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ТЕМАТИЧЕСКИЙ РЕФЕРАТИВНЫЙ СБОРНИК № 43-1

“Ultrawideband Radar”
(«Сверхширокополосная радиолокация»)

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Журнальные публикации

"A Compact Wideband Antenna Integrated With a Pulse-Forming Line for Transient Pulse Radiation"

A compact wideband antenna integrated with a pulse-forming line for transient pulse radiation is proposed in this paper. It can be used in the fields such as ultrawideband (UWB) radar, ground-penetrating radar, UWB communications, etc. This antenna is integrated with a solid-state switch and a planar Blumlein pulse-forming line. The dimension of the antenna is 300 mm Ч 300 mm Ч 3 mm. In the experiment, the switch was triggered by a laser with a wavelength of 1064 nm. The peak power of a single antenna was 14.45 MW when the applied voltage was 17 kV. A Gaussian doublet pulse with a duration of 1.5 ns and a peak-peak amplitude of 305.7 V/m at a distance of 2 m from the antenna along the main beam direction was recorded in the experiment. The measured waveform was in good agreement with the predicted one. [J1]

"Wireless Sensing of Human Respiratory Parameters by Low-Power Ultrawideband Impulse Radio Radar"

The simultaneous tracking of the chest respiratory rate and amplitude of human beings using a low-power ultrawideband (UWB) impulse radio signal is investigated for the application of sleep apnea monitoring. The measurement of respiratory amplitude, in addition to the breathing rate, is crucial for sleep apnea assessment which requires, among other things, the accurate estimation of tidal volume per minute. Backscattered UWB impulse radio signals from a human subject are detected in the time domain to calculate the chest displacements in this paper. Since the pulse disposition in time is linearly related to the chest movement, the amplitude of the chest movement can be extracted accurately without calculation approximations normally used in many of the existing methods. The multipeak detection of the pulse disposition method, instead of using only the single pulse peak detection, is also proposed to improve the accuracy of the calculation further. The experiments are carried out on four human subjects with different sizes and genders. The correlation of the chest movements' amplitude and breathing rate between the simultaneously measured results obtained by our method and by the respiratory chest band is very good. [J2]

"A Sparse Aperture MIMO-SAR-Based UWB Imaging System for Concealed Weapon Detection"

A high-resolution imaging system based on the combination of ultrawideband (UWB) transmission, multiple-input-multiple-output (MIMO) array, and synthetic aperture radar (SAR) is suggested and studied. Starting from the resolution requirements, spatial sampling criteria for nonmonochromatic waves are investigated. Exploring the decisive influence of the system's fractional bandwidth (instead of previously claimed aperture sparsity) on the imaging capabilities of sparse aperture arrays, a MIMO linear array is designed based on the principle of effective aperture. For the antenna array, an optimized UWB antenna is designed allowing for distortionless impulse radiation with more than 150% fractional bandwidth. By combining the digital beamforming in the MIMO array with the SAR in the orthogonal direction, a high-resolution 3-D volumetric imaging system with a significantly reduced number of antenna elements is proposed. The proposed imaging system is experimentally verified against the conventional 2-D SAR under different conditions, including a typical concealed-weapon-detection scenario. The imaging results confirm the correctness of the proposed system design and show a strong potential of the MIMO-SAR-based UWB system for security applications. [J3]

"Dual-Polarized Coupled Sectorial Loop Antennas for UWB Applications"

In this letter, we present two compact dual-polarized UWB antennas based on the coupled sectorial loops antenna (CSLA) concept. The first antenna is a directional dual-polarized cavity-backed asymmetric CSLA for radar and communications applications. The antenna has the added advantage of easily controllable gain compared to conventional dual-polarized antennas. The second antenna design is a planar CSLA in a crossed dipole configuration that offers both polarization and pattern diversities. Its dimensions are $0.44 lambda_{rm m} times 0.44 lambda_{rm m}$, where $lambda_{rm m}$is the wavelength at the lowest operating frequency. These

dimensions are about 20% higher than those of the original CSLA, but with the advantage of providing an extra polarization. This antenna is fabricated with an integrated balun feed and measured. The measurements and the simulations agree well and show good matching over more than two octaves of bandwidth and isolation better than 25 dB between the two polarization ports. [J4]

"UWB High-Isolation Directive Coupled-Sectorial-Loops Antenna Pair"

In this letter, we present a transmit/receive antenna pair for radar and communications applications. The overall antenna pair size is $0.72 lambda_{rm m} times 0.6 lambda_{rm m} times 0.27 lambda_{rm m}$, where $lambda_{rm m}$is the wavelength at the minimum operating frequency. The concept of this antenna is based on the sectorial-loops antenna backed with a cylindrical cavity. A prototype antenna pair is designed, fabricated, and measured. The measurement results show that the antenna pair has good impedance matching and more than 20 dB isolation over 3.3:1 bandwidth. In addition, using time-domain analysis, it is shown that the antenna is nondispersive. The antenna pair can also be used in diversity applications where an envelope correlation less than 20 dB is observed over the band. [J5]

"Antenna Placement for Minimizing Target Localization Error in UWB MIMO Noise Radar"

An iterative approach is applied to estimate target location in an ultrawideband multiple-input-multiple-output noise radar system, and the lower bound of its performance is analyzed. The analysis clearly shows that target location estimation accuracy depends on the antenna locations. An approach to efficiently deploy the antennas is proposed. Simulations demonstrate that the root mean square error in target location estimation is inversely proportional to the square root of the product of the number of transmit and receive antennas numbers, and it is able to achieve the derived lower bound at high signal-to-noise ratios. [J6]

"Measurement of Radar Spurious Emission With High Dynamic Range and Optimized Measurement Time"

The purpose of this paper is to propose and analyze a novel field-capable method for measuring the spurious emission levels of weather radar. The method consists of time- and frequency-domain measurements. The time-domain measurements determine radar parameters, such as pulse duration, duty cycle, pulse repetition rate, and antenna rotation time; these are then used in the frequency-domain sweep measurements to obtain the relative level of radar spurious emissions in a given bandwidth with a minimum measurement time for a given average percentage of measured bandwidth. A large dynamic range (≥100 dB) is obtained by using a calibrated bandstop (BS) filter for controlled attenuation of the pulse spectrum at the nominal frequency. Results are shown for commercial weather radar at 5 GHz. This paper shows the need for radar signal filtering to prevent interference with other radio systems, such as radio local access network (RLAN) worldwide interoperability for microwave access (WiMAX), ultrawideband (UWB), and terrestrial radio relay systems, particularly those operating just above or below the nominal frequency of radar. The results give important information for radar system planning and communication network operations. [J7]

"Analysis of GPR UWB Half-Ellipse Antennas With Different Heights of Backed Cavity Above Ground"

Ultrawideband (UWB) antenna is a critical part of the ground penetrating radar (GPR) system, and the bow-tie antenna is the most popular one in all kinds of UWB antennas. In this letter, an antenna with two half-elliptical-shape arms, which is an improvement of the bow-tie antenna, is presented with the input impedance of around 100 ??. The voltage standing wave ratio (VSWR) and radiated waveform are analyzed as the antennas with different backed cavity heights and different elevations above ground surface. The influence of the vehicle on which the half-ellipse antenna (HEA) is mounted is also given in the above three aspects. [J8]

"Modified Kirchhoff Migration for UWB MIMO Array-Based Radar Imaging"

In this paper, the formulation of Kirchhoff migration is modified for multiple-input-multiple-output (MIMO) array-based radar imaging in both free-space and subsurface scenarios. By applying the Kirchhoff integral to the multistatic data acquisition, the integral expression for the MIMO imaging is explicitly derived. Inclusion of the Snell's law and the Fresnel's equations into the integral formulation further expends the migration technique to subsurface imaging. A modification of the technique for strongly offset targets is proposed as well. The developed migration techniques are able to perform imaging with arbitrary MIMO configurations, which allow further exploration of the benefits of various array topologies. The proposed algorithms are compared with conventional diffraction stack migration on free-space synthetic data and experimentally validated by ground-penetrating radar experiments in subsurface scenarios. The results show that the modified Kirchhoff migration is

superior over the conventional diffraction stack migration in the aspects of resolution, side-lobe level, clutter rejection ratio, and the ability to reconstruct shapes of distributed targets. [J9]

"Outdoor Propagation Channel Modeling in Foliage Environment"

Foliage is a rich scattering environment that is slowly time varying. Most previous investigations in foliage models center on the statistical modeling of clutters and targets. Ideally, it would be desirable to characterize the nature of the propagation channel in foliage; however, it has not been investigated in detail up until now. This paper studies the problem of nonline-of-sight (NLOS) channel modeling based on extensive data collected using both narrowband and ultrawideband (UWB) radars. The modeling adopts the CLEAN algorithm, in which the channel-impulse response (CIR) is accomplished. It is observed that the multipath contributions arriving at the receiver are grouped into clusters. The arrival of clusters can be modeled as a Poisson process, whereas within each cluster, subsequent multipath contributions or rays also arrive according to a Poisson process. However, the arrival rate is quite different, along with the carrier frequency. It is also proposed that the amplitude of multipath channels can more accurately be characterized by a log-logistic distribution (LLD) other than commonly used clutter models such as the log-normal, the Weibull, or the Rayleigh fading model. The proposed foliage channel model is extendable to other outdoor environments. This is a great advantage for the specification and development of future wireless systems. [J10]

"Review on SAW RFID tags"

SAW tags were invented more than 30 years ago, but only today are the conditions united for mass application of this technology. The devices in the 2.4-GHz ISM band can be routinely produced with optical lithography, high-resolution radar systems can be built up using highly sophisticated, but low-cost RF-chips, and the Internet is available for global access to the tag databases. The "Internet of Things," or I-o-T, will demand trillions of cheap tags and sensors. The SAW tags can overcome semiconductor-based analogs in many aspects: they can be read at a distance of a few meters with readers radiating power levels 2 to 3 orders lower, they are cheap, and they can operate in robust environments. Passive SAW tags are easily combined with sensors. Even the "anti-collision" problem (i.e., the simultaneous reading of many nearby tags) has adequate solutions for many practical applications. In this paper, we discuss the state-of-the-art in the development of SAW tags. The design approaches will be reviewed and optimal tag designs, as well as encoding methods, will be demonstrated. We discuss ways to reduce the size and cost of these devices. A few practical examples of tags using a timeposition coding with 106 different codes will be demonstrated. Phase-coded devices can additionally increase the number of codes at the expense of a reduction of reading distance. We also discuss new and exciting perspectives of using ultra wide band (UWB) technology for SAW-tag systems. The wide frequency band available for this standard provides a great opportunity for SAW tags to be radically reduced in size to about 1 x 1 mm2while keeping a practically infinite number of possible different codes. Finally, the reader technology will be discussed, as well as detailed comparison made between SAW tags and IC-based semiconductor device. [J11]

"An Improved Design of Planar Elliptical Dipole Antenna for UWB Applications"

In this letter, an enhanced planar elliptical dipole antenna design for ultrawideband (UWB) communication and impulse radar systems is presented. The printed-circuit-elliptical (PCE) antenna has been investigated to be an effective radiator for UWB applications. To enhance gain and return loss bandwidth of the antenna, elliptical slots are used on the dipole arms. The gain performance of the antenna has been increased by means of elliptical slots in the frequency range from 2.7 to 11 GHz. The standing wave ratio is less than 2 (SWR < 2) along 94.4% of operation bandwidth from 1.1 to 11 GHz. The radiation pattern in E- and H-plane for certain frequencies, the return loss, and the gain performance are presented with the experimental and simulation results. Moreover, the time domain analysis of the antenna is presented. The antenna introduces low-level ringing and pulse distortion. Consequently, the antenna is very useful for impulse and UWB communication systems. [J12]

"An Impulse Response Function for Evaluation of UWB SAR Imaging"

