviewed TF representation and order statistics setup are employed to obtain signals caused by moving parts. The second technique can be applied in the case of very emphatic m-D effect. In the first step the rotating parts are recognized, based on the

inverse Radon transform (RT). After masking these patterns, a radar image with the rigid body reflection can be obtained. The proposed methods are illustrated by examples [J100]

"Range/Doppler ambiguity elimination in high-frequency chirp radars"

Range/Doppler ambiguity is an important problem in chirp radar operations with all the existing schemes for ambiguity elimination relying on multiple waveform switching. Now, a new method for ambiguity elimination is proposed. It is based on a single waveform and only involves a series of software computations associated with the instantaneous amplitudes of the target under consideration at adjacent range bins. Besides the ambiguity factor, the instantaneous range of the target is also estimated. The method can greatly improve the target detection and tracking capability of high-frequency chirp radars. Both simulation and real data processing results are demonstrated to validate of the method [J101]

"A High-Resolution Dual-Doppler Technique for Fixed Multiantenna Airborne Radar"

A new technique is presented for the analysis of data collected by pairs of aircraft (AC)-mounted fixed radar beams directed ~30deg apart, leading to two-dimensional wind field syntheses in the horizontal and vertical planes. The technique was applied to the 95-GHz Wyoming Cloud Radar (WCR) configurations aboard the University of Wyoming King Air and the National Center for Atmospheric Research C-130 research AC. The construction of the data grid allows to closely follow the AC flight attitude, and thus the beam scanned surfaces, with a resolution between 30 and 45 m. A weighted least squares method is employed to solve the velocity inverse decomposition problem for every valid grid cell. The effect on the solution of the nonmeasured (cross-plane) wind component is minimized by using an external estimate of the ambient wind. The error sources are discussed, and maximum expected values for the velocity field errors are provided with reference to the radar system, the data collection process, and specific aspects of the target under investigation. These uncertainties (1-2 m/s) are quantified for two case studies that show the potential of the technique in retrieving the kinematic field in transects of cumulus and stratus clouds. The technique produces smooth fine-scale kinematic fields although each velocity point is the result of an independent calculation, and no binding constraint is imposed among neighboring points as is done in other dual-Doppler techniques [J102]

"Doppler visibility of coherent ultrawideband random noise radar systems"

Random noise radar has recently been used in a variety of imaging and surveillance applications. These systems can be made phase coherent using the technique of heterodyne correlation. Phase coherence has been exploited to measure Doppler and thereby the velocity of moving targets. The Doppler visibility, i.e., the ability to extract Doppler information over the inherent clutter spectra, is constrained by system parameters, especially the phase noise generated by microwave components. Our paper proposes a new phase noise model for the heterodyne mixer as applicable for ultrawideband (UWB) random noise radar and for the local oscillator in the time domain. The Doppler spectra are simulated by including phase noise contamination effects and compared with our previous experimental results. A genetic algorithm (GA) optimization routine is applied to synthesize the effects of a variety of parameter combinations to derive a suitable empirical formula for estimating the Doppler visibility in dB. According to the phase noise analysis and the simulation results, the Doppler visibility of UWB random noise radar depends primarily on the following parameters: 1) the local oscillator (LO) drive level of the receiver heterodyne mixer, 2) the saturation current in the receiver heterodyne mixer, 3) the bandwidth of the transmit noise source, and 4) the target velocity. Other parameters such as the carrier frequency of the receiver LO and the loaded quality factor of the LO have a small effect over the range of applicability of the model and are therefore neglected in the model formulation. The Doppler visibility curves generated from this formula match the simulation results very well over the applicable parameter range within 1 dB. Our model may therefore be used to quickly estimate the Doppler visibility of random UWB noise radars for trade-off analysis [J103]

"Effect of earth's rotation and range foldover on space-based radar performance"

Space-based radar (SBR) by virtue of its motion generates a Doppler frequency component to the clutter return from any point on the Earth as a function of the SBR-Earth geometry. The effect of the rotation of the Earth around its own axis also adds an additional component to this Doppler frequency. The overall effect of the rotation of the Earth on the Doppler turns out to be two correction factors in terms of a crab angle affecting the azimuth angle, and a crab magnitude scaling the Doppler magnitude of the clutter patch. Interestingly, both these quantities depend only on the SBR orbit inclination and its latitude and not on the location of the clutter patch of interest. Further, the crab angle has maximum effect for an SBR on a polar orbit that is above the equator. The crab magnitude, on the other hand, peaks for an SBR on an equatorial orbit. Together with the range foldover phenomenon, their overall effect is to generate Doppler spread/splitting resulting in wider clutter notches that degrade the clutter nulling performance of adaptive processing techniques. A detailed performance analysis and

methods to minimize these effects are discussed here [J104]

"Optically generated arbitrary waveforms for radar applications"

A fibred optoelectronic arbitrary waveform generator for radar calibration purposes is proposed. The ability to generate radar arbitrary waveforms composed of 700 Doppler frequency components from 12 to 14 GHz with 20 dB spurious free dynamic range is demonstrated. [J105]

"Optimization of waveform and detection threshold for range and range-rate tracking in clutter"

We address an optimization problem to obtain the combined sequence of waveform parameters (pulse amplitudes and lengths, and FM sweep rates) and detection thresholds for optimal range and range-rate tracking in clutter. The optimal combined sequence minimizes a tracking performance index under a set of parameter constraints. The performance index includes the probability of track loss and a function of estimation error covariances. The track loss probability and the error covariances are predicted using a hybrid conditional average algorithm. The effect of the false alarms and clutter interference is taken into account in the prediction. A measurement model in explicit form is also presented which is developed based on the resolution cell in the delay-Doppler plane for a single Gaussian pulse. Numerical experiments were performed to solve the optimization problem for several examples. [J106]

"Detection and Processing of bistatically reflected GPS signals from low Earth orbit for the purpose of ocean remote sensing"

We will show that ocean-reflected signals from the global positioning system (GPS) navigation satellite constellation can be detected from a low-earth orbiting satellite and that these signals show rough correlation with independent measurements of the sea winds. We will present waveforms of ocean-reflected GPS signals that have been detected using the experiment onboard the United Kingdom's Disaster Monitoring Constellation satellite and describe the processing methods used to obtain their delay and Doppler power distributions. The GPS bistatic radar experiment has made several raw data collections, and reflected GPS signals have been found on all attempts. The down linked data from an experiment has undergone extensive processing, and ocean-scattered signals have been mapped across a wide range of delay and Doppler space revealing characteristics which are known to be related to geophysical parameters such as surface roughness and wind speed. Here we will discuss the effects of integration time, reflection incidence angle and examine several delay-Doppler signal maps. The signals detected have been found to be in general agreement with an existing model (based on geometric optics) and with limited independent measurements of sea winds; a brief comparison is presented here. These results demonstrate that the concept of using bistatically reflected global navigation satellite systems signals from low earth orbit is a viable means of ocean remote sensing. [J107]

"Linear antenna arrays with bidirectional phase center motion"

The theoretical and experimental studies of linear antenna arrays with bidirectional phase center motion (BPCM) is presented. BPCM is achieved by exciting only part of the linear array elements and sweeping the excited part from one end to the other and back. The sidelobes of the linear arrays with BPCM experience both upper and lower Doppler frequency shift effect in turn, as compared to linear arrays with unidirectional phase center motion (UPCM). Numerical results show that linear arrays with BPCM are also capable of synthesizing low/ultralow sidelobes, but with a much lower excitation dynamic range ratio as compared to that in conventional arrays. In addition, some characteristics, such as passband bandwidth or sideband levels, are better than those of arrays with UPCM or time modulated variable aperture size arrays. An L-band 16-element printed dipole linear array with BPCM was designed. Experimental results show that a -35 dB relative sidelobe level (SLL) can be achieved. [J108]

"Ambiguity-free Doppler centroid estimation technique for airborne SAR using the Radon transform"

In synthetic aperture radar (SAR) signal processing, the Doppler centroid estimation technique, called the "clutter-lock", is important because it is related to the signal-to-noise ratio, geometric distortion, and radiometric error of the final SAR image. Conventional algorithms have either ambiguity problems or somewhat high computational load. Using the fact that the Doppler centroid and the squint angle are directly related, we propose an ambiguity-free Doppler centroid estimation technique using Radon transform, named geometry-based Doppler estimator. The proposed algorithm is computationally efficient and shows good performance of estimating the absolute Doppler centroid. [J109]