Based on analysis of a point target imaged by different synthetic aperture radar (SAR) systems, the commonly used impulse response function in SAR Imaging (IRF-SAR)-a two-dimensional (2-D) sincfunction-is shown to be inappropriate for ultrawideband-ultrawidebeam (UWB) SAR systems utilizing a large fractional signal bandwidth and a wide antenna beamwidth. As a consequence, the applications of the 2-D sincfunction such as image quality measurements and spatial resolution estimations are limited to narrowband-narrowbeam (NB) SAR systems exploiting a small fractional signal bandwidth and a narrow antenna beamwidth. In this paper, a more general IRF-SAR, which aims at UWB SAR systems, is derived with an assumption of flat two-dimensional (2-D) Fourier transform (FT) of a SAR image and called IRF-USAR. However, the derived IRF-USAR is also valid for

NB SAR systems. [J13]

"Ultrawideband Antennas for Magnetic Resonance Imaging Navigator Techniques"

Due to its high appreciation for medical diagnostics worldwide, recent developments in magnetic resonance imaging (MRI) aim at adding the capability of creating focused images of moving objects. Among the potential navigator techniques required for such an improved MRI is ultrawideband (UWB) radar. We have studied the performance of UWB antennas for biomedical imaging inside the 3-Tesla MRI system at PTB Berlin. The strong static and time variant magnetic fields give rise to severe mechanical and electrical interactions due to the induced electromagnetic forces. On the other side, the high magnetic field homogeneity required for MR scans can also be affected adversely by the presence of the UWB antennas. The requirements resulting for the design of MRI compatible antennas have been identified and implemented in terms of a novel type of double-ridged horn antennas. We describe the general design strategy and the successful experimental verification of the antenna concept as well as biomedical results achieved with a combination of both UWB and MRI systems. [J14]

"Quasi-Elliptic UWB Bandpass Filter Using Multilayer Liquid Crystal Polymer Technology"

A novel ultra-wideband (UWB) bandpass filter (BPF) with quasi-elliptic response using non-uniform periodical structures is presented. In the design, a periodical unit structure is proposed and studied, which can provide transmission zeros at both lower and upper stopbands to improve the selectivity. The proposed periodical unit structure consists of broadside coupling patches, slotted ground and embedded quarter-wavelength resonator. It can be implemented using a multilayer structure with a compact size. A high selectivity UWB BPF with multiple transmission zeros can be designed by cascading a few proposed non-uniform periodical units. As a demonstration, a UWB BPF with five periodical units is developed by full-wave simulation. Multilayer liquid crystal polymer technology is used to implement the designed prototype. The predicted results are verified by the experiments, which show that the fabricated filter has an ultra wide fractional bandwidth, a wide stopband and a high selectivity with quasi-elliptic response. The proposed filter is attractive for UWB communication and radar systems. [J15]

"Corrections to “Signal Processing for Improved Detection of Trapped Victims Using UWB Radar” [JApr 10 2005-2014]"

In the above paper (this issue, pp. 2005-2014), there is an error in the top line of the right column, page 2010, which is corrected in this paper. [J16]

"Multiple-Input Multiple-Output Radar for Lesion Classification in Ultrawideband Breast Imaging"

This paper studies the problem of applying multiple-input multiple-output (MIMO) radar techniques for lesion classification in ultrawideband (UWB) breast imaging. Ongoing work on this topic has suggested that benign and malignant masses, which usually possess remarkable architectural differences, could be distinguished by exploiting their morphology-dependent UWB microwave backscatter. We have previously approached this problem by deriving the complex natural resonances of the late-time target response, where the damping factors vary with the border profiles of anomalies. In this paper, we investigate the potential advantage of MIMO radar to enhance the resonance scattering phenomenon in breast tissue discrimination. MIMO radar can choose freely the probing signals transmitted via its antennas to exploit the independence between signals at the array elements, thereby enhancing the performance of target classification. Based on the observed damping factors and the receiver operating characteristics at different classifiers, which correspond to various diversity paths in the MIMO radar system, two data-fusion rules are proposed for robust lesion differentiation. Finally, numerical examples are provided to demonstrate the efficacy of the proposed imaging technique. [J17]

"Ultrawideband Chirp Scaling Algorithm"

A new version of chirp scaling (CS), the so-called ultrawideband (UWB) CS (UCS), is proposed in this letter. UCS aims at UWB synthetic aperture radar (SAR) systems utilizing large fractional bandwidth and wide antenna beamwidth associated with a wide integration angle. Furthermore, it is also valid for SAR systems with special characteristics such as ground-moving-target-indication SAR systems with a very high pulse repetition frequency. [J18]

"An Electronic Circuit System for Time-Reversal of Ultra-Wideband Short Impulses Based on Frequency-Domain Approach"

In this paper, a compact and low-cost electronic circuit system is designed for time-reversal of ultra-wideband

short impulses (with nanosecond and sub-nanosecond temporal durations). A frequency-domain approach is adopted to avoid high sampling rate in time. Specifically, the proposed system obtains the discrete spectra of input impulses first; then realizes time-reversal in frequency domain; and finally synthesizes the time-reversed impulses using discrete continuous wave elements. This system is composed of common and commercially available circuits, and hence, can embody a system-on-chip implementation. Its performance is verified by circuit-electromagnetic co-simulations using impulses with 3-10-GHz frequency band coverage. Advanced Design System and two full-wave Maxwell's equations solvers are used for circuit and electromagnetic simulations, respectively, and their results are coupled and integrated. In the circuit part, most of nonidealities of realistic circuits are taken into account. It is shown by the simulation results that, although realistic circuits unavoidably introduce errors to time-reversal, such errors do not affect the ??focusing?? phenomena in the context of electromagnetic wave propagation. As a conclusion, the proposed system can be deployed in practical time-reversal communication and radar applications. [J19]

"Quasi-Multistatic MIST Beamforming for the Early Detection of Breast Cancer"

Microwave imaging via space-time (MIST) beamforming has been shown to be one of the most promising imaging modalities for detecting small malignant breast tumors. This paper outlines two modifications to the MIST system developed by Hagness for the early detection of breast cancer, resulting in a quasi-multistatic MIST beamformer (multi-MIST). Multistatic MIST beamforming involves illuminating the breast with an ultrawideband (UWB) signal from one antenna while collecting the reflections at an array of antennas, as opposed to traditional monostatic MIST beamforming where only the transmitting antenna records the reflections from the breast. In order to process the multistatic data, traditional data-adaptive artifact removal algorithms have to be modified to accommodate signals from all antennas. Also, the MIST beamforming algorithm, which spatially focuses the signal and compensates for frequency-dependent propagation effects, has to be modified. The algorithms are tested on a 2-D anatomically accurate finite-difference time-domain model of the breast. The multi-MIST beamformer described here is shown to offer an improved signal to clutter ratio when compared to the traditional monostatic MIST beamformer. [J20]

"Derivation and Discussion of the SAR Migration Algorithm Within Inverse Scattering Problem: Theoretical Analysis"

The analysis of synthetic aperture radar (SAR) migration developed by Gilmore has been refined within the context of the inverse scattering problem, particularly the distorted-wave Born approximation (DWBA). The SAR migration algorithm can be deduced from the DWBA-based inversion formulation when the following assumptions are satisfied: 1) homogeneous and nonfrequency-dependent background medium; 2) the exploding source model; and 3) the well-resolved targets described by an orthogonal relation derived in this paper. In addition, the other contributions of this paper are as follows: 1) The removal of the ??2term has been clarified by the derived orthogonal relation; 2) a scale factor that balances the near-far field has been derived; and 3) a novel SAR migration algorithm for the imaging of targets embedded in a layered medium has been proposed. [J21]

"Hermite-Rodriguez UWB Circular Arrays"

Pulsed circular arrays are collecting growing interest in radar applications such as automotives and indoor navigations. This contribution presents the analytic derivation of the space-time and energy patterns of pulsed circular arrays in terms of geometrical and electrical parameters as well as of the signal distortion produced by the antennas' response. It is shown that the field emitted by circular arrays with many elements can be represented as a summation of a practically finite set of high-order Hermite-Rodriguez waveforms, while the energy pattern is a generalized hypergeometric function. The angular and temporal resolutions are finally related, through handy formulas, to the array size, the input signals and to the antenna types. [J22]

"A Comparison of a Wide-Slot and a Stacked Patch Antenna for the Purpose of Breast Cancer Detection"

A wide-slot UWB antenna is presented for intended use in the detection scheme being developed at the University of Bristol, based on the principle of synthetically focused UWB radar using a fully populated static array. The antenna's measured and simulated, input and radiation characteristics are presented and compared to an existing, stacked patch antenna that has been designed for the same purpose. The results of this study show that the wide-slot antenna has excellent performance across the required frequency range. Compared to the stacked-patch antenna used in our previous array, the wide-slot antenna can be 3 times smaller (in terms of front surface). The compact nature of the slot antenna means that the detection array can be densely populated. Additionally, this new antenna offers better radiation coverage of the breast. For angles up to 60?? away from bore-sight radiated pulses are almost identical (fidelity >95%), whereas for the patch antenna fidelity falls to 58%

at the angular extremes. This uniform radiation into the breast should result in focused images with low levels of clutter. [J23]

"Signal Processing for Improved Detection of Trapped Victims Using UWB Radar"

Detection of trapped victims using ultrawideband radar is considered a highly challenging task due to multiple unknown parameters and generally very low signal-to-noise-and-clutter ratio (SNCR) conditions. In this paper, we propose a novel detection algorithm which is designed for detection of periodic motion caused by, e.g., respiratory motion of the victim for low SNCR conditions. The aim is to separate the respiratory-motion response of a trapped victim from nonstationary clutter originating from moving objects in the scene of interest. The algorithm performs stationary-clutter removal, high-level noise, and nonstationary-clutter suppression, indicates presence of the trapped victim, and estimates its range. The performance of the algorithm is investigated, both by means of simulation and experimental verification. The results show improved detection capabilities in low SNCR over an existing algorithm proposed by Zaikov et al. [J24]

"Study of a Uniplanar Monopole Antenna for Passive Chipless UWB-RFID Localization System"

The principle of a passive chipless ultrawideband-enabled radio-frequency identification (UWB-RFID) and localization system is firstly introduced. A uniplanar monopole antenna with a size of only 23 ?? 23 ?? 0.508 mm is then designed. Six passive chipless tags based on the antenna structure are subsequently developed for the system application. The backscattering characteristics of the tags are theoretically and experimentally studied in both the frequency and time domain. Following that, a simple receiver structure is proposed to simultaneously identify these tags and find their ranges. Results show that the proposed tags are excellent candidates for passive chipless UWB-RFID localization system applications. [J25]

"Development of Packaged Ultra-Wideband Bandpass Filters"

In this paper, we present a very compact ultra-wideband (UWB) filter (patent pending), which is integrated in a commercial leaded package. This UWB filter is designed through quasi-equally allocating the first three resonant frequencies of the stub-loaded resonator. Input/output excitation is realized by a technique of wire-bonded interdigital capacitors for obtaining strong wideband coupling. After formulating the resonance conditions and analyzing the characteristics of the stub-loaded resonator, an equivalent-circuit topology is developed and a single-stage prototype is fabricated. Measured results agree well with the results generated from both circuit and full-wave simulations. In order to improve the selectivity, two stages of stub-loaded resonators are cascaded. A two-stage prototype is then assembled in a commercial leaded package and measured with a test fixture. Both simulation and measurement results validate our proposed design methods and packaging solutions. This filter is the first demonstration of integrated UWB filters with a commercial package, which can be conveniently applied in UWB communication and radar systems. [J26]

"Unified Time- and Frequency-Domain Approach for Accurate Modeling of Electromagnetic Radiation Processes in Ultrawideband Antennas"