"Potential to estimate the canting angle of tilted structures in clouds from microwave radiances around 183 GHz"

The effects of cloud structures on microwave radiances at frequencies from 89-190 GHz are investigated by simulations using the Goddard cumulus ensemble model data as input for a radiative transfer model. It was found that the brightness temperatures at these frequencies have different sensitivities to clouds with a tilted structure. The different sensitivities to altitude and amount of hydrometeors allow the estimation of the canting angle and tilt direction of tilted clouds using brightness temperatures at the water vapor channels at 183.3 ± 1 and 183.3 ± 7 GHz. The estimated canting angle and tilt direction are in agreement with the model situation. This method provides a potential to estimate tilted convective structures from microwave radiometric observations at 183.3 ± 1 and 183.3 ± 7 GHz. It is applied to a tilted storm observed from the National Aeronautics and Space Administration's ER-2 aircraft flying at about 20 km on August 26, 1998 during the third Convection and Moisture Experiment using the observed downlooking brightness temperatures at the water vapor channels of a Millimeter-wave Imaging Radiometer. The estimated results are in good agreement with the realistic storm situation obtained from the simultaneous observations of the ER-2 Doppler radar. This method also provides information about the vertical displacement of cloud structure and thereby to estimate the accurate location of surface rainfall. This is important when validating precipitation retrieval based on observations of the ice scattering above surface rainfall against surface rain observations using the microwave frequencies sensitive to high altitudes. [J110]

"Daytime interference ing of OSMAR"

In order to cancel the daytime interference of Ocean State Monitoring and Analyzing Radar, which appears in some consecutive days, we analyze the interference characteristic. Based on the characteristic the sidelobe cancellation technique and the orthogonal expansion method are proposed to cancel the interference. Both methods increase the sea-echo-to-interference ratio, but the latter achieves better effect in the far distance, which confirms the orthogonal expansion is the best method to remove the interference. [J111]

"Effects of platform rotation on STAP performance"

The effects of platform rotation, and in particular antenna rotation, on the performance of space-time adaptive processing (STAP) in clutter limited, forward looking airborne radar applications are considered. It is shown that there are two principal mechanisms. One involves the change of shape of the clutter surface in angle-Doppler space as the antenna rotates. STAP appears much more resilient to roll than yaw when this mechanism is dominant, although the problems of yaw can be alleviated by the application of motion compensated phase delay steering. The other mechanism involves the presence of discontinuous sharp transitions across a STAP data vector, for which one possible cause is non-ideal motion compensated steering of the antenna. These discontinuities effectively increase the bandwidth and can result in significant performance deterioration [J112]

"Estimation of gravity wave momentum flux with spectroscopic imaging"

Atmospheric gravity waves play a significant role in the dynamics and thermal balance of the upper atmosphere. In this paper, we present a novel technique for automated and robust calculation of momentum flux of high-frequency quasi-monochromatic wave components from spectroscopic imaging and horizontal radar wind measurements. Our approach uses the two-dimensional (2-D) cross periodogram of two consecutive Doppler-shifted time-differenced (TD) images to identify wave components and estimate intrinsic wave parameters. Besides estimating the average perturbation of dominant waves in the whole field of view, this technique applies 2-D short-space Fourier transform to the TD images to identify localized wave events. With the wave parameters acquired, the momentum flux carried by all vertically propagating wave components is calculated using an analytical model relating the measured intensity perturbation to the wave amplitude. This model is tested by comparing wave perturbation amplitudes inferred from spectroscopic images with those from sodium lidar temperature measurements. The proposed technique enables characterization of the variations in the direction and strength of gravity waves with high temporal resolution for each clear data-taking night. The nightly results provide statistical information for investigating seasonal and geographical variations in momentum flux of gravity waves. [J113]

"Ionospheric decontamination and sea clutter suppression for HF skywave Radars"

In this paper, a cascaded correction and suppression method of reducing ionospheric phase path contamination and sea clutter to enable detection of targets travelling at speeds near the Bragg Doppler is addressed. The Hankel rank reduction (HRR) technique based on singular value decomposition (SVD) has been used to estimate the ionospheric phase distortion and suppress the sea clutter. Simulation results show that such a technique is helpful for the worse conditions when the target masking effect happens even after ionospheric phase

decontamination. Finally, an attempt to combine another phase decontamination algorithm based on the piecewise polynomial phase modeling with the clutter cancellation stage for faster phase fluctuation is discussed briefly and some results are given. [J114]

"Mm wavelengths complex Doppler analysis using dark field illumination"

Experimental results that indicate that at least two fundamental modes of Doppler generation are present when a rotating steel cylinder is broadside illuminated by radar. Improvised bistatic measurements at 77GHz are discussed and second order Doppler effects studied. Complex Doppler returns, consisting of two or more Doppler contributions, are decomposed and studied using empirical methods. In particular, ground illumination techniques are used to study Doppler in the shadow region of a cylinder of circumference 81 wavelengths. It is concluded that the complex Doppler response from the spinning cylinder consists of both direct (first order) and delayed (second order) Doppler components. Further measurements are proposed to study the delayed Doppler effect further. [J115]

"Absolute calibration of C-band weather radars using differential propagation phase in rain"

Described is a method for calibrating C-band weather radars which have both polarisation and Doppler capabilities. Attenuation corrections for both co-polar and differential reflectivities are performed gate-to-gate progressively and the differential propagation phase is estimated from the corrected reflectivity profiles. Comparison with the measured differential propagation phase shows high sensitivity to the absolute calibration of the co-polar reflectivity. The method is implementable in almost real time for operational systems and is also capable of correcting for rain on radome effects at C-band. [J116]

"Radar detection in clutter"

Clutter is defined as any unwanted radar return. The presence of clutter in a range/Doppler cell complicates the detection of a target return signal in that cell. In order to quantify the effect of clutter on the probability of detection, we must first specify sets of models suitable for representing the clutter and target. The simplest and most common model for clutter is based on the gamma density. We include two additional models, the NCG and NCGG clutter models for low grazing angles. They are motivated by physical arguments, the latter of which can accommodate the well-known phenomenon of speckle. Using one of these models for clutter together with one of several models for targets, we determine, in a range/Doppler cell, expressions for probabilities of detection of a target in the presence of clutter. It is important to control the probability of false alarms. The presence of clutter in a cell necessitates an increase in the detection threshold setting in order to control false alarms, thus lowering the probability of detection. If the clutter level is unknown, then we need to take measurements of the clutter and use it to adjust the threshold. The more clutter samples we take, the better the estimate of the clutter level and the less is the resulting detection loss. Using the expressions for the probability of detection in clutter, we can quantify the detection loss for a pair of commonly used constant false-alarm rate (CFAR) techniques and investigate how the loss varies with different parameter values, especially with regard to the number of clutter samples taken to estimate the clutter level. [J117]

"IWRAP: the Imaging Wind and Rain Airborne Profiler for remote sensing of the ocean and the atmospheric boundary layer within tropical cyclones"

The Imaging Wind and Rain Airborne Profiler (IWRAP) is the first high-resolution dual-band airborne Doppler radar designed to study the inner core of tropical cyclones (TCs). IWRAP is operated from a National Oceanic and Atmospheric Administration WP-3D aircraft during missions through TCs and severe ocean storms. The system is designed to provide high-resolution dual-polarized C- and Ku-band reflectivity and Doppler velocity profiles of the atmospheric boundary layer (ABL) within the inner core precipitation bands of TCs and to study the effects precipitation has on ocean wind scatterometry as it applies to TCs. IWRAP implements a very unique measurement strategy; it profiles simultaneously at four separate incidence angles (approximately 30°, 35°, 40°, and 50°) while conically scanning at 60 rpm. A summary of the principles of operation and the design of the instrument is given, followed by examples of IWRAP's unique imaging capability. To our knowledge, these examples include the highest resolution measurements of the ABL winds in a hurricane ever obtained. [J118]

"Probability hypothesis density-based multitarget tracking with bistatic range and Doppler observations"

R.P.S. Mahler's probability hypothesis density (PHD) provides a promising framework for the passive coherent location of targets observed via multiple bistatic radar measurements. A particle filter implementation of the Bayesian PHD filter is applied to target tracking using both range and Doppler measurements from a simple non-

directional receiver that exploits non-cooperative FM radio transmitters as its 'illuminators of opportunity'. Signal-to-noise ratios, probabilities of detection and false alarm and bistatic range and Doppler variances are incorporated into a realistic two-target scenario. Bistatic range cells are used in calculating the birth particle proposal density. The tracking results are compared to those obtained when the same tracker is used with range-only measurements. This is done for two different probabilities of false alarm. The PHD particle filter handles ghost targets well and has improved tracking performance when incorporating Doppler measurements along with the range measurements. This improved tracking performance, however, comes at the cost of requiring more particles and additional computation. [J119]

"Passive coherent location radar systems. Part 2: waveform properties"

Resolution and ambiguity in both range and Doppler are parameters of fundamental importance in the design and subsequent performance of any radar system. In this paper, practical measurements of transmitted waveforms are reported and used to illustrate their effects on the resulting system design and performance. In particular, the 'self-ambiguity' which enables the limits on range and Doppler resolution to be evaluated is computed. The bistatic form of the ambiguity function is subsequently presented and used to illustrate how these best case parameters vary as a function of transmitter, receiver and target locations. Understanding the forms that these functions can take and subsequently the implications for system performance is most important if this type of radar is to be used effectively. It is shown that the radar designer does in fact have some limited freedoms to improve system performance. Finally, the implications of transmitter waveform and bistatic geometry on target detection, location and imaging are discussed. [J120]

"Generalized approach to resolution analysis in BSAR"

Bistatic synthetic aperture radars (BSARs) have been the focus of increasing research activity over the last decade. The generalized ambiguity function (GAF) of bistatic SAR is introduced here. First, the GAF for BSAR is represented in the delay-Doppler domain, and is then expanded to the spatial (coordinates) domain. From the GAF, comprehensive knowledge regarding the resolution of BSAR can be extracted, including the range and azimuth resolutions, as well as the area of a resolution cell of BSAR. These general results are also applied to the performance analysis of several particular BSAR geometries, including the space-surface-BSAR (SS-BSAR) system, to demonstrate the potential ability of this newly introduced system. [J121]

"Maximum likelihood angle-frequency estimation in partially known correlated noise for low-elevation targets"

In radar applications, the received echo signals reach the array elements via a multiplicity of paths despite the fact that there exists only one target. We address the problem of joint direction of arrival and Doppler frequency estimation using a sensor array in partially known additive noise. We consider a specular reflection model with a radar cross section fluctuating from one pulse repetition interval to another. The proposed model allows the estimation of more paths than sensors. Two approximate maximum likelihood algorithms are proposed. The first approach uses a linear expansion of the noise covariance matrix, whereas the second employs a combination of oblique projections and a zero-forcing solution to alleviate the effect of noise. In contrast to other classical methods, the two approaches are more robust to spatially correlated noise, and they employ more compact cost functions that reduce the dimension of the optimization search. Numerical simulations are provided to assess the basic performance of the two approaches, which are compared to the Cramer'r-Rao bound. [J122]

"Polyphase code design for Orthogonal Netted Radar systems"

Orthogonal netted radar systems (ONRS) can fundamentally improve radar performance by using a group of specially designed orthogonal signals. A novel hybrid algorithm is proposed to numerically optimize such orthogonal polyphase code sets. The proposed algorithm integrates a statistical simulated annealing algorithm with the traditional iterative code selection method and is demonstrated to be effective for the design of polyphase signals used in ONRS. Some of the design results are presented and discussed. The effect of Doppler frequency shift on the performance of the designed signals is also investigated. [J123]

"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. [J124]

"Range correlation and I/Q performance benefits in single-chip silicon Doppler radars for noncontact cardiopulmonary monitoring"

Direct-conversion microwave Doppler-radar transceivers have been fully integrated in 0.25-µm silicon CMOS and BiCMOS technologies. These chips, operating at 1.6 and 2.4 GHz, have detected movement due to heartbeat and respiration 50 cm from the subject, which may be useful in infant and adult apnea monitoring. The range-correlation effect on residual phase noise is a critical factor when detecting small phase fluctuations with a high-phase-noise on-chip oscillator. Phase-noise reduction due to range correlation was experimentally evaluated, and the measured residual phase noise was within 5 dB of predicted values on average. In a direct-conversion receiver, the phase relationship between the received signal and the local oscillator has a significant effect on the demodulation sensitivity, and the points can be avoided with a quadrature (I/Q) receiver. In this paper, measurements that highlight the performance benefits of an I/Q receiver are presented. While the accuracy of the heart rate measured with the single-channel chip ranges from 40% to 100%, depending on positioning, the quadrature chip accuracy is always better than 80%. [J125]

"A practical millimeter-wave radar calibration target"

A simple rectangular-plate millimeter-wave radar calibration target gives RCS values ranging from hundreds to thousands of square meters. This enable tests over extended ranges and with equipment having modest output power. Precise mechanical alignment mechanisms and an optical sight are mandatory, due to the narrow beamwidth. Absorber collars provide an easy way of adjusting the actual RCS according to specific mission requirements, and effectively reduce edge-diffraction effects. The measured V-band calibration uncertainty was less than 0.5 dB, and the pointing resolution was better than 0.05°. [J126]

"Improved ultra-low range sidelobe pulse compression waveform design"

A continuous nonlinear FM waveform design capable of achieving range sidelobe levels of better than -70 dB, suitable for use with a satellite-borne precipitation radar, is presented. The waveform shows good Doppler tolerance. It is shown that slowly-varying phase and amplitude errors in the transmitter and receiver have relatively little effect, but rapidly-varying errors result in paired echo sidelobes, the level of which can be significant. A closed-loop calibration system will undoubtedly be required to remove such errors. [J127]

"Doppler measurements of smooth and rough surface high frequency scattering from spinning steel cylinders"

Preliminary measurement results gathered using a fully coherent 77GHz phase coded pulse Doppler polarimetric radar and investigating the electromagnetic signatures of electrically large spinning steel cylinders are presented. New and novel results showing the Doppler contributions due to dynamic rough and smooth surface scattering effects are discussed and analysed. In the latter case, significant sideband conversion occurs together with a rapid fall off in the power density spectrum. Future work is proposed and discussed. A fuller analysis of these preliminary results and further results was presented. [J128]

"Targetmaspect-dependent RCS: the effect on assumed beam angle"

First Page of the Article [J129]

"Investigation of the variability of Doppler spectra with radar frequency and grazing angle"

The effect of varying grazing angle on the Doppler spectra of radar backscatter from wind waves has been investigated in a laboratory wave tank. Five different radar frequencies were used and six different wind conditions, for a range of grazing angles between 3° and 24°. The results show linear relationships between the velocity of the dominant scattering components and the grazing angle. This effect is hard to reconcile with a scattering mechanism based on Bragg resonance. Data from a cliff-top radar were also examined. [J130]

"Target-aspect-dependent RCS: the effect on assumed beam angle"

Traffic speed enforcement is becoming more reliant on automated speed-detection devices, particularly the use

of photographically linked slant radar devices. We have conducted an analysis of whether target-aspect-dependent radar cross section (RCS) could have an effect on the accuracy of speed measurements. It was found that there is the potential for a 2.5% error (for a radar aligned at 22° to the road, with a -3 dB beamwidth of 5°) in the speed measured by the radar devices. This is because of the interference between the RCS and the radar beam pattern, if only the main lobe is considered. There are cases, however, when the interference between the RCS and the radar beam patterns are such that the strongest return occurs in the first sidelobe. In these cases, the potential speed error is about 7%. This would be unlikely to occur in practice, however, because of the inverse fourth-power relationship with range. We have not included the details of RCS sidelobe returns in the analysis. [J131]

"Effect of antenna phase centre displacement on FM-CW measurements: application to radar system"

In FM-CW measurements, the displacement of the phase centre of the antenna generates a parasitic Doppler effect. Comparisons between measurements and simulations of a LPD antenna are described and validated. The Doppler effect induced by this antenna is then computed for the FM-CW radar application and compared to the classical one due to the aircraft movement. [J132]

"Application of a six-port wave-correlator for a very low velocity measurement using the Doppler effect"