A singularity-expansion-method-based methodology is proposed for the accurate time- and frequency-domain analysis and modeling of wave radiation processes in ultrawideband antennas. By means of this approach, the transient electromagnetic field distribution in the Fraunhofer region is presented in analytical closed form as the superposition of outgoing propagating non-uniform spherical waves. The time dependence of the wave amplitudes is determined by the resonant phenomena occurring in the structure. Analytical expressions for the antenna gain and effective height are derived. The major novelties of the presented formulation lie in a dedicated two-step vector fitting procedure for a minimal pole/residue spherical harmonic expansion of the time-domain equivalent electric and magnetic currents excited on a suitable spherical Huygens surface enclosing the antenna under analysis, as well as in the introduction of a new class of incomplete spherical Bessel functions useful to describe transient wave phenomena in truncated structures. The proposed approach is validated by application to an ultrawideband resistively loaded bow-tie antenna for ground-penetrating radar applications. [J27]

"Ultrawideband Synthetic Aperture Radar Unexploded Ordnance Detection"

Airborne ultrawideband (UWB) synthetic aperture radar (SAR) can perform wide-area detection of unexploded ordnance (UXO) to locate former bombing ranges efficiently. Two main issues in UWB SAR UXO detection, feature extraction, and discriminator design are considered. A space-wavenumber distribution and moment invariants-based method is proposed to extract the multi-aspect feature of UXO with both amplitude and spatial distribution information. Based on the extracted feature, a support vector machine (SVM) with hypersphere classification boundary, referred to as HS-SVM, is used as the UXO discriminator, which can be trained with a small training set of only UXO samples. Furthermore, the problem of HS-SVM kernel choice is studied, and the

hidden Markov model (HMM) kernel is proved to be better than the Gaussian kernel. The efficiency of the proposed feature extraction method and the HMM kernel HS-SVM is validated using real data collected by a UWB SAR system. [J28]

"Detection of Moving Targets by Focusing in UWB SAR-Theory and Experimental Results"

Moving-target detection in ultrawideband (UWB) synthetic aperture radar (SAR) is associated with long integration time and must accommodate azimuth focusing for reliable detection. This paper presents the theory on detection of moving targets by focusing and experimental results on single-channel SAR data aimed at evaluating the detection performance. The results with respect to both simulated and real data show that the ability to detect moving targets increases significantly when applying the proposed detection technique. The improvement in signal-to-clutter noise ratio, which is a basic requisite for evaluating the performance, reaches approximately 20 dB, using only single-channel SAR data. This gain will be preserved for the case of multichannel SAR data. The reference system for this study is the airborne UWB low-frequency SAR Coherent All RAdio BAnd Sensing II. [J29]

"Design of a K-Band Chip Filter With Three Tunable Transmission Zeros Using a Standard 0.13-CMOS Technology"

A novel bandpass filter (BPF), which is fabricated with a commercial CMOS process, demonstrating a low insertion loss in the passband and multiple transmission zeros in stopbands, is presented for 24-GHz automotive ultrawideband (UWB) radar systems. The filter combines a second-order asymmetrically compact resonator filter with a source-load coupling mechanism to realize three transmission zeros; two zeros are arranged in the lower stopband, and one zero is located in the upper stopband. To achieve a compact layout size and a low insertion loss, a semilumped approach, which is accomplished with mixed utilization of high-impedance coplanar waveguide lines and lumped capacitors, is used to construct the chip filter. A K-band experimental prototype that has a very compact size of 0.35 Ч 0.8 mm2was realized. The average insertion loss in the filter's passband is about 2.7 dB, the return loss is greater than 15 dB within the frequencies of 24-27.5 GHz, and the attenuation levels at the three transmission zeros all greater than 35 dB. [J30]

"ML Period Estimation With Application to Vital Sign Monitoring"

The real time estimation of the period of signals that are periodic over short time intervals requires fast algorithms. In this letter, the maximum likelihood (ML) period estimator is derived for a periodic signal with additive white Gaussian noise. A low complexity approximation is then proposed, and compared with the state of the art of the estimation techniques in a practical scenario for the remote estimation of human heart rate using an ultra wide band radar. [J31]

"Indirect Localization and Imaging of Objects in an UWB Sensor Network"

A method for the localization and the rough 2-D microwave imaging of objects is described. It detects and utilizes line-of-sight (LOS) paths between a mobile node and several fixed nodes of a distributed ultrawideband (UWB) sensor network. Objects are imaged in an indirect way, i.e., by a combination of maps, which show the distribution of LOS paths of individual network nodes. The method is demonstrated by means of ray-tracing simulations and measurements in a realistic environment. Performance limitation by diffraction and the question of temporal network node synchronization are discussed. [J32]

"Ultrawideband Random Noise Radar Design for Through-Wall Surveillance"

We have developed an ultrawideband (UWB) random noise radar for through-wall surveillance applications. The operating frequency is in the ultrahigh frequency range, and the entire system is built around the concept of software defined radio. The radar receiver performance is statistically evaluated using both simulation studies and actual measurement results. We also discuss the phenomena of interference level and radar cross section (RCS) of the human target using the receiver operating characteristics (ROC). Experimental results presented show that random noise radars are useful for detecting and tracking humans obscured by building walls. [J33]

"Experimental demonstration of high-resolution ultra-wideband impulse radar based on electrical-optical hybrid pulse generation"

A high-resolution ultra-wideband (UWB) impulse radar has been developed in order to realise high-resolution object imaging in a ground-penetrating radar (GPR) for landmine detection. The UWB impulse radar is based on an electrical-optical hybrid pulse generation scheme such that a clean, short pulse train with small, short ringing can be generated. The generated UWB impulse train has a pulse duration of approximately 200-ps and a

repetition rate of less than 1-GHz. Its estimated equivalent isotropically radiated power was well matched with a spectral mask for GPRs, as defined by the Federal Communications Commission of the USA. From an experimental demonstration, it was observed that the developed high-resolution UWB impulse radar was able to resolve a relative positional change of an object with a resolution of less than 10-mm, resulting in accurate imaging of a complex three-dimensional object. [J34]

"A Quasi-Planar Conical Antenna With Broad Bandwidth and Omnidirectional Pattern for Ultrawideband Radar Sensor Network Applications"

A quasi-planar conical antenna with broad bandwidth (more than 10:1) and omnidirectional radiation pattern has been designed. In order to achieve mechanical stability, conical radiator is realized through thin metallic coating over a cavity etched into a dielectric slab. Due to dielectric loading, the conical antenna in this paper is quasi-planar, low-cost, light, mechanically robust, and easy to fabricate, integrate, and re-configure. A simulation tool based on the Method of Moments is developed to analyze the quasi-planar antenna. With simulation results as the guideline, the dielectric loading's material and geometries are optimized to attain wideband input impedance and omnidirectional radiation pattern. Three antenna prototypes are fabricated by using high density polyurethane foam as the dielectric loading material. Simulation and measurement data show excellent agreements. Input impedance bandwidths of all the three prototypes are greater than 10:1; and all of them show omnidirectional patterns in the azimuth plane. These quasi-planar conical antennas can be readily applied to ultrawideband communication and radar applications. In this paper, an ultrawideband radar sensor network testbed is constructed using one of the three prototype designs. Target localization is successfully demonstrated by five radar nodes with the aid of grid based location estimation algorithm. [J35]

"Experimental Validation of a Linear Inverse Scattering TWI Algorithm by a SF-CW Radar"

We present the experimental validation of a through-wall imaging (TWI) algorithm based on a sliced linearized inverse scattering approach. The experimental validation is performed by processing measurements collected by a stepped frequency ultrawideband radar in a realistic TWI scenario. [J36]

"A Planar, Differential, and Directive Ultrawideband Antenna"

A novel planar differential ultrawideband antenna is described and both numerically and experimentally characterized. The proposed antenna is formed by two disc monopoles fed by 50-Ohm microstrip lines with a structured ground plane. Simulations and measurements demonstrate that it is possible to achieve a huge increase in directionality with respect to conventional monopoles by carefully engineering the ground plane and by exploiting the array effect. [J37]

"Ultrawideband Filter Technologies"

Following the adoption by the Federal Communications Committee (FCC) in February 2002 [1] of the unlicensed use of ultrawideband (UWB) communications spectrum from 3.1 GHz to 10.6 GHz, there has been increasingly interesting research on UWB techniques by academics and private industry. UWB systems have several advantages: They have a bandwidth of 7.5 GHz, which can support a high transmission data rate (up to 500 Mb/s); they have low energy density over a wideband spectrum generated by short pulse excitation, which not only makes the UWB system difficult to intercept but also minimizes interference by other radio systems; and they have extremely low transmission energy (less than 1.0 mW), which is favorable for hand-held radio systems. UWB techniques have been used for many applications, such as positioning, rescue radar system for rescuing survivors buried under collapsed buildings in many emergency situations, imaging, short-range high-data-rate communication systems, and wireless personal area networks (WPANs) for personal computer and electronic devices. [J38]

"A Modified Bow-Tie Antenna for Improved Pulse Radiation"

The analysis, design, and realization of a modified bow-tie antenna optimized for impulse ground penetrating radar (GPR) applications is described. The proposed antenna shows improved properties important for GPR, which include its compact size (in comparison with a conventional bow-tie antenna) and ability to radiate UWB pulses with increased amplitude and very small late-time ringing. A substantial increase in the amplitude of the transmitted pulse is achieved by utilizing radiation from discontinuities introduced by the resistive loading employed in the antenna to suppress late-time ringing. By choosing an optimal distance between the antenna's feed point and the location of the resistive loading, radiations that occur from the antenna's feed point and the mentioned discontinuities at the resistive loading will combine constructively in the boreside direction of the antenna. As a result, one will observe a substantial increase of the amplitude of the transmitted pulse in the boreside direction. Furthermore, an analytical expression describing approximate time-harmonic current

distribution is derived to indicate an optimal resistive loading profile for the proposed antenna. Additionally, the traveling-wave current distribution of the antenna is theoretically analyzed to examine the applicability of the obtained time-harmonic expression for pulse excitation. It has been found that when the antenna is resistively loaded both the time-harmonic and traveling-wave currents decay to approach nearly the same value at the end section of the antenna. As the amount of current at the antenna ends corresponds to the level of reflection which occurs there, the derived expression is found to be useful to indicate an optimal loading profile for the proposed antenna. A theoretical model of the proposed antenna has been developed to perform numerical analysis using a modified NEC-2 code. In addition, an experimental verification has been carried out and both the simulation and e--xperiment confirmed the improved properties of the proposed antenna. [J39]

"Planar-Monopole-Fed, Surface-Mounted Quasi-TEM Horn Antenna for UWB Systems"

A compact, quasi-TEM horn antenna is presented. This planar-monopole-fed, surface-mounted, UWB antenna has nearly constant gain of 4.8 ± 0.65 dBi from 2.75-12 GHz. It is λ/4 (45 mm) long at the lowest operating frequency. It also has nearly linear phase response in this ultrawideband. The radiation pattern in the azimuth plane is broad and the pattern in the elevation plane is relatively narrow. [J40]

"Balanced Antipodal Vivaldi Antenna With Dielectric Director for Near-Field Microwave Imaging"

A balanced antipodal Vivaldi antenna is designed to be used as a sensor for a microwave breast cancer detection system. The antenna has the ability to send short electromagnetic pulses into the near-field, with low distortion, low loss and in a directional manner. The antenna directivity is further improved by the inclusion of a novel feature in the antenna aperture called a "director" which consists of a profiled piece of higher dielectric constant material. Several simulated results are successfully confirmed with measurements. Reflections of a tumor placed in a breast model are simulated for two cases, namely a balanced antipodal Vivaldi antenna with and without a director. Greater tumor responses are recorded with the director present, demonstrating the potential of this feature for microwave breast imaging. [J41]

"RFI Suppression in Ultrawideband SAR Using an Adaptive Line Enhancer"

In this letter, we propose an approach to suppress radio-frequency interference (RFI) in ultrawideband (UWB) low-frequency synthetic aperture radar (SAR). According to the proposal, RFI is suppressed by using an adaptive line enhancer controlled by the normalized least mean square algorithm. The approach is tested successfully on real UWB low-frequency SAR data. In order to keep the computational burden down, possible ways to integrate the RFI suppression approach into SAR imaging algorithms are also suggested. [J42]