A new radar system based on a six-port wave-correlator is proposed for measuring the Doppler frequency of a moving object. The six-port wave-correlator is operated as a two-channel wave receiver and the vector relation, both amplitude and phase, between the two input signals is determined directly by measuring the power levels. By using the six-port wave-correlator, no circulator or mixer is needed for the phase measurement. The proposed system has been applied for the measurement of an object moving at a very low velocity. The experiment and simulation results at 10 GHz show that the target velocity around 0.2 mm/s has been successfully inferred, which proved the validity of the proposed scheme. [J133]

"Removing autocorrelation sidelobes by overlaying orthogonal coding on any train of identical pulses"

A coherent train of identical linear FM (LFM) pulses is used extensively in radar because of its good range and Doppler resolution. Its relatively high autocorrelation function (ACF) sidelobes are sometimes reduced through spectrum shaping (e.g., nonlinear FM, or intrapulse weighting on receive). We show how to completely remove most of the ACF sidelobes about the mainlobe peak, without any increase to the mainlobe width, by diversifying the pulses through overlaying them with orthonormal coding. A helpful byproduct of this design is reduced ACF recurrent lobes. The overlaid signal also results in reduced Doppler tolerance, which can be considered as a drawback for some applications. The method is applied to several trains of identical pulses (LFM and others) using several orthonormal codes. The effect on the three important properties of the radar signal: ACF, ambiguity function (AY), and frequency spectrum is presented. The effect on Doppler tolerance is studied, and implementation issues are discussed. The new design is also compared with complementary and sub-complementary pulse trains and is shown to be superior in many aspects. [J134]

"Acoustic and electromagnetic wave interaction: estimation of Doppler spectrum from an acoustically vibrated metallic circular cylinder"

The idea of using acoustically induced Doppler spectra as a means of target detection and identification is introduced. An analytical solution for the calculation of the bistatic scattered Doppler spectrum from an acoustically excited, vibrating, metallic, circular cylinder is presented. First, the electromagnetic scattering solution of a slightly deformed circular cylinder is obtained using a perturbation method. Then, assuming the vibration frequency is much smaller than the frequency of the incident electromagnetic wave, a closed form expression for the time-frequency response of the bistatic scattered field is obtained which can be used directly for estimating the Doppler spectrum. The acoustic scattering solution for an incident acoustic plane wave upon a solid elastic cylinder is applied to give the displacement of the cylinder surface as a function of time. Results indicate that the scattered Doppler frequencies correspond to the mechanical vibration frequencies of the cylinder, and the sidelobe Doppler spectrum level is, to the first order, linearly proportional to the degree of deformation and is a function of bistatic angle. Moreover, the deformation in the cylinder, and thus the Doppler sidelobe level, only becomes sizeable near frequencies of normal modes of free vibration in the cylinder. Utilizing the information in the scattered Doppler spectrum could provide an effective means of buried object identification, where acoustic waves are used to excite the mechanical resonances of a buried object. [J135]

"Digital radio frequency memory linear range gate stealer spectrum"

In this paper, we develop an expression for the frequency spectrum of a digital radio frequency memory (DRFM) linear range gate stealer (RGS) electronic attack (EA) signal. A DRFM linear RGS EA signal has a slightly different center frequency than the input radar signal and evenly spaced harmonics or spectral lines. Previously, we presented a top-level analysis to predict the center frequency shift and the spacing of the spectral lines. However, our top-level analysis did not address the magnitude of the spectral lines. The expression developed in this paper reveals the magnitude of the spectral lines along with the center frequency shift and the spacing of the spectral lines. We also present laboratory spectral measurements to demonstrate the validity of the expression. [J136]

"Beamforming using the fractional Fourier transform"

We present a new method of beamforming using the fractional Fourier transform (FrFT). This method encompasses the conventional minimum mean-squared error (MMSE) beamforming in the frequency domain or spatial domain as special cases. It is especially useful for applications involving chirp signals such as signal enhancement problems with accelerating sinusoidal sources where the Doppler effect generates chirp signals and a frequency shift and active radar problems where chirp signals are transmitted. Numerical examples demonstrate the potential advantage of the proposed method over the ordinary frequency or spatial domain beamforming for a moving source scenario. [J137]

"Benefits of space-time adaptive processing (STAP) in bistatic airborne radar"

The paper investigates the merits of using STAP for clutter suppression in bistatic airborne radar. Particular emphasis is placed on the clutter angle-Doppler inter-relationships in bistatic geometries, and it is demonstrated that there can be ground regions where small changes in arrival angle imply large changes in the Doppler shift. STAP clutter rejection methods are not ideally suited to these cases. It is also shown that the angle-Doppler inter-relationships vary with the ground topography, but the effects of this are usually small. Finally, it is shown that the clutter-suppression performance is dependent on the transmit and receive beam mainlobe/sidelobe interactions. [J138]

"Subcomplementary code pairs: new codes for ST/MST radar observations"

A new type of codes, named subcomplementary codes, are introduced. These codes are close to, but not strictly, complementary. Each of the two sequences of the pair has an equal number of opposite elements, which enables the codes to have very high interference-suppression-factor (ISF) performances in and around the radar center frequency. The disadvantage of these codes is the presence of sidelobes of amplitude of -N in their autocorrelation functions for lag 1 (N being the code length). Some properties of these codes are presented along with a technique for generating the code pairs. Subcomplementary code pairs have been found for values of N equal to 4, 8, 16, 20, and 32. A simulation study confirms a major improvement in ISF over complementary code pairs around the zero Doppler frequency. Experimental observations were performed with the middle and upper atmosphere radar in Japan using complementary and subcomplementary code pairs of length 16 and an uncoded pulse for range resolution performance comparisons. The results obtained so far indicate that the effects of the sidelobes in the subcomplementary code pair are minimal for wind observations, although significant for shear velocity observations. The degradation in performance in signal-to-noise ratio observations is found to be noticeable but not severe. The subcomplementary code pairs may, therefore, be used in situations where their advantages for interference suppression are exploited and where the effects of their weaknesses are not so important as in the case of observations for applications in meteorology. [J139]

"Effects of bistatic clutter dispersion on STAP systems"

The performance of several space-time adaptive processing (STAP) approaches in bistatic applications is analysed. Specific consideration is given to the effects of bistatic clutter spectral dispersion on covariance estimation and the algorithm's resulting clutter-rejection capability. The role of adaptive processing methods capable of high performance with efficient utilisation of the required training data is emphasised. A deterministic two-dimensional (angle-Doppler) compensation technique is used as a pre-processor and is compared to the Doppler warping approach. The algorithm performance is assessed using the output signal to interference plus noise ratio (SINR) compared to that of the matched filter with a known covariance. [J140]

"Comparison of Doppler clutter cancellation techniques for naval multi-function radars"

The authors describe a comparison of fixed and adaptive clutter cancellation processes applied to measured multi-function radar (MFR) data in a littoral environment. The adaptive filters require estimates of the clutter

covariance, and comparisons of different strategies for obtaining this are made. The results for the adaptive filters generally show substantially improved target detectabilities over non-adaptive filters. [J141]

"Robust Doppler classification technique based on hidden Markov models"

A classification algorithm is presented that uses hidden Markov models (HMMs) to carry out recognition between three classes of targets: personnel, tracked vehicles and wheeled vehicles. It exploits the time-varying nature of radar Doppler data in a manner similar to techniques used in speech recognition, albeit with a modified topology, to distinguish targets with different Doppler characteristics. The algorithm was trained and tested on real radar signatures of multiple examples of moving targets from each class, and the performance was shown to be invariant to target speed and orientation and was able to be generalised with respect to variants within a class. [J142]

"An empirical model of EM scattering from steepening wave profiles derived from numerical computations"

The variation in scattered power from steepening wave profiles, as functions of radar frequency and bistatic grazing angles, has been investigated using a hydrodynamic code called CHY and a version of the forward-backward (FB) electromagnetic scattering code. A comparison of the frequency response of the FB numerical results with radar data showed excellent agreement and has indicated that the lateral coherence of a breaking wave is around one third of the water wavelength. A simple empirically derived model based on the height spectrum of the surface has been shown to capture almost all the important trends in the scattering, including the Doppler velocities, but with the exception of the effect of multipath. The Doppler spectrum of the steepening wave was found to be well modeled by a Lorentzian lineshape with different spectral widths for vertical-vertical and horizontal-horizontal polarization. [J143]