"A Through-Dielectric Radar Imaging System"

Through-lossy-slab radar imaging will be shown at stand-off ranges using a low-power, ultrawideband (UWB), frequency modulated continuous wave (FMCW) radar system. FMCW is desirable for through-slab applications because of the signal gain resulting from pulse compression of long transmit pulses (1.926-4.069 GHz chirp in 10 ms). The difficulty in utilizing FMCW radar for this application is that the air-slab boundary dominates the scattered return from the target scene and limits the upper bound of the receiver dynamic range, reducing sensitivity for targets behind the slab. A method of range-gating out the air-slab boundary by significant band-limiting of the IF stages facilitates imaging of low radar cross section (RCS) targets behind the slab. This sensor is combined with a 1D linear rail and utilized as a rail synthetic aperture radar (SAR) imaging system. A 2D model of a slab and cylinder shows that image blurring due to the slab is negligible when the SAR is located at a stand-off range of 6 m or greater, and thus, the two-way attenuation due to wave propagation through the slab is the greatest challenge at stand-off ranges when the air-slab boundary is range-gated out of the scattered return. Measurements agree with the model, and also show that this radar is capable of imaging target scenes of cylinders and rods 15.24 cm in height and 0.95 cm in diameter behind a 10 cm thick lossy dielectric slab. Further, this system is capable of imaging free-space target scenes with transmit power as low as 5 pW, providing capability for RCS measurement. [J43]

"A Novel UWB Sampling Receiver and Its Applications for Impulse GPR Systems"

A novel ultrawideband (UWB) synchronous receiver for a UWB radar system is presented. The developed receiver is the first to employ a sampling phase detector, which integrates a step recovery diode and a pair of Schottky diodes, to sample the UWB signal of a radar, enabling the miniaturization of the design. It achieves a 6-GHz sampling bandwidth, a dynamic range of more than 50 dB, and low harmonic distortion of the output baseband signal. The receiver's down-converted IF signals closely match with their original shape, demonstrating its good performance to reconstruct the microwave signals from a receiving antenna. These IF signals can be converted to digital signals by a low-cost A/D. For verification, the performance of the UWB

receiver is tested through the experiments of buried steels at different thicknesses in the sand when it is applied to the ground-penetrating radar (GPR). The results show that the GPR system has good horizontal resolution and large detection depth. Therefore, this GPR system is very attractive and effective for applications of short-range and high-resolution detection. [J44]

"UWB CMOS Monocycle Pulse Generator"

A low-complexity fully integrated ultrawideband (UWB) monocycle pulse generator realized in 90-nm CMOS technology by ST-Microelectronics is presented. The circuit provides a monocycle pulse when activated by a negative edge of an external trigger signal provided by a microcontroller by exploiting the operating principle of nonlinear waveform shapers. This pulse generator represents a building block of an innovative wearable system-on-chip UWB radar on silicon for cardiopulmonary monitoring. On-chip measurements show that the pulse generator provides monocycle pulses with a duration time equal to 380 ps and a peak-to-peak amplitude of 660 mV (including the losses of the microprobes, cables, and electrostatic-discharge-protected pads), which are in very good agreement with the postlayout simulations. The power consumption is 19.8 mW from a 1.2-V power supply. [J45]

"Through-Wall Imaging of Moving Targets Using UWB Random Noise Radar"

For a through-wall ultrawideband (UWB) random noise radar using array antennas, subtraction of successive frames of the cross-correlation signals between each received element signal and the transmitted signal is able to isolate moving targets in heavy clutter. Images of moving targets are subsequently obtained using the back projection (BP) algorithm. This technique is not constrained to noise radar, but can also be applied to other kinds of radar systems. Different models based on the finite-difference time-domain (FDTD) algorithm are set up to simulate different through-wall scenarios of moving targets. Simulation results show that the heavy clutter is suppressed, and the signal-to-clutter ratio (SCR) is greatly enhanced using this approach. Multiple moving targets can be detected, localized, and tracked for any random movement. [J46]

"Ultrawideband (UWB) Radar Imaging of Building Interior: Measurements and Predictions"

In this paper, we explore using the ultrawideband radar technology for sensing through-the-wall imaging. We conducted a field experiment with our in-house designed impulse-based radar, in which a stripmap synthetic aperture radar (SAR) geometry was employed in mapping an abandoned army barrack building with a large footprint area. The images obtained from two sides of the building were combined in order to obtain the full building layout, including the interior structure. Computer simulations performed with Xpatch, a physical optics-based ray tracing code, are used to explain some phenomena observed in the measured SAR images. [J47]

"Capacitive Circuit Method for Fast and Efficient Design of Wideband Radar Absorbers"

A simple, fast and efficient method for designing wideband radar absorbers is proposed. The idea is to modify the circuit analog absorber method without perturbing the bandwidth. This is done by utilizing the asymptotic behavior of such an absorber at low frequency and replacing the band-stop resonating frequency selective surfaces with low-pass capacitive ones, which can be synthesized by square patches. It is shown that higher frequencies are not influenced by these modifications. A thin wideband capacitive circuit absorber (CCA) is presented with 28% reduction of thickness and 57% increase of bandwidth in comparison to the Salisbury screen. It is also explained why some optimized metamaterial designs fail to compete with the CCA method. For high permittivity layers, it is shown that the CCA is a better solution than the Jaumann absorber and improvements both in thickness and bandwidth are possible. A three layered ultrawideband CCA is presented with total thickness of 15.1 mm. [J48]

"Combining magnetic resonance imaging and ultrawideband radar: A new concept for multimodal biomedical imaging"

Due to the recent advances in ultrawideband (UWB) radar technologies, there has been widespread interest in the medical applications of this technology. We propose the multimodal combination of magnetic resonance (MR) and UWB radar for improved functional diagnosis and imaging. A demonstrator was established to prove the feasibility of the simultaneous acquisition of physiological events by magnetic resonance imaging and UWB radar. Furthermore, first in vivo experiments have been carried out, utilizing this new approach. Correlating the reconstructed UWB signals with physiological signatures acquired by simultaneous MR measurements, representing respiratory and myocardial displacements, gave encouraging results which can be improved by optimization of the MR data acquisition technique or the use of UWB antenna arrays to localize the motion in a focused area. [J49]

"Experimental Tests of Microwave Breast Cancer Detection on Phantoms"

We report on experimental tests of microwave breast cancer detection using the radar-based imaging method and breast phantoms, i.e., structures whose size and shape are similar to reality, and whose electric properties are close to those known for the normal and tumoral tissues. Different antennas have been designed, fabricated and tested in operation in the experimental setup. Measurements were carried out in the frequency domain, with transient response synthetically obtained via numerical processing of data. We have found that alcohol is a useful coupling medium, and devised a practical arrangement to avoid contact between the breast and such a medium. We propose a new algorithm to reduce the sensitivity of the reconstruction algorithm to the assumption of the propagation velocity of the wave in the background and in the normal tissue. In our experiments, the contrast between the media simulating normal and tumoral tissues was between 1.65 and 2.45 in permittivity and 0.45 to 1.45 in conductivity. We were able to correctly detect tumor-simulating obstacles with 1 cm diameter, without false positives. We have found that the band below 1 GHz was of paramount importance for the correct imaging, while we did not observe significant advantages in including the band between 1 and 9 GHz. [J50]

"Radar-Based Breast Cancer Detection Using a Hemispherical Antenna Array-Experimental Results"

In this contribution, an ultrawideband (UWB) microwave system for breast cancer detection is presented. The system is based on a novel hemispherical real-aperture antenna array, which is employed in a multi-static radar-based detection system. The array consists of 16 UWB aperture-coupled stacked-patch antennas located on a section of a hemisphere. The radar system is designed to be used with realistic three-dimensional (3D) breast phantoms, which have been developed, as well as with real breast cancer patients during initial clinical trials. Images are formed using two different beamforming algorithms and the performance of these algorithms is firstly compared through numerical simulation. Experimental results for the same beamforming techniques are then presented, demonstrating the successful detection of 4 and 6 mm diameter spherical tumors in the curved breast phantom. [J51]

"CTBV Integrated Impulse Radio Design for Biomedical Applications"

Improving quality of service in wireless communication links is of vital importance in biomedical applications. Limitations of current technology are evident with a limited number of channels and prone to fading. In this paper, we are exploring impulse radio as a feasible technology for health monitoring and even as novel detached sensors. By exploring advanced deep submicron technology and novel architectures, improved quality of service may be granted. Additional interesting biomedical functionality of the impulse radio is detached body sensors (short-range medical radar). [J52]

"A Study of UWB FM-CW Radar for the Detection of Human Beings in Motion Inside a Building"

A study of an ultrawideband frequency-modulated continuous-wave radar with an extended frequency sweep from 0.5 to 8 GHz is presented. It has been applied to through-the-wall human detection. This work presents the modeling of wall attenuation followed by real measurements. The radar system is presented, and trials of human being tracking are shown. This radar will enable large stand-off distance capabilities and dasiadasiain-depthpsilapsila building detection. [J53]

"A Fast and Accurate Far-Field Pseudopolar Format Radar Imaging Algorithm"

A novel imaging algorithm to be used under the condition of having an image scene in the far field of a linear radar aperture is presented. This is an application scenario that is drastically different from those of spaceborne and airborne synthetic aperture radar (SAR) systems, which has not been properly addressed to date. The technique is particularly tailored for a stepped-frequency continuous wave (CW) or frequency-modulated CW radar. The radar aperture must be linear and can be formed either with a physical or synthetic array. With the suggested method, the radar reflectivity of the image scene is obtained through an interpolation-free series expansion, where only 2-D fast Fourier transforms of the frequency-domain backscatter data are required. The resulting image is sampled on a ldquopolarlikerdquo or pseudopolar grid, which is introduced to simplify the formulation. The main advantages of this method are its extremely low computational cost and the high accuracy of the resulting imagery. The technique is extensively validated both with numerical simulations and two ground-based SAR data sets. Last but not least, numerical simulations show that this technique can be used with an ultrawideband radar of 1 GHz of bandwidth. [J54]

"Post-Compensation of Ultra-Wideband Antenna Dispersion Using Microwave Photonic Phase

Filters and Its Applications to UWB Systems"

We demonstrate experimental post-compensation of ultra-wideband (UWB) antenna dispersion at a receiver front-end by using programmable microwave photonic phase filtering. After the received RF signal is modulated onto an optical carrier, we utilize a hyperfine resolution optical pulse shaper to apply the conjugate of its spectral phase in the optical domain. After optical-to-electronic conversion, this yields an electrical waveform, which is compressed to bandwidth-limited duration. Further we use this technique in two schemes: a radar configuration in which we resolve two close echoes from different paths, which initially interfere and mask each other due to the dispersed response of the antenna link, and a spread-time UWB transmission configuration in which we retrieve and compress a distorted signal received in line-of-sight. To our knowledge, this is the first experimental demonstration of dispersion post-compensation of UWB RF waveforms to approach the ultimate bandwidth-limited resolution, as well as identification of such signals by matched filtering and compression. Our technique is programmable and offers potential to enhance performance in UWB radar and communications. [J55]

"Directive Coupled Sectorial Loops Antenna for Ultrawideband Applications"

This letter presents a modified coupled sectorial loops antenna (CSLA) architecture with electrically small dimensions capable of unidirectional radiation over a very wide bandwidth. The proposed antenna is composed of two nonplanar sectorial loops in conjunction with a tapered slot fin in front that bisects the angle between the loops, all backed by a metallic reflector. The metallic reflector produces the required front-to-back ratio, and the tapered slot facilitates forward radiation of high-frequency components. The antenna can fit in a box having dimensions 0.43lambda times 0.32lambda times 0.25lambda, where lambda is the wavelength at the lowest operating frequency. The antenna shows excellent impedance matching over the frequency band 0.5-6 GHz and a stable radiation pattern in the band 0.5-2.25 GHz, with front-to-back ratio better than 10 dB and gain higher than 5 dBi. The antenna was designed, fabricated, and measured. The measured results show good agreement with the simulation results and validate the design accuracy and performance of the antenna. The antenna is proposed for usage in low-frequency, ultrawideband (UWB) radars requiring a compact antenna with relatively high directivity. [J56]

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

The concept of characteristic polarization states (CPSs) is extended to an ultrawideband (UWB) context. This is achieved by a sparse representation of the target UWB scattering spectrum by a set of frequency bands associated with the target natural resonance modes. The polarization description involves using the average power within each resonant frequency band to derive the Kennaugh power matrix and, subsequently, a set of CPSs using the Lagrangian optimization procedure. To validate this, preliminary feature sets are formed by extracting robust information from each derived CPS and then implementing a correlation measure criterion from which the relationships between these preliminary feature sets as a function of resonance order are established. These relationships are invariant to range and target orientation about the radar-target direction and are robust to noise. [J57]

"Development and Implementation of a Real-Time See-Through-Wall Radar System Based on FPGA"

This paper presents the development of a low-cost real-time ultrawideband (UWB) see-through-wall (STW) imaging radar system. The designs of the microwave front end, the UWB data acquisition, and the system integration are discussed in detail. As for the most challenging task, the UWB data acquisition, we introduce a custom low-cost module based on commercial field-programmable gate array (FPGA) boards and low-speed analog-to-digital converters. The introduced module does not require a custom implementation of high-speed wideband mixed-signal circuitry but only depends on the FPGA firmware design, which favors a rapid system prototyping. The data acquisition module accomplishes a 100-ps equivalent-time sampling resolution at 100-Msamples/s real-time rate, while the developed STW system provides a 2-D real-time view of motion with a 1.5-ms speed behind walls. The system allows for an easy reconfiguration to support multiple operating frequency ranges, pulse sampling resolutions, and array deployments, thus providing a tremendous experimental flexibility. Our studies indicate that utilizing available technologies and off-the-shelf components could produce a practical stand-alone STW system at reasonable design effort and cost, which will lead to a better understanding of the challenging problems associated with STW technology. [J58]

"Noninvasive probing of the human body with electromagnetic pulses: Modeling of the signal path"

The biomedical applications of ultrawideband (UWB) radar promise a very important means to remotely monitor physiological signatures such as myocardial deformation and respiration. Accurate numerical and analytical techniques to predict the propagation of UWB signals in biological tissue are of great interests to researchers as

an aid in developing signal processing algorithms. We propose applying an analytic transmit/receive signal path model considering the antennas, the human body, and the signal processing part of the UWB unit. Furthermore, the frequency dependency of the different biological tissues' dielectric properties and the individual continuous motion of intrathoracic tissue layers are incorporated. [J59]

"Non-contact detection of myocardium's mechanical activity by ultrawideband RF-radar and interpretation applying electrocardiography"

Electromagnetic waves can propagate through the body and are reflected at interfaces between materials with different dielectric properties. Therefore the reason for using ultrawideband (UWB) radar for probing the human body in the frequency range from 100 MHz up to 10 GHz is obvious and suggests an ability to monitor the motion of organs within the human body as well as obtaining images of internal structures. The specific advantages of UWB sensors are high temporal and spatial resolutions, penetration into object, low integral power, and compatibility with established narrowband systems. The sensitivity to ultralow power signals makes them suitable for human medical applications including mobile and continuous noncontact supervision of vital functions. Since no ionizing radiation is used, and due to the ultralow specific absorption rate applied, UWB techniques permit noninvasive sensing with no potential risks. This research aims at the synergetic use of UWB sounding combined with magnetic resonance imaging (MRI) to gain complementary information for improved functional diagnosis and imaging, especially to accelerate and enhance cardiac MRI by applying UWB radar as a noncontact navigator of myocardial contraction. To this end a sound understanding of how myocardial's mechanic is rendered by reflected and postprocessed UWB radar signals must be achieved. Therefore, we have executed the simultaneous acquisition and evaluation of radar signals with signals from a high-resolution electrocardiogram. The noncontact UWB illumination was done from several radiographic standard positions to monitor selected superficial myocardial areas during the cyclic physiological myocardial deformation in three different respiratory states. From our findings we could conclude that UWB radar can serve as a navigator technique for high and ultrahigh field magnetic resonance imaging and can be beneficial preserving the high resolution capability of this imaging modality. Furthermo- re it can potentially be used to support standard electrocardiography (ECG) analysis by complementary information where sole ECG analysis fails, e.g., electromechanical dissociation. [J60]

"Microwave Analog Real-Time Spectrum Analyzer (RTSA) Based on the Spectral-Spatial Decomposition Property of Leaky-Wave Structures"

A novel analog real-time spectrum analyzer (RTSA) for the analysis of complex nonstationary signals (such as radar, security and instrumentation, and electromagnetic interference/compatibility signals) is presented, demonstrated, and characterized. This RTSA exploits the space-frequency mapping (spectral-spatial decomposition) property of the composite right/left-handed (CRLH) leaky-wave antenna (LWA) to generate the real-time spectrograms of arbitrary testing signals. Compared to digital RTSAs, it exhibits the advantages of instantaneous acquisition, low computational cost, frequency scalability, and broadband or ultra-wideband operation. The system is demonstrated both theoretically by a commercial full-wave simulator and an efficient Green's function approach and experimentally by a parallel-waveguide prototype including a metal-insulator-metal CRLH LWA, 16 patch antenna probe detectors circularly arranged around the LWA, and a digital oscilloscope performing analog/digital conversion and time-domain acquisition before the postprocessing and displaying of the spectrogram. The system is tested for a large diversity of nonstationary signals and generates, in all cases, spectrograms that are in excellent agreement with theoretical predictions. The fundamental tradeoff between time and frequency resolutions inherent to all RTSA systems is also discussed, and an interchangeable multi-CRLH LWA solution is proposed to handle signals with different time durations. [J61]

"Feed-forward linearisation technique for impulse radar ultra-wideband over fibre"

The authors present the linearisation of impulse radar ultra-wideband (IR-UWB) transmission system over fibre. The radio frequency signal of IR-UWB is transmitted over 50 km of the single mode fibre (SMF) using external Mach Zehnder modulator (MZM), amplified, linearised and detected by photodetector receiver. For improving the linearity and suppressing the four-wave mixing (FWM) caused by semiconductor optical amplifier (SOA) and 50 km SMF, the system uses feed-forward technique. Link performance was evaluated for two IR-UWB signals to suppress the FWM. The theoretical simulation results demonstrate a distortion cancellation that is produced by SOA of better than 25 dB over 1550 nm single mode optical fibre cable. In addition, the characteristic transmission of UWB pulse radio through 50 km single mode radio over fibre (RoF) system, such as BER measurements to evaluate the performance of the UWB with respect to different laser power output level, is investigated. This technique has been used to successfully transmit indirectly modulated data using laser diode at 10 GB/s light-wave transmission system. [J62]

"Microwave Radar-Based Breast Cancer Detection: Imaging in Inhomogeneous Breast Phantoms"

This letter presents, for the first time, experimental work on microwave breast cancer imaging using inhomogeneous breast phantoms. A recently designed 31-antenna array is used in imaging experiments. The imaging system operates in the full ultrawideband frequency range, between 3 and 10 GHz. To verify imaging performance of our system, new breast phantoms with inhomogeneous interior were developed. For three different breast phantoms presented in this work, the contrast between spherical phantom tumors and surrounding materials ranges from 5:1 to 1.6:1. Our results show that the biggest challenge in radar microwave imaging is the inhomogeneity of the volume being sensed, and not the contrast itself. In addition to experimental results, we also present the new image formation algorithm, which is a modified version of the delay-and-sum (DAS) algorithm. The new algorithm makes use of a new weighting factor, the coherence factor. The new algorithm is effective in reducing clutter, providing better images. For the most demanding imaging example presented herein, the new algorithm improves the peak clutter-to-target energy ratio by 3.1 dB. [J63]

"Compact Ultrawideband UHF Array Antenna for Through-Wall Radar Applications"

A compact ultrawideband (UWB) array antenna has been developed for through-wall radar surveillance and tested using a noise radar. The operating frequency is in the UHF range, and the design is based on the concept of future wearable array antennas. The printed elliptical patch antenna element features an available bandwidth of almost 100% (325-1000 MHz) and a compact size of 10.2 ?? 10.2 ?? 0.3 cm3(0.14??L?? 0.14?? L?? 0.004??L). It has useful merits, including vertical polarization and omnidirectional coverage in azimuth plane. A portable eight-element antenna array, with a maximum dimension less than 1.8 m, was subsequently developed for a through-wall noise radar. This small array has been tested with uniform amplitude distributions for the preliminary beamforming evaluation. [J64]

"Application of Bionics in Antenna Radar Cross Section Reduction"

Bionics principle is applied to antenna radar cross section (RCS) reduction in this letter for the first time. To authenticate the method, a novel bionic ultrawideband (UWB) antenna is proposed by use of a model of insect tentacle. Its UWB-related radiation characteristics are simulated and experimentally verified. Monostatic RCS of an insect tentacle antenna (ITA) terminated with three different loads are studied and compared with that of a common printed circular-disc monopole antenna (PCDMA). The results show that compared to the reference antenna, the novel bionic antenna has lower RCS and favorable radiation performances. Hence, applying bionics principle to antenna RCS reduction is feasible, which will serve as a good candidate for the future design of antennas with a requirement of RCS control. [J65]

"Spectral Difference Between Microwave Radar and Microwave-Induced Thermoacoustic Signals"

This letter presents a spectral content comparison of the signals generated in the microwave radar (MR) and microwave-induced thermoacoustic (MIT) imaging systems. Two physical processes occur when microwave interacts with a lossy dielectric object. First, due to the contrast in the complex permittivity between the embedded object and background medium, reflection of microwave energy occurs at the interface. Second, due to the contrast in the absorption coefficient between the object and background medium and the consequent thermal expansion, microwave induces an acoustic wave. As a method of comparison between the inputs and outputs of the MR and MIT processes, we define the MR and MIT channels. We use a two-dimensional (2-D) example to demonstrate that the MR channel over the ultrawideband (UWB) spectrum from 3.1 to 10.6 GHz manifests different fading from the MIT channel over the ultrasonic spectrum from 0.32 to 1.10 MHz. The two output signals are distinctive, but they are co-registered to the same object. Hence, using the information provided by both could enhance the imaging modality. We apply this dual-physics scheme in the context of breast tumor detection. [J66]

"Investigation of the Performance of Multiband Orthogonal Frequency Division Multiplexing Ultrawideband Over Fiber Transmission Under the Presence of In-Band Interferers"

Multiband (MB) orthogonal frequency division multiplexing (OFDM) ultrawideband (UWB) wireless, which provides high-data-rate access, must be distributed by use of optical fiber. UWB receivers are anticipated to operate under hostile interference environments. So the study of the coexistence of various communication standards with MB-OFDM UWB over fiber is an important issue. The performance of MB-OFDM UWB over fiber transmission system is investigated, considering the effect of in-band narrowband jammers such as WiMAX, MIMO WLAN, WLAN, and marine radar. Experiments were performed to show the effect of fiber transmission under various interferer power levels. It is found that in-band interferers can cause severe degradation in system performance if any interferer to the UWB peak power ratio is not held below a certain level. The results also

show that MB-OFDM UWB over fiber transmission is more vulnerable to certain interferers such as WiMAX and radar signals than to the other in-band jammers. [J67]

"Dual-Orthogonal Polarized Antenna for UWB-IR Technology"