"Assessment of chaos-based FM signals for range-Doppler imaging"

The authors analysed a set of random frequency modulated (FM) signals for wideband radar imaging and assessed their resolution capability and sidelobe distribution on the range-Doppler plane. To this effect deterministic, bounded, nonlinear iterated maps were first considered. The initial condition of each chaotic map was assigned to a random variable to obtain statistically independent samples with invariant probability density function. The resulting sequences, which have white time-frequency representations, are used to construct wideband stochastic FM signals. These FM signals are ergodic and stationary. The autocorrelation, spectrum and the ambiguity surface associated with each of the FM signals were characterised. It was also demonstrated that the ambiguity surface of an FM signal generated via a chaotic map with uniform sample distribution and tail-shifted chaotic attractor is comparable to the ambiguity function of a Gaussian FM signal [J144]

"High-resolution time-frequency distributions for manoeuvring target detection in over-the-horizon radars"

A novel high-resolution time-frequency representation method is proposed for source detection and classification in over-the-horizon radar (OTHR) systems. A data-dependent kernel is applied in the ambiguity domain to capture the target signal components, which are then resolved using root-MUSIC based coherent spectrum estimation. This two-step procedure is particularly effective for analysing a multicomponent signal with time-varying complex time-Doppler signatures. By using the different time-Doppler signatures, important target manoeuvring information, which is difficult to extract using other linear and bilinear time-frequency representation methods, can be easily revealed using the proposed method [J145]

"Frequency-coded waveforms for enhanced delay-Doppler resolution"

In this paper, we propose techniques for the construction of frequency-coding sequences that give rise to frequency-coded waveforms having ambiguity functions with a clear area-containing no sidelobes-in a connected region surrounding the main lobe. These constructed sequences are called pushing sequences. First, two important properties of pushing sequences are investigated: the group D4dihedral symmetry property and the frequency omission property. Using the group D4dihedral symmetry property, we show how to construct additional pushing sequences from a given pushing sequence. Using the frequency omission property, we show how to construct pushing sequences of any length N and design proper frequency-coded waveforms that meet specific constraints in the frequency domain. Next, we use the Lempel T4construction of Costas sequences to construct pushing sequences with power 1. Finally, we show how to construct pushing sequences with any desired power using Lee codewords. Because these arbitrary-power pushing sequences constructed using Lee codewords do not have the Costas property, we derive expressions for the pattern of hits in the geometric array.

Based on this, the general form of the positions and levels of all the sidelobe peaks are derived. [J146]

"Multichannel ATI-SAR with application to the adaptive Doppler filtering of ocean swell waves"

Multichannel along-track interferometric (MATI) SAR systems are discussed from the point of view of ocean remote sensing. It is shown that the signals scattered by range moving scatterers can be Doppler filtered using a MATI-SAR. Processing techniques are presented, including a phase screen method for the removal of phase errors (including systematic errors and also those resulting from platform motion). A particular radar system (the ESR, enhanced surveillance radar) is described; this has a 3 cm wavelength MATI with two, three or four beams. It is used for investigating and exploiting Doppler effects in ocean radar scattering. It is demonstrated that, by applying adaptive Doppler filtering techniques, the MATI-SAR can significantly increase the imaging sensitivity of ocean features with respect to a conventional SAR. Examples illustrate the use of the ESR MATI-SAR system for imaging ship generated swell waves. Using three beams, the visibility of the wave images is increased by 9.5 dB looking downwind and 5.0 dB looking upwind for horizontal polarisation at grazing angles of 39° and 32°, respectively. Associated Doppler filter responses are shown which show that the scatterers modulated by the swell wave are located in the neighbourhood of the wave crests. [J147]

"Human walking estimation with radar"

Radar can be used to observe humans that are obscured by objects such as walls. These humans cannot be visually observed. The radar measurements are used to animate an obscured human in virtual reality. This requires detailed information about the motion. The radar measurements give detailed information about the movements of the human body parts; the Doppler signatures are time-varying and observed in the spectrogram. The authors focus on the extraction of parameters and describe a method for estimating human walking parameters from radar measurements. The parameters are estimated by minimising the difference between a simulated model and real measurements. A human walking model is presented which can be used both to calculate the radar response and visually to animate a walking person. The method is applied to real radar measurements of inbound walking humans from a distance of 20 m. The results show that estimation of the walking parameters is possible. The animated walking human generated with estimated parameters is a realistic likeness of the real walking human. [J148]

"Manoeuvring target detection in over-the-horizon radar using adaptive clutter rejection and adaptive chirplet transform"

In over-the-horizon radar (OTHR) systems, the signal-to-clutter ratio (SCR) used for moving target detection is very low. For slowly moving targets such as ships, the SCR is typically from -50 dB to -60 dB and their Doppler frequencies are close to that of the clutter. For manoeuvring targets, such as aircraft and missiles, the Doppler frequencies are time-varying when a long integration time is considered. When a target does not move uniformly, the Fourier transform based target detection techniques, including super-resolution spectrum techniques, may fail to work appropriately. In such situations, the Doppler signatures are time-varying and, therefore, time-frequency analysis techniques can be used for manoeuvring target detection. In addition, clutter rejection is also required for target detection due to the low SCR. The existing adaptive clutter rejection algorithms combine clutter rejection with spectrum analysis methods, which usually assume uniformly moving target (i.e. sinusoidal Doppler signature) models. An adaptive clutter reject algorithm is proposed together with the adaptive chirplet transform technique for manoeuvring target detection in a multipath environment. Simulation results using a simulated manoeuvring target signal with received raw OTHR clutter data show that targets with SCR below -50 dB can be detected by using the proposed algorithm [J149]

"Distortion in the inverse synthetic aperture radar (ISAR) images of a target with time-varying perturbed motion"

Large distortion in ISAR images of a moving target has been investigated and demonstrated under controlled experiments. The distortion is a result of small time-varying perturbed motion experienced by the target and is attributed to a modulation effect in the phase of the radar return from the target. The Doppler motion of the target, modulated by a time-varying perturbation, results in a broad smear in the phase of the radar signal. A numerical model of the distortion based on the phase modulation effect has been developed. Simulated ISAR images produced by this model are in good agreement with experimental results. The numerical and experimental studies described provide a better understanding of the distortion mechanism that affects the ISAR images of a target in motion [J150]

"Medium PRF radar PRF selection using evolutionary algorithms"

Evolutionary algorithms are applied to the optimization of pulse repetition frequency (PRF), for both eight-and nine PRFs, in medium PRF radar while considering the detailed effects of sidelobe clutter and many other technical factors. The algorithm presented also ensures that all the solutions produced are fully decodable and have no blind velocities. The evolutionary algorithm was able to identify near-optimum PRF sets for a realistic radar system with only a modest computational effort. [J151]

"Effect of nonuniform target motion on radar backscattered waveforms"

The effect of nonuniform motion on radar waveforms is discussed. By considering the physical model of a perfectly reflecting mirror with an arbitrary law of motion r(t), it is possible to determine the functional form of the scattered wave at the receiver for any waveform in general. The particular example of an interrupted continuous wave waveform is used to analyse the effect of nonuniform motion on the return spectrum. These models provide a theoretical foundation for the observations of micro-Doppler that have been discussed by a number of authors. Finally, some of the implications, both physical and mathematical, of nonuniform motion for time-frequency methods are addressed [J152]

"Micro-Doppler analysis of vibrating targets in SAR"

Vibrating targets cause phase modulation of the azimuth phase history for a SAR system. The phase modulation may be seen as a time-dependent micro-Doppler frequency. It is useful to analyse such signals with Cohen's (1995) class time-frequency methods due to their superior resolution potential. The method must be chosen with care, as the effective time integration window of the kernel should not be longer than about a cycle of the modulation signal. Using the adaptive optimal kernel method (AOK), the authors obtained good results from a controlled experiment where two oscillating corner reflectors were placed within a SAR scene collected by the US Navy APY-6 radar. The oscillation frequency and amplitude were calculated from the time-frequency distributions and the results agree well with available ground truth. To resolve the instantaneous frequencies, the kernel time extent had to be sufficiently short [J153]

"Analysis of micro-Doppler signatures"

Mechanical vibration or rotation of a target or structures on the target may induce additional frequency modulations on the returned radar signal which generate sidebands about the target's Doppler frequency, called the micro-Doppler effect. Micro-Doppler signatures enable some properties of the target to be determined. In the paper, the micro-Doppler effect in radar is introduced and the mathematics of micro-Doppler signatures is developed. Computer simulations are conducted and micro-Doppler features in the joint time-frequency domain are exploited [J154]

"Strengths and limitations of the Fourier method for detecting accelerating targets by pulse Doppler radar"

The Fourier transform method has been generally used in pulse Doppler radar for detecting targets that are moving with acceleration, despite the phenomenon known as Doppler smearing which limits the performance of the method. Examples of accelerating targets are manoeuvring aircraft and missiles. The authors quantify the effects of Doppler smearing. In using a pulse Doppler radar to detect a nonaccelerating target in additive white Gaussian noise and to estimate its radial velocity, the Fourier method provides an output signal-to-noise ratio (SNR) that increases linearly with the number of pulses. When the target is accelerating, the Fourier method may still be used to detect the target and estimate its median velocity, provided the acceleration is small enough in the sense described. For a given acceleration, when the number of pulses is increased, the output SNR of the Fourier method varies as a concave function, increasing to a maximum and then decreasing, before the method fails catastrophically. Thus the number of pulses and the acceleration have to be matched to achieve optimum performance. Empirical formulas for the dependence of the optimum SNR and the optimum number of pulses on the acceleration are given. The results are shown to be relevant to the design of generalised likelihood ratio test detectors that apply a search over a grid [J155]

"Interferometric alignment of the X-SAR antenna system on the space shuttle radar topography mission"

The on-orbit alignment of the antenna beams of both the X-band and C-band radar systems during operations of the shuttle radar topography mission/X-band synthetic aperture radar (SRTM/X-SAR) was a key requirement for achieving best interferometric performance. In this paper, we consider the X-SAR antenna beam alignment in azimuth. For a single-pass cross-track SAR interferometer, we establish the relation between yaw and pitch misalignment of the antenna beams and the resulting relative shift of the Doppler frequency bands. This relation

is used to provide solutions for the mechanical adjustments of the outboard antenna and electronic beam steering to correct for azimuth misalignment. Furthermore, the effects of the X-SAR effective outboard antenna pattern on the azimuth beam alignment are analyzed. As a result, a so-called "relaxing" factor is derived, which increases the limit for the difference in antenna azimuth angle with respect to the requirement on spectral overlap, and hence spatial interferogram resolution. However, we also show that the alignment requirement is driven by the constraint on decreasing the azimuth ambiguity-to-signal ratio (AASR) for the effective outboard antenna pattern to reduce the resulting additional height error. The strategy for misalignment determination and correction is presented, and results of the analysis of the in-flight X-SAR antenna beam alignment are discussed [J156]

"Minimum mean square error space-varying filtering of interferometric SAR data"

This paper addresses the problem of filtering interferometric synthetic aperture radar (IFSAR) signals in presence of nonplanar topography to mitigate geometrical decorrelation effects. The problem is space-variant. The authors assume knowledge about the scene topography and derive an optimal, minimum mean square error (MMSE), filtering procedure. The algorithm is flexible and, beside the standard stripmap-stripmap interferometry, it may be applied to IFSAR data acquired in any operative mode. For instance, in scan-scan, scan-strip, and scan-spot interferometry. The scene topography contribution may be either derived from an external rough digital elevation model (DEM) or directly estimated from the SAR data. The filtering technique is extended to the azimuth direction to account for possible Doppler centroid decorrelation. Experimental results carried out on real data confirm the validity of the theory and show that this filtering procedure allows the authors to obtain a reduction of the interferometric noise content. Its gain is particularly marked in the cases of steep topography, where application of the standard common band filters could deteriorate the signal quality, or for large Doppler centroid shifts between the two acquisitions [J157]

"Performance characterisation of hybrid STAP architecture incorporating elevation interferometry"

Radar space-time adaptive processing (STAP) techniques have classically focused on azimuth-Doppler adaptivity while placing minimal emphasis on elevation. Elevation beamforming offers significant clutter suppression improvement, allowing further suppression of interference sources having identical Doppler and azimuth. This work incorporates elevation adaptivity through an interferometric approach, greatly improving clutter suppression while providing an often overlooked target height discrimination capability. A mathematical construct encapsulating the multistage processing framework is developed for the proposed technique. This framework allows extension of the traditional factored time-space (FTS) technique into the azimuth-Doppler-elevation hypercube and represents a subclass of more generalised hybrid methods. The proposed concept is validated through results based on simulated airborne radar data. Target detection improvement of the order of 25 dB, when compared to standard two-dimensional FTS processing, is demonstrated for an 8 Ч 8 nonuniform rectangular array. Elevation pattern data are provided to illustrate achievable null width/depth capabilities. These data also indicate target height discrimination is inherently provided and further development is warranted [J158]

"Doppler compensation for binary phase-coded waveforms"

Codes used in phase-coded pulse compression waveforms suffer from Doppler mismatch. Based on an analysis of the effects of Doppler mismatch on binary phase-coded waveforms, a class of codes is proposed (hereafter referred to as the component codes), its derivation and processing is described, and the performance results are analyzed. This technique solves the problem of the Doppler mismatch of binary phase-coded waveforms at the expense of about 3 dB loss in signal-to-noise ratio (SNR). This technique may be used in tracking applications, such as accurately and rapidly measuring and tracking targets of unknown speeds. Simulation results demonstrate the validity of this technique. [J159]

"Minimal sample support space-time adaptive processing with fast subspace techniques"

The authors investigate finite data support for subspace or projection methods for STAP which are robust against strong clutter returns. A theoretical analysis of the eigenvector projection technique is presented that provides insight into the problem of determining the optimum choice of the projected clutter subspace and matched filter adjustments (with respect to target Doppler frequency). An estimator of the optimum subspace dimension, which is significantly smaller than clutter rank, as a function of the number of samples is presented. This result, combined with a previously proposed near-optimal eigenvector-free projection techniques with minimal sample support, reduce the computational burden so drastically that even fully adaptive optimum STAP with large degrees of freedom may become practical for real-time applications. [J160]

"A delay/Doppler-mapping receiver system for GPS-reflection remote sensing"

A delay/Doppler-mapping receiver system, developed specifically for global positioning system (GPS)-reflection remote sensing, is described, and example delay/Doppler waveforms are presented. The high-quality data obtained with this system provide a more accurate and detailed examination of ground-based and aircraft GPS-reflection phenomenology than has been available to date. As an example, systematic effects in the reflected signal delay waveform, due to nonideal behavior of the C/A-code auto-correlation function, are presented for the first time. Both a single-channel open-loop recording system and a recently developed 16-channel recorder are presented. The open-loop data from either recorder are postprocessed with a software GPS receiver that performs the following functions: signal detection; phase and delay tracking; delay, Doppler, and delay/Doppler waveform mapping; dual-frequency (L1 and L2) processing; C/A-code and Y-code waveform extraction; coherent integrations as short as 125 μs; navigation message decoding; and precise observable time tagging. The software can perform these functions on all detectable satellite signals without dead time, and custom signal-processing features can easily be included into the system [J161]

"Doppler estimator operating with matched filter for vehicular spread spectrum radar"

A Doppler estimator is designed for vehicular spread spectrum radar operating with the matched filter. Simulation results demonstrate that the estimated error of the relative speed between the leading car and the host car decreases with the relative speed. The maximum estimated error of the relative speed could be reduced to ±0.15 km/h within 0.84667 μs processing time [J162]

"Super resolution feature extraction of moving targets"

High range resolution (HRR) moving target indicator (MTI) is becoming increasingly important for many military and civilian applications such as the detection and classification of moving targets in strong clutter background. We consider the problem of extracting the HRR features of moving targets with very closely spaced scatterers in the presence of strong stationary clutter, where the range migration and Doppler frequency are taken into account. A relaxation-based algorithm, which is robust and computationally simple, is proposed to deal with the above problem. Numerical results have shown that the proposed algorithm exhibits super resolution and excellent estimation performance [J163]

"Impact of clutter spectra on radar performance prediction"