This letter presents a design of a dual-orthogonal, linear polarized antenna for the UWB-IR technology in the frequency range from 3.1 to 10.6 GHz. The antenna is compact with dimensions of 40 times 40 mm of the radiation plane, which is orthogonal to the radiation direction. Both the antenna and the feeding network are realized in planar technology. The radiation principle and the computed design are verified by a prototype. The input impedance matching is better than -6 dB. The measured results show a mean gain in copolarization close to 4 dBi. The cross-polarizations suppression w.r.t. the copolarization is better than 20 dB. Due to its features, the antenna is suited for polarimetric ultrawideband (UWB) radar and UWB multiple-input-multiple-output (MIMO) applications. [J68]

"Scanning Performances of Wideband Connected Arrays in the Presence of a Backing Reflector"

In this paper, the scanning performances of connected arrays that include backing reflectors are investigated. The comparison between connected dipoles and slots is based on the properties of the corresponding Green's functions (GFs). The investigation reveals that connected arrays of dipoles are better suited to scan to wide angles (45deg), retaining the minimal number of transmit/receive (T/R) modules. This paper quantifies and motivates this preference. Eventually, the theoretical design of a fully efficient, 40% bandwidth (BW), planar array with the lowest possible cross polarization is presented. [J69]

"Design of Compact UWB Planar Monopole Antennas for Cross-Hole Radar Application"

Printed rectangular antennas with a relatively small width (less than 60 cm) have been specifically designed to serve in a cross-hole radar for soil characterization in the frequency band [0.5; 1.5] GHz. Antenna geometries, including coplanar waveguide or microstrip line feed lines, have been optimized to show a low S11 when inserted in an air-filled borehole surrounded by a high dielectric soil supposed to be wet in a practical situation. [J70]

"High-Resolution 3-D Imaging Algorithm With an Envelope of Modified Spheres for UWB Through-the-Wall Radars"

Through-the-wall imaging techniques with ultrawideband (UWB) radars are promising candidates for non-destructive testing and reliable human detection, especially in disaster areas, where victims are buried under collapsed walls. These applications require high-resolution target imaging to identify the object shape, such as a human body. We have already proposed a high-quality 3-dimensional (3-D) imaging algorithm in the form of envelope that is aimed at near field sensing for non-contact measurement or target identification for robots. Envelope achieves real-time accurate 3-D imaging with group mapping from multiple observed ranges to target points, and offers a reliable image even in noisy situations. However, this method does not maintain its quality for through-the-wall imaging because an observed range shift due to wall penetration causes a serious distortion in the image. This paper presents a high-resolution 3-D imaging algorithm by modifying the original envelope, and which gives a more accurate object shape behind a wall. Furthermore, to enhance the resolution of the estimated images, this method is combined with a direct waveform compensation method, known as spectrum offset correction. Numerical simulations and an experiment verify that our proposed method achieves high-resolution 3-D imaging for through-the-wall radar applications. [J71]

"RF MEMS on the radar"

This article gives an overview of applications of radio frequency (RF) microelectromechanical system (MEMS) technology in radio detection and ranging (radar). RF MEMS components for radar include attenuators, limiters, (true-time-delay) phase shifters, transmit/receive (T/R) switches and tunable matching networks. Radar subsystems that benefit from RF MEMS technology include active electronically scanned arrays (T/R modules), passive electronically scanned arrays (lenses, reflect arrays, subarrays, and switched beamformers), and radomes. Using a bottom-up approach, the figures of merit for RF MEMS technology are related to the figures of merit for radar subsystems. The article also discusses ultrawideband RF MEMS reflect array and T/R module design as examples. First, electronically scanned array, radar and RF MEMS fundamentals are briefly introduced. [J72]

"Reconfigurable planar filters"

Electronically reconfigurable or tunable microwave filters are attracting more attention for research and

development because of their increasing importance in improving the capability of current and future wireless systems. For instance, emerging ultrawideband (UWB) technology requires the use of a wide radio spectrum. However, the frequency spectrum as a resource is valuable and limited, so the spectrum is always being used for several purposes, which means it is full of unwanted signals when an operation such as a UWB wireless system is concerned. In this case, existing undesired narrowband radio signals, which vary from place to place and from time to time, may interfere with the UWB system's range. A solution for this is to introduce an electronically switchable or tunable narrow rejection band (notch) within the passband of a UWB bandpass filter. Such an electronically reconfigurable filter is also desired for wideband radar or electronic warfare systems. This paper discusses the development of electronically reconfigurable filter types. [J73]

"Code-Division Multiple Transmission for High-Speed UWB Radar Imaging With an Antenna Array"

The ultrawideband (UWB) radar is a promising high-resolution 3-D imaging technique for near targets. We have developed a high-speed imaging algorithm, SEABED, for a UWB pulse radar, a key real-time imaging technology. When the algorithm is applied to UWB, antenna scanning for data acquisition takes significantly longer than calculating the SEABED algorithm itself. This presents a serious problem for the real-time application of UWB radar. In this paper, we use pseudonoise (PN) sequences as the transmitting waveforms, while the original work on the SEABED algorithm assumed impulsive short-wave pulses. Using PN sequences enables us to simultaneously transmit signals with multiple antennas, eliminating the need to scan antennas. We demonstrate that the proposed radar system works well using random sequences to suppress direct waves, which is critical in achieving high speeds for imaging. [J74]

"A Balloon-Shaped Monopole Antenna for Passive UWB-RFID Tag Applications"

A balloon-shaped ultrawideband (UWB) antenna is developed, and its scattering characteristics are theoretically and experimentally studied in both the frequency and time domain. The radar cross-section (RCS) and scattering waveforms of the UWB antenna terminated with three different kinds of loads are simulated and measured. The results which are in good agreement show that, the balloon-shaped antenna is with almost omnidirectional scattering pattern, and its scattering of antenna mode and structural mode are obviously separated in the time domain. Therefore, this antenna is an eligible candidate for the passive ultrawideband-enabled radio-frequency identification (UWB-RFID) tag applications. Furthermore, the scattering waveform of this antenna is valuable to clarify the differences on the definitions of structural and antenna modes. [J75]

"The Detection of Buried Pipes From Time-of-Flight Radar Data"

Ultrawideband radar is commonly used in the frequency range of 50-500 MHz to detect buried pipes at a depth of about 1-2 m depending on the soil characteristics. The typical feature used to locate the pipes is the hyperbolic pattern of the time of flight generated by a linear scan of the antenna above the surface. When the pipes are close together, the hyperbolas overlap, and a straightforward least squares fit is not possible. The Hough transform provides one possible solution. This paper extends the Hough transform by introducing a weighting factor depending on the differentials of the unknown parameters with respect to the experimental errors, namely, the probe position error and the time-of-flight error. This enables optimally placed sets of data pairs to be given greater weight than "ill-conditioned" sets, as for example when all data pairs lie near one end of the arc. The result is a decrease in the background amplitude with respect to the maximum of the peaks in the Hough accumulator space. It is shown that this improvement persists even when many arcs are present. A mathematical analysis with analytical results is given for the case of four unknowns: pipe radius R, pipe center position (Y, Z), and soil propagation velocity V. The results are presented through simulations introducing controlled uncertainties in the probe position, the time of flight, and its bin size. The simulations demonstrate the correlations that occur between the radius, depth, and velocity for given experimental uncertainties. [J76]

"Estimating the Breast Surface Using UWB Microwave Monostatic Backscatter Measurements"

This paper presents an algorithm for estimating the location of the breast surface from scattered ultrawideband (UWB) microwave signals recorded across an antenna array. Knowing the location of the breast surface can improve imaging performance if incorporated as a priori information into recently proposed microwave imaging algorithms. These techniques transmit low-power microwaves into the breast using an antenna array, which in turn measures the scattered microwave signals for the purpose of detecting anomalies or changes in the dielectric properties of breast tissue. Our proposed surface identification algorithm consists of three procedures, the first of which estimates points on the breast surface given channels of measured microwave backscatter data. The second procedure applies interpolation and extrapolation to these points to generate points that are approximately uniformly distributed over the breast surface, while the third procedure uses these points to generate a 3-D estimated breast surface. Numerical as well as experimental tests indicate that the maximum

absolute error in the estimated surface generated by the algorithm is on the order of several millimeters. An error analysis conducted for a basic microwave radar imaging algorithm (least-squares narrowband beamforming) indicates that this level of error is acceptable. A key advantage of the algorithm is that it uses the same measured signals that are used for UWB microwave imaging, thereby minimizing patient scan time and avoiding the need for additional hardware. [J77]

"Sampling Procedures for Resonance Based Radar Target Identification"

The performance of radar target identification using the natural E-Pulse technique is significantly degraded if the sampling rates of the target response and the E-Pulse filter are ignored. In this work, improved sampling procedures over that previously reported by Antony and Shuley (Electron. Lett., vol. 40) in 2004 are proposed. Numerical results demonstrate that the proposed procedures significantly improve the target identification performance. [J78]

"An investigation of the wideband properties of resistively loaded conical-cylindrical V-shaped antenna"

This paper investigates the V-shaped conical-cylindrical antenna where each arm consists of two parts: a conducting lower cylindrical part and an upper conical part with finite conductivity. The performance of this antenna was tested for different opening angles, different dimensions of each part of the antenna, and different finite conductivity materials. The simulated reflected energy, return loss, radiation pattern, and fidelity factor are presented. For this design, an increase in bandwidth has been achieved and a very high fidelity greater or equal to 0.97 has been obtained. The broadband characteristics are obtained by a suitable choice of antenna geometry. The proposed antenna can be used for a wide range of applications, especially ultrawideband (UWB) microwave radar applications such as biological sensing and imaging. [J79]

"Confocal Microwave Imaging for Breast Cancer Detection: Delay-Multiply-and-Sum Image Reconstruction Algorithm"

A new image reconstruction algorithm, termed as delay-multiply-and-sum (DMAS), for breast cancer detection using an ultra-wideband confocal microwave imaging technique is proposed. In DMAS algorithm, the backscattered signals received from numerical breast phantoms simulated using the finite-difference time-domain method are time shifted, multiplied in pair, and the products are summed to form a synthetic focal point. The effectiveness of the DMAS algorithm is shown by applying it to backscattered signals received from a variety of numerical breast phantoms. The reconstructed images illustrate improvement in identification of embedded malignant tumors over the delay-and-sum algorithm. Successful detection and localization of tumors as small as 2 mm in diameter are also demonstrated. [J80]

"Refocusing Through Building Walls Using Synthetic Aperture Radar"

Through-wall imaging/sensing using a synthetic aperture array technique is studied by employing ultrawideband antennas and for wide incidence angles. The propagation through building walls, such as brick and poured concrete in response to point sources near the walls, is simulated by using high-frequency methods. Reciprocity is used to find the responses of point targets behind walls, which are then used to simulate the synthetic aperture radar (SAR) imaging through the walls. The effect of building walls on the target-image distortions is investigated by simulations and measurements. It is shown that by using the idea of match filtering, the effect of the wall can be compensated for, and the point target response can be reconstructed, provided that the wall parameters are known. An optimization method based on minimization of squared error in the SAR image domain within an area confined within the expected point-spread function is used to estimate the wall parameters and sharpen the image simultaneously. A controlled experiment within the laboratory environment is performed to verify the methods presented. It is shown that for an ultrawideband system operating over a frequency band of 1-3 GHz, highly distorted images of two point targets in close proximity of each other behind a wall can be resolved after refocusing. A dual-frequency synthetic method is also presented that can improve the cross-range resolution of the refocused image. [J81]

"Link Budget Analysis and Modeling of Short-Range UWB Channels"

Ultrawideband (UWB) technology is an attractive alternative for short-range applications, e.g., wireless personal area networks. In these applications, transmit and receive antennas are very close to each other and the far-field condition assumed in most of the link budget models may not be satisfied. Under near-field conditions, variations in the link budget and pulse shape compared to the far-field can be observed. In this work, a novel line-of-sight UWB link budget model for very short distances is proposed and validated with measurements using different

types of antennas. The proposed model, which takes into account all main near-field effects (i.e., phase error, antenna mismatch and reradiation between antennas) and includes frequency, antenna size and orientation as parameters, shows a good agreement with the simulations and the measurements. This model has also been applied to dispersive antennas (e.g., notch-antennas), and can be used in the design and analysis of short-range UWB communication systems. [J82]