The effect on radar detection of the shape of the Doppler spectrum of windblown vegetated ground clutter is analyzed. An extensive experimental campaign carried out by MIT Lincoln Laboratory showed the shape of the windblown clutter Doppler spectrum to be exponential, in contrast to two other widely-used spectral models (i.e., Gaussian and power-law). The detection performance of two classes of surveillance radar, ground-based and Airborne Early Warning, is evaluated and compared against windblown ground clutter using the three above-mentioned Doppler spectral shapes. The analysis is first done with closed-form equations, and subsequently validated using a set of measured clutter data. It is demonstrated that the exponentially shaped Doppler spectrum should be used as the reference to model windblown ground clutter for the prediction of radar detection performance [J164]

"Surface clutter due to antenna sidelobes for spaceborne atmospheric radar"

A spaceborne radar for atmospheric observation must be able to detect atmospheric backscatter in the presence of clutter from the surface, due to antenna sidelobes. Such clutter can come from the same pulse as that observing the atmosphere if the radar antenna is pointed off-nadir. However pulses both prior and subsequent to the pulse observing the atmosphere can also contribute to clutter, and surface clutter can be a problem even for nadir-looking radars. Here, the problem is analyzed by deriving a method for computing clutter which includes effects of all contributing transmit pulses, Doppler shifting, finite receiver bandwidth, and curved Earth's surface. The results are applied to analysis of existing radars and design of future radar systems [J165]

"Application of the linear dispersion relation with respect to depth inversion and remotely sensed imagery"

Remote sensing methods have been developed to estimate bathymetry through the use of a theoretical relationship between wave speed and water depth known as the linear, finite depth, dispersion equation for surface gravity waves. The authors describe a validation effort encompassing several hundred observations of wavenumber magnitude for sea-swell frequencies obtained over a wide variety of conditions to investigate possible error sources resulting from the practical application of this relationship. These wavenumber estimates were computed from pressure gauge signals using signal processing algorithms that can be equivalently applied to measurements of wave phase as imaged through remote sensors. The major goal was to determine the accuracy of the dispersion relation while attempting to minimize errors associated with sensor positioning, tidal

variations, and Doppler shifts due to mean currents. For water depths outside the surf zone, the linear dispersion relation is highly accurate, with average depth estimation errors on the order of 3-9% of the observed depth. In shallower regions, nominally less than 4 m for this field site, where wave breaking is evident and nonlinear shoaling effects are more pronounced, normalized depth errors of over 50% were commonly observed with most predictions being deeper than observations. Strong correlation between these bias errors and measured wave heights emphasizes the importance of accounting for wave amplitude in the calculation of shallow water phase speeds for depth estimation. A simple depth correction is provided to allow for bathymetry estimation within the surf zone [J166]

"On the feasibility of a Doppler weather radar for estimates of drop size distribution using two closely spaced frequencies"

Dual-frequency weather radar data can be gathered using a single broadband power amplifier and antenna for the purpose of estimating parameters of the hydrometeor size distribution. This is an attractive feature for observation platforms that are limited with respect to mass or available power. Whether useful properties of the scattering medium can be obtained from data of this type is the focus of the paper. Generally, as the center frequency or the bandwidth is decreased, the reflectivity factor difference falls below the level of the inherent signal fluctuations. Even if large numbers of independent samples can be gathered to permit estimates of the differential signals, the question remains as to whether the signal can be related unambiguously to properties of the rain or snow. Center frequencies at or near 35 GHz with bandwidths in excess of 5% give relatively strong differential signals. The signal, moreover, is directly related to the median mass diameter of the size distribution. The differential mean Doppler at frequencies where non-Rayleigh scattering effects are significant is also of use because the quantity depends only on the terminal velocity of the drops and is insensitive to the mean air and platform motion. In principle, the mean and differential mean Doppler velocities from a nadir-viewing radar can be used to estimate the mean vertical air motion and the median drop diameter of the size distribution [J167]

"Synchronization improvements using traceability in spread spectrum signal design"

Synchronization improvements using traceability information found in the narrowband auto-ambiguity function (NB AAF) are demonstrated. This new auto-ambiguity function property, traceability, is the key to defining a signal design approach for solving the synchronization problems in spread spectrum system such as communication systems, radar networks, and sonar systems. This work defines the property and introduces a new tracing synchronization scheme that significantly reduces initial synchronization time and the number of false synchronization events [J168]

"Analysis of distortion in the high range resolution profile from a perturbed target"

Experimental results have demonstrated that even when a target possesses very small perturbed rotational motion, its high range resolution (HRR) radar image profile can be severely distorted. A numerical model has been developed and is able to accurately simulate the observed distorting effects. The well known range-Doppler coupling effect offers a partial explanation for the distortion of a target's HRR profile when the perturbing rotational motion is constant in time during radar interrogation. A more interesting and much more dramatic situation arises when the perturbing motion is time-varying; severe distortion in the target's HRR profile can occur due to the excitation of higher-order sidebands in the phase of the target echo [J169]

"Doppler compensation in forward-looking STAP radar"

For air- and spaceborne MTI radar the clutter Doppler frequency depends on range for all array geometries other than linear sidelooking. This applies particularly to forward-looking arrays. The range dependence of the clutter Doppler causes specific problems in clutter rejection through STAP (space-time adaptive processing) techniques. One aspect is the lack of training data required for adapting the STAP filter. Another aspect is that the STAP filter becomes range dependent. A technique for compensating for the range dependence is proposed. The efficiency of the method is verified by use of clutter data measured with the multichannel radar AER II (airborne experimental radar) [J170]

"High-resolution ISAR imaging of maneuvering targets by means of the range instantaneous Doppler technique: modeling and performance analysis"

Very high resolution inverse synthetic aperture radar (ISAR) imaging of maneuvering targets is a complicated task. In fact, the conventional range Doppler (RD) ISAR technique does not work properly when target motions generate terms higher than the first order in the phase of the received signal relative to each scatterer. This effect typically happens when at least one of these situations occur: (1) very high resolution images are required;

(2) the target maneuvers; and (3) the target undergoes significant angular motions (roll, pitch, and yaw). A novel ISAR technique, named range instantaneous Doppler (RID), has been proposed for the reconstruction of very high resolution images of maneuvering targets. In this paper, we analytically show that the RID technique works properly when high-resolution ISAR images are required of maneuvering and/or rolling, pitching, and yawing targets; we also quantify the performance improvement of the RID technique with respect to the RD technique. The problem is tackled from an analytical point of view. First, we define a new model of the ISAR received signal that is valid for maneuvering targets, then we derive and compare the analytical expression of the point spread function (PSF) for the two techniques. Furthermore, we perform a statistical analysis to evaluate the improvement of the RID technique versus the RD technique in terms of spatial resolution. Finally, we prove the effectiveness of the RID technique by simulating the imaging process for two different targets: (1) a ship that undergoes roll, pitch and yaw motions and (2) a fast maneuvering airplane [J171]

"The near-surface current velocity determined from image sequences of the sea surface"

A method to measure the ocean's near-surface current velocity vector based on the analysis of remote sea-surface image sequences was developed. The spatial and temporal records were transformed to the wavenumber-frequency domain, resulting in a three-dimensional (3-D) image power spectrum. In the spectrum, the signal energy of the waves is localized on a shell defined by the dispersion relation of surface waves. The sum of the sensor's velocity and the near-surface current profile deforms the dispersion shell due to the Doppler-frequency shift. An iterative least-squares fitting technique and an error-estimation model was implemented. To improve the method's accuracy, spectral wave energy found in higher harmonics of the dispersion shell and aliasing effects are taken into account. The most important nonlinear mechanism leading to higher harmonics is explained as resulting from wave shadowing due to the low grazing angles typical for ground- or ship-based radars. The improved method is examined analytically and is tested with Monte Carlo simulations. The variation of the shape of the measured or simulated 3-D image spectra, especially the peak wavenumber, the directional spread, and the main travel direction, controls the behavior and accuracy of the technique. A comparison of velocities acquired by nautical radar and independent Doppler log current measurements is presented. The technique's accuracy, its limits, and its adaptability are discussed. Additional improvements are proposed [J172]

"Frequency estimation in the presence of Doppler spread: performance analysis"