"High-Resolution and Real-Time Three-Dimensional Imaging Algorithm With Envelopes of Spheres for UWB Radars"

Ultrawideband pulse radars have a great potential for high-range resolution in near field imaging and can be used for noncontact measuring in precision or specular products such as reflector antennas and aircraft fuselages. We have already proposed a high-speed 3-D imaging algorithm, SEABED, which is based on a reversible transform, which is the boundary scattering transform, between the received signals and the target shape. However, the estimated image with SEABED is unstable with random noise because it utilizes a derivative of the received data. In this paper, we propose a robust 3-D imaging algorithm with an envelope of spheres that completely resolves the instability due to derivative operations. Moreover, to enhance the resolution of estimated images, this method is combined with a direct waveform compensation method that does not sacrifice high-speed calculation. Numerical simulations and an experiment confirm that the proposed method can realize fast, robust, and high-resolution 3-D imaging for arbitrary targets. [J83]

"Hilbert-Huang transform analysis of human activities using through-wall noise and noise-like radar"

Various parts of the human body have different movements when a person is performing different physical activities. There is a need to remotely detect and recognise specific human activities for applications involving anti-terrorism, hostage liberation and search-and-rescue. An ultrawideband noise radar system has been built to detect signatures of human activities. The Hilbert-Huang transform, which is used to extract the human-induced Doppler frequency shift from the received signal, facilitates the identification and recognition of various human activities. A non-stationary Doppler model is developed to describe various aspects of human motion, which compares well with measured data. The theoretical analysis and experimental results are discussed. [J84]

"UWB radar for patient monitoring"

During the last few years the Moscow Aviation Institute (Russia) and the Industrial Technology Research Institute (Taiwan) have worked jointly on the development of ultrawideband (UWB) medical radars for remote and contactiess monitoring of patients in hospitals. Preliminary results of these works were published in [1]. As of the present, several radars have been produced and tested in real conditions in hospitals in Russia and Taiwan. Some results of these tests are given. [J85]

"Feature Extraction and Discriminator Design for Landmine Detection on Double-Hump Signature in Ultrawideband SAR"

An air- or vehicleborne ultrawideband synthetic aperture radar (UWB SAR) has ground penetrating capability, which provides a sufficient approach to detect landmines over wide areas from a safe standoff distance. In this paper, a support vector machine (SVM) with hypersphere classification boundary, which is referred to as HyperSphere-SVM (HS-SVM), using a hidden Markov model (HMM) kernel on the feature vector extracted by a postfilter-based method is proposed for landmine detection. The postfilter-based method can extract the feature containing not only the amplitude but also the amplitude varying information of the double-hump signature of metallic and plastic landmines. Compared with simple kernels, e.g., the Gaussian kernel, the HMM kernel employs the state-transition information in the extracted feature into the discrimination procedure and, thus, can improve detection performance. The proposed postfilter-based feature extraction method and the HMM kernel HS-SVM are verified on the field data collected by a UWB SAR system in different scenarios. [J86]

"Investigation of Radar Propagation in Buildings: A 10-Billion Element Cartesian-Mesh FETD Simulation"

Large-scale full-wave simulations are performed to investigate radar wave propagation inside buildings. In principle, a radar system combined with sophisticated numerical methods for inverse problems can be used to determine the internal structure of a building. The composition of the walls (cinder block, rebar) may effect the propagation of the radar waves in a complicated manner. In order to provide a benchmark solution of radar propagation in buildings, including the effects of cinder block and rebar, we performed large-scale full-wave simulations using a finite-element time domain (FETD) method. This particular FETD implementation is tuned for the special case of an orthogonal Cartesian mesh and hence resembles finite-difference time domain (FDTD) in

accuracy and efficiency. The method was implemented on a general-purpose massively parallel computer. In this paper we briefly describe the radar propagation problem, the FETD implementation, and we present results of simulations that used over 10-billion elements. [J87]

"Breast Tumor Characterization Based on Ultrawideband Microwave Backscatter"

Characterization of architectural tissue features such as the shape, margin, and size of a suspicious lesion is commonly performed in conjunction with medical imaging to provide clues about the nature of an abnormality. In this paper, we numerically investigate the feasibility of using multichannel microwave backscatter in the 1-11 GHz band to classify the salient features of a dielectric target. We consider targets with three shape characteristics: smooth, microlobulated, and spiculated; and four size categories ranging from 0.5 to 2 cm in diameter. The numerical target constructs are based on Gaussian random spheres allowing for moderate shape irregularities. We perform shape and size classification for a range of signal-to-noise ratios (SNRs) to demonstrate the potential for tumor characterization based on ultrawideband (UWB) microwave backscatter. We approach classification with two basis selection methods from the literature: local discriminant bases and principal component analysis. Using these methods, we construct linear classifiers where a subset of the bases expansion vectors are the input features and we evaluate the average rate of correct classification as a performance measure. We demonstrate that for 10 dB SNR, the target size is very reliably classified with over 97% accuracy averaged over 360 targets; target shape is classified with over 70% accuracy. The relationship between the SNR of the test data and classifier performance is also explored. The results of this study are very encouraging and suggest that both shape and size characteristics of a dielectric target can be classified directly from its UWB backscatter. Hence, characterization can easily be performed in conjunction with UWB radar-based breast cancer detection without requiring any special hardware or additional data collection. [J88]

"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 [J89]

"Ultrawideband Radar Measurements of Thickness of Snow Over Sea Ice"

An accurate knowledge of snow thickness and its variability over sea ice is crucial in determining the overall polar heat and freshwater budget, which influences the global climate. Recently, algorithms have been developed to extract snow thicknesses from satellite passive microwave data. However, validation of these data over the large footprint of the passive microwave sensor has been a challenge. The only method used thus far has been with meter sticks during ship cruises. To address this problem, we developed an ultrawideband frequency-modulated continuous-wave radar to measure the snow thickness over sea ice. We synthesized a very linear chirp signal by using a phase-locked loop with a digitally generated chirp signal as a reference to obtain a fine-range resolution. The radar operates over the frequency range from 2-8 GHz. We made snow-thickness measurements over the Antarctic sea ice by operating the radar from a sled in September and October 2003. We performed radar measurements over 11 stations with varying snow thicknesses between 4 and 85 cm. We observed an excellent agreement between radar estimates of snow thickness with physical measurements, achieving a correlation coefficient of 0.95 and a vertical resolution of about 3 cm. Comparison of simulated radar waveforms using a simple transmission line model with the measurements confirms our expectations that echoes from snow-covered sea ice are dominated by reflections from air-snow and snow-ice interfaces. [J90]

"Multistatic Ground-Penetrating Radar Experiments"

A multistatic ground-penetrating radar (GPR) system has been developed and used to measure the response of a number of targets to produce data for the investigation of multistatic inversion algorithms. The system consists of a linear array of resistive-vee antennas, microwave switches, a vector network analyzer, and a 3-D positioner, all under computer control. The array has two transmitters and four receivers which provide eight bistatic spacings from 12 to 96 cm in 12-cm increments. Buried targets are scanned with and without surface clutter, which is a layer of rocks whose spacing is empirically chosen to maximize the clutter effect. The measured responses are calibrated so that the direct coupling in the system is removed, and the signal reference point is located at the antenna drive point. Images are formed using a frequency-domain beamforming algorithm that compensates for the phase response of the antennas. Images of targets in air validate the system calibration and the imaging algorithm. Bistatic and multistatic images for the buried targets are very good, and they show the effectiveness of the system and processing. [J91]

"Backscattering Cross Section of Ultrawideband Antennas"

Backscattering of ultrawideband (UWB) antennas is theoretically and experimentally studied in this letter. The finite-difference time-domain (FDTD) method using Berenger's perfectly matched layer absorbing boundary condition (PML-ABC) is employed for simulation and the measurement is carried out in indoor environment. Monostatic radar cross section (RCS) of square-slot antenna and printed circular-disc monopole antenna (PCDMA) terminated with three different kinds of loads are numerically calculated and experimentally verified. They are in good agreement in the frequency range from 3 to 11 GHz. Afterwards, scattering characteristics of the structural and antenna modes of two kinds of UWB antenna structures are extensively characterized in both the frequency domain and time domain [J92]

"Ultrawideband Radar Committee (UWBRC) Progress Report [JStandards]"

First Page of the Article [J93]

"Pulse Design for Time Reversal Method as Applied to Ultrawideband Microwave Breast Cancer Detection: A Two-Dimensional Analysis"

We conduct a two-dimensional study of pulse design for electromagnetic time-reversal (TR) imaging as applied to ultrawideband (UWB) breast cancer detection. We consider the situation when a tumor located in the human breast is surrounded by a large number of small tissue inhomogeneities that create strong signal clutter. When applying the TR algorithm, the excitation pulse should be properly designed such that there are distinguishable differences between the tumor and clutter responses. In this paper, we propose four pulse design criteria for the TR-based tumor detection. The modulated and modified Hermite polynomials (MMHPs) that fit well into the real pulse shapes are used as a general waveform template for the design process. Finally, numerical examples are used to demonstrate the usefulness of the proposed analytical framework. This paper can be a guide in the selection of suitable waveforms for which the tumor response can be enhanced and/or the clutter interference can be suppressed. The investigation is also well suited for applications to surface-penetrating radar using UWB signals [J94]

"Ultrawideband Hybrid EBG/Ferrite Ground Plane for Low-Profile Array Antennas"

The design and analysis of an ultrawideband and low-profile hybrid electromagnetic band-gap (EBG)/ferrite ground plane is presented for implementation with antenna systems in airborne foliage penetrating radar and EW applications. The hybrid EBG/ferrite ground plane consists of an EBG structure with a ferrite slab placed on top of the structure's perfect electric conductor (PEC) ground plane. Reflectivity and phase analyses show that the hybrid EBG/ferrite ground plane offers ultrawideband operation beginning in the 100s of MHz with one design version offering an operational bandwidth exceeding 22:1 starting at 170 MHz. Additionally, analysis of the hybrid ground plane implemented with dipole antennas verifies that the hybrid ground plane effectively produces uni-directional radiation for bi-directional radiating antennas. The designed hybrid ground plane is also simulated with Raytheon's long slot array antenna and the obtained results further verify its ultrawideband performance [J95]

"Investigation of Time–Frequency Features for GPR Landmine Discrimination"

Ground-penetrating radar (GPR) is capable to detect plastic antipersonnel landmines as well as other subsurface targets. In order to reduce false alarms, an option of automatic landmine discrimination from neutral minelike targets would be very useful. This paper presents a possibility for such discrimination and analyzes it experimentally. The authors investigate time-frequency features of an ultrawideband (UWB) target response for the discrimination between buried landmines and other objects. The discrimination method includes the

extraction of an early-time target impulse response, its time-frequency transformation, and the extraction of time-frequency features based on a singular value decomposition of the transformed image. In order to take into account the changes in the UWB target signals, the experimental conditions are completely controlled to focus on the behavior of the target's response with respect to its depth and the horizontal position of the GPR above it. The dependence of the features on the GPR bandwidth is analyzed as well. The Mahalanobis distance is used as a criterion for optimal discrimination. The obtained results define the best features and conditions when the landmine discrimination is successful. For comparison, the discriminant power of the proposed features has been tested on a dataset, acquired during a field campaign in Angola [J96]

"UWB Perimeter Surveillance"

This program will develop an automated and unmanned ultra-wide band (UWB) perimeter surveillance sensor designed to provide detection and tracking of personnel and vehicles at the perimeter of critical areas such as military installations and other such facilities. This effort describes the work being done for the protection of high value assets using a compact system which incorporates two technologies to enhance the probability of detection in stressing environments [J97]

"A Novel Antenna for Transient Applications in the Frequency Band 300 MHz – 3 GHz: The Valentine Antenna"