We are concerned with the estimation of the frequency of a complex sinusoid that has been corrupted by complex-valued multiplicative and additive noise. This problem is important in many applications including array processing in the case of spatially distributed sources and synchronization in the context of time-selective channels. The multiplicative noise smears the spectral line due to the sinusoid. This smearing, which is often called Doppler spreading, may significantly degrade the estimation accuracy. The goal of this paper is to analytically assess this degradation. The finite-sample Cramer-Rao bounds (CRBs) are derived, and closed-form expressions are given for the large-sample CRB. The latter gives insights into the effective coherent and noncoherent SNRs for frequency estimation. We then analyze the accuracy of frequency estimators that are based on the angles of the sample covariances. Simulations results are presented to illustrate the theoretical results [J173]

"Optimal “focusing” for low resolution ScanSAR"

Deals with the focusing of low resolution ScanSAR data, for both detected amplitude images and interferometric applications. The SAR reference is exploited to achieve ScanSAR focusing in conventional techniques. Such techniques provide quite effective compensation of the azimuth antenna pattern (e.g. no scalloping) when the azimuth time-bandwidth product of the ScanSAR echo is large, but fail to do so as the burst shortens, being reduced to an ineffective weighting of the output. The result is an azimuth varying distortion of the focused impulse responses, a distortion that is partly compensated for in the multilook average (not available for interferometric applications) at the price of a reduction in the processed Doppler bandwidth. This paper proposes quite a different approach. A set of short kernels, each suitable for “focusing” at a specific azimuth bin, has been optimized to reconstruct source reflectivity in the minimum mean square error sense. That pseudoinversion converges to the “conventional” focusing when the burst extent is large and for short bursts, edge effects are accounted for. These azimuth-varying kernels can be suitably tuned to meet constraints in the resolution/sidelobes trade-off and have proved capable of providing fairly undistorted output and fine resolution. They better exploit the available Doppler bandwidth, maximizing the number of looks and the interferometric quality. A decomposition is suggested that implements the inverse operator as a fast preprocessing to be followed by a conventional ScanSAR processor [J174]

"A compact manufacturable 76-77-GHz radar module for commercial ACC applications"

The design and measured results of a single-substrate transceiver module suitable for 76-77-GHz pulsed-Doppler radar applications are presented. Emphasis on ease of manufacture and cost reduction of commercial millimeter-wave systems is employed throughout as a design parameter. The importance of using predictive modeling techniques in understanding the robustness of the circuit design is stressed. Manufacturing techniques that conform to standard high-volume assembly constraints have been used. The packaged transceiver module, including three waveguide ports and intermediate-frequency output, measures 20 mmЧ22 mmЧ8 mm. The circuit is implemented using discrete GaAs/AlGaAs pseudomorphic high electron mobility transistors (pHEMTs), GaAs Schottky diodes, and varactor diodes, as well as GaAs p-i-n and pHEMT monolithic microwave integrated circuits mounted on a low-cost 127-μm-thick glass substrate. A novel microstrip-to-waveguide transition is described to transform the planar microstrip signal into the waveguide launch. The module is integrated with a quasi-optical antenna. The measured performance of both the component parts and the complete radar transceiver module is described [J175]

"Moving target feature extraction for airborne high-range resolution phased-array radar"

We study the feature extraction of moving targets in the presence of temporally and spatially correlated ground clutter for airborne high-range resolution (HRR) phased-array radar. To avoid the range migration problems that occur in HRR radar data, we first divide the HRR range profiles into low-range resolution (LRR) segments. Since each LRR segment contains a sequence of HRR range bins, no information is lost due to the division, and hence, no loss of resolution occurs. We show how to use a vector auto-regressive (VAR) filtering technique to suppress the ground clutter, Then, a parameter estimation algorithm is proposed for target feature extraction. From the VAR-filtered data, the target Doppler frequency and the spatial signature vectors are first estimated by using a maximum likelihood (ML) method. The target phase history and direction-of-arrival (DOA) (or the array steering vector for an unknown array manifold) are then estimated from the spatial signature vectors by minimizing a weighted least squares (WLS) cost function. The target radar cross section (RCS)-related complex amplitude and range-related frequency of each target scatterer are then extracted from the estimated target phase history by using RELAX, which is a relaxation-based high-resolution feature extraction algorithm. Numerical results are provided to demonstrate the performance of the proposed algorithm [J176]

"Simulation of ISAR imaging of moving targets"

The simulation of inverse synthetic aperture radar (ISAR) imaging of moving targets is described and the effects of the target's rotations on ISAR imaging are analysed. The simulation of ISAR imaging of an aircraft with a circular motion is demonstrated. An ideal ISAR image of a target can be derived by projection of the target onto an image projection plane. Time-varying Doppler shifts induced by roll, pitch and yaw motions are analysed using the rotation matrix and the effective rotation vector. Through the simulation, the individual effect of roll, pitch and yaw motion on ISAR imaging is observed and studied [J177]

"Ground target tracking with STAP radar"

The problem of tracking ground moving targets by a moving radar (airborne, spaceborne) is addressed. Tracking of low Doppler targets within a strong clutter background is of special interest. The motion of the radar platform induces a spreading of the clutter Doppler spectrum so that low Doppler target echoes may be buried in the clutter band. Detection of such targets can be much alleviated by space-time adaptive processing (STAP), which implicitly compensates for the Doppler spread effect caused by the platform motion. Even if STAP is applied, low Doppler targets can be masked by the clutter notch. This physical phenomenon is frequently observed and results in a series of missing detections which may seriously degrade the tracking performance. A new sensor model adapted to STAP is proposed and its benefits to tracking well-separated targets are discussed. By exploiting a priori information on the sensor specific clutter notch, the model in particular provides a more appropriate treatment of missing detections. In this context, the minimum detectable velocity (MDV) proves to be an important sensor parameter, explicitly entering into ground moving target indication (GMTI) tracking [J178]

"Cramer-Rao bounds for estimating range, velocity, and direction with an active array"

We derive Cramer-Rao bound (CRB) expressions for the range (time delay), velocity (Doppler shift), and direction of a point target using an active radar or sonar array. First, general CRB expressions are derived for a narrowband signal and array model and a space-time separable noise model that allows both spatial and temporal correlation. We discuss the relationship between the CRB and ambiguity function for this model. Then, we specialize our CRB results to the case of temporally white noise and the practically important signal shape of a linear frequency modulated (chirp) pulse sequence. We compute the CRB for a three-dimensional (3-D) array with isotropic sensors in spatially white noise and show that it is a function of the array geometry only through the “moments of inertia” of the array. The volume of the confidence region for the target's location is proposed

as a measure of accuracy. For this measure, we show that the highest (and lowest) target location accuracy is achieved if the target lies along one of the principal axes of inertia of the array. Finally, we compare the location accuracies of several array geometries [J179]

"Experimental analysis of sea clutter in shipborne HFSWR"

The spreading of the dominant first order Bragg lines in shipborne HFSWR (high-frequency surface wave radar) severely obscures targets with Doppler frequencies within the spreading domain. STAP (space-time adaptive processing) is one of the effective methods for solving the problem. The experimental one-dimensional spreading spectrum and two dimensional space-time spectrum of sea clutter in shipborne HFSWR are given. The eigenvalue distribution of the space-time covariance matrix is also obtained. All experimental results show good agreement with the spreading model of sea clutter and theoretical analysis of the eigenspectrum for a random process, which is of advantage for sea clutter suppression and target detection in shipborne HFSWR with STAP [J180]

"Doppler modelling of radar sea clutter"

Data from a cliff top radar experiment conducted off the south coast of England are examined in order to investigate the applicability of a three-component model for radar Doppler spectra, developed using laboratory wavetank data, to coastal water sea clutter. This is achieved by a detailed analysis of the prominent features in the cliff top radar data in terms of polarisation and Doppler characteristics, and decorrelation times. This analysis confirms the presence of the same Bragg and non-Bragg scattering mechanisms as observed in the laboratory wave tank. A dependence of each of the scattering mechanisms on wind direction can also be inferred, showing that Bragg resonant scattering from capillary waves and non-Bragg scattering from highly disturbed white water after a wave has broken are present in both the up and down wind cases, while the highly polarised HH `sea spikes' appear only when the radar is looking into the wind. It is shown that the three-component Bragg-whitecap-spike model for Doppler spectra is able to describe both the up and down wind cases well, and that the RMS tilt angle of the underlying gravity waves can be extracted from the Bragg scattering polarisation ratio via the composite surface scattering model [J181]

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