We propose a novel ultrawideband (UWB) antenna designed specially for transient UWB radar applications. This work is a part of a new project concerning an optoelectronic UWB radar demonstrator with an array of four antennas. This project required the development of a new UWB antenna: the Valentine antenna. This antenna must be lighter and more compact in H-plane to allow the assembly of the array. This array must have a volume lower than 1 m3. This antenna, which is composed of curved metallic strips, radiates ultrashort pulses in the frequency band 300 MHz-3 GHz with very low dispersion, a high gain and a low cross-polarization in the axial direction. The Valentine antenna must support 10kV of peak voltage. This paper describes the Valentine antenna and its main radiation characteristics [J98]

"Ultrawideband Double Rhombus Antenna With Stable Radiation Patterns for Phased Array Applications"

A broadband microstrip-fed printed antenna is proposed for phased antenna array systems. The antenna consists of two parallel-modified dipoles of different lengths. The regular dipole shape is modified to a quasi-rhombus shape by adding two triangular patches. Using two dipoles helps maintain stable radiation patterns close to their resonance frequencies. A modified array configuration is proposed to further enhance the antenna radiation characteristics and usable bandwidth. Scanning capabilities are studied for a four-element array. The proposed antenna provides endfire radiation patterns with high gain, high front-to-back (F-to-B) ratio, low cross-polarization level, wide beamwidth, and wide scanning angles in a wide bandwidth of 103% [J99]

"SEABED Algorithm and Comments on “Modeling and Migration of 2-D Georadar Data: A Stationary Phase Approach”"

An imaging algorithm with a transform between the real and data spaces was proposed by Greenhalgh and Marescot for georadar data in 2006. This technique utilizes a reversible transform between the real space (X, Z = F(X)) and the data space (x, z = f(x)). The inverse transform is equivalent to the imaging method that is proposed by Li et al. (2005) if an antenna interval is short. This method was applied to preprocessing for breast cancer detection in 2005. These transforms were originally proposed by Sakamoto and Sato (2004) for an imaging with ultrawideband radar systems. By utilizing these transforms, a high-speed imaging algorithm, which is called as SEABED algorithm, was developed, which was extended to compensate for the phase rotation at caustic points, which was also described by Greenhalgh and Marescot. In addition, the SEABED algorithm was extended to apply to noisy data, 3D systems, experimental data, and bistatic radars. Note that the transform is fundamentally sensitive to noise because it includes derivative operations. A new algorithm was developed by extending the SEABED algorithm to avoid the derivative operations, which is stable and has a high resolution even for noisy data. The reversible transform in is now simultaneously and independently studied by some research groups because it is the sole solution for the imaging with wave fields. In addition, the transform has a variety of applications because it can be applied to electromagnetic waves, sonic and ultrasonic waves, seismic waves, and other waves. [J100]

"Fast Evaluation of the Radiation Patterns of True Time Delay Arrays With Beam Steering"

A multilevel algorithm for the computation of the transient radiation patterns of true time delay (TTD) conformal

arrays over a range of observation and beam steering directions is presented. The multilevel algorithm is based on hierarchical decomposition of the array into smaller sub-arrays of elements. At the finest level of decomposition, the angular-temporal radiation patterns of single-element sub-arrays are obtained over a sparse angular grid of directions and short temporal duration, by either measurement or calculation. Subsequent steps of the algorithm comprise multilevel aggregation of delayed sub-array contributions. This process continues until the transient radiation pattern of the whole array is obtained. At each level, the radiation pattern is interpolated to a finer angular grid of observations and steering directions followed by temporal delay compensation. The multilevel array decomposition algorithm attains a computational complexity substantially lower than that of the direct evaluation. Furthermore, the algorithm is particularly efficient for large arrays with large numbers of elements. [J101]

"An Electrically Switchable Optical Ultrawideband Pulse Generator"

A novel electrically switchable optical ultrawideband (UWB) pulse generator that is capable of generating both Gaussian monocycle and Gaussian doublet pulses by using a polarization modulator (PolM) and a fiber Bragg grating is proposed and experimentally demonstrated. The polarity and the shape of the generated UWB pulses can be electrically switched by adjusting the voltages applied to two arbitrary wave plates (AWPs), which are incorporated at the input and the output of the PolM to adjust the polarization state of the lightwaves. The key component in the UWB pulse generator is the PolM, which is a special phase modulator that can support both transverse electric and transverse magnetic modes but with opposite phase modulation indexes. Depending on the polarization state of the incident lightwave to the PolM that is linearly polarized and aligned to one principle axis of the PolM or circularly polarized, UWB monocycle or doublet pulses are generated. The polarity of the UWB pulses can be electrically switched by adjusting the voltages applied to the AWPs. The proposed system is implemented, and the generation of UWB monocycle and doublet pulses is experimentally demonstrated. Gaussian monocycle and doublet pulses with a fractional bandwidth of about 150% and 160% are experimentally generated. The proposed electrically switchable optical UWB pulse generator has the potential for applications in UWB communications and radar systems that employ pulse polarity modulation and pulse shape modulation schemes. [J102]

"An Integrated Ultra-Wideband Timed Array Receiver in 0.13 μm CMOS Using a Path-Sharing True Time Delay Architecture"

A fully integrated CMOS ultra-wideband 4-channel timed array receiver for high-resolution imaging application is presented. A path-sharing true time delay architecture is implemented to reduce the chip area for integrated circuits. The true time delay resolution is 15 ps and the maximum delay is 225 ps. The receiver provides 11 scan angles with almost 9 degrees of spatial resolution for an antenna spacing of 3 cm. The design bandwidth is from 1 to 15 GHz corresponding to less than 1 cm depth resolution in free space. The chip is implemented in 0.13 mum CMOS with eight metal layers, and the chip size is 3.1 mm by 3.2 mm. Measurement results for the standalone CMOS chip as well as the integrated planar antenna array and the CMOS chip are reported. [J103]

"Ultrawideband Synthetic Aperture Radar Landmine Detection"

In this paper, we consider landmine detection using ultrawideband synthetic aperture radar, where the two main challenges are feature extraction and discriminator design. The space-wavenumber processing is proposed to retrieve the frequency-and aspect-angle-dependent scattering features of suspected objects. In order to reduce the dimensionality of the input feature vector for a discriminator, the sequential forward floating selection method is used to choose efficient features. Based on the obtained feature vector, a fuzzy hypersphere support vector machine is designed to deal with the problem of detecting landmines in an unconstrained environment. The experimental results show that the proposed method can achieve a significant improvement in detection performance for antitank mines. [J104]

"Refraction and Dispersion Effects Compensation for UWB SAR Subsurface Object Imaging"

It is a trend to use airborne or vehicle-borne ultrawideband synthetic aperture radar (UWB SAR) to quickly detect subsurface objects, i.e., landmines or minefields, over large areas from a safe standoff distance. The traditional image formations without considering the refraction and dispersion of electromagnetic wave will lead to locating error and defocusing for subsurface objects. In this paper, an efficient refraction and dispersion effects compensation method is proposed, which can be integrated with the traditional three-stage automatic target detection framework for detection of subsurface landmines. The compensation method can focus and correctly locate multiple objects buried in different soils with different depths over large areas, which satisfies the operating requirement of an airborne or vehicle-borne UWB SAR system. The proposed method is proved efficient for subsurface object imaging by the field data collected by a UWB SAR system. [J105]

"GA design of a thin-wire bow-tie antenna for GPR applications"

A microgenetic algorithm has been applied to design a new ultrawideband thin-wire bow-tie antenna for ground-penetrating radar applications. The broadband performance of the antenna is achieved by resistive loading and by optimizing the number of wires and the angular distances between those wires. The radiation characteristics of the optimized antenna are discussed, and its performance is compared to that of a resistively loaded Wu-King dipole. [J106]

"Accounting for the effects of widespread discrete clutter in subsurface EMI remote sensing of metallic objects"

In practice, most signal processing strategies for discrimination of buried objects are clutter limited. This applies even to discrimination of shallow sizable metallic objects, such as unexploded ordnance (UXO), which are to be found predominantly in the top meter of soil. The environment typically features widespread metallic clutter from detonated ordnance or other sources. Such fragments can be numerous and are often shallower than the objects of interest. Currently, the preeminent remote sensing mode for buried UXO is ultrawideband electromagnetic induction (EMI), operating over part or all of the band from some tens of hertz up to perhaps hundreds of kilohertz. Particularly because EMI fields fall off sharply with range, signals from shallow clutter may be relatively strong and can easily obscure essential scatterer signatures. To treat this, a rational theory of EMI scattering from widespread metallic clutter is formulated and tested. For dense, well-distributed clutter, analytical rules are derived for dependence of signal strength on sensor elevation, under various fundamental excitation types. For more erratic, sparse clutter distributions, signal statistics from Monte Carlo simulations show patterns like those from the analytical rules. The dependence of clutter signal magnitude on antenna elevation is determined for both thin surface layers and for volume layers of widespread small items, and for both dense and sparse clutter distributions. These are contrasted with the patterns expected from single, larger, discrete objects of interest, and the contrast is exploited in discrimination exercises for the screening problem. For sparse clutter distributions, results from inversion processing formulations that account for the patterns of clutter statistics are compared to simple least squares treatments. [J107]

"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 [J108]

"Noncoherent pulse compression"

Pulse compression can be performed in noncoherent radars by using coded on-off keying (OOK). We show how any bipolar pulse-compression code (e.g., Barker) can be modified into unipolar OOK through Manchester coding. The resulted transmitted signal is a burst of dense subpulses, with pulse position modulation. In the receiver, the envelope-detected signal is aperiodically cross-correlated with a mismatched bipolar reference signal, yielding noncoherent integration with a low-sidelobe response. The concept can be used in simple radars where Doppler information is not required, in direct-detection laser radars and in ultrawideband (UWB) radars. Examples are given with bursts of 13 and 70 subpulses. Detection probabilities dependence on SNR is studied and compared with coherent processing. [J109]

"Estimation of the Frequency-Dependent Average Dielectric Properties of Breast Tissue Using a

Time-Domain Inverse Scattering Technique"

Ultrawideband (UWB) microwave radar imaging techniques for breast cancer detection typically require estimates of the spatially averaged dielectric properties of breast tissue. We propose an algorithm for estimating patient-specific, frequency-dependent average dielectric properties from scattered UWB microwave signals. The algorithm is a variation of an iterative finite-difference time-domain (FDTD) technique for solving the time-domain inverse scattering problem. The assumption is made that the breast consists of two homogeneous regions: skin and underlying tissue. This two-medium geometry results in an inverse scattering problem that is not as ill-posed as those typically encountered in microwave tomography because the number of unknowns being sought is very small. We test the performance of the algorithm on data simulated using anatomically realistic 2-D numerical breast phantoms [J110]

"Very Fast Rise-Time Short-Pulse High-Voltage Generator"

This paper relates to the development of an ultrafast compact system readily applicable to the field of ultrawideband microwave applications such as transient radar or laser drivers. The design, production, and experimental results of a short-pulse generation system are presented in this paper. The coaxial generator technology based on the principle of a line discharge by means of a high-pressure gas switch in a simple transmission line arrangement is described. In the first stage of the process, the coaxial generator was charged by a high-voltage direct current source. Interesting results were obtained, but due to the jitter of the discharge formative time, the reproducibility of the output pulses was not sufficient. To improve the performance, a pulsed source was developed in order to apply an overvoltage to the gap switch and thus reduce the jitter of the discharge formative time. The characteristics of the pulsed source are defined. A thyristor Marx generator and a pulse transformer using magnetic properties of ferrite cores were combined in order to produce this pulsed source. The main performances of this source are a pulse amplitude of 60 kV, a rise time of 250 ns, and a maximum frequency of 900 Hz from a 1-kV dc supply. Finally, the complete generation system is able to generate pulses with 25-kV amplitude and 70-ps rise time through a 50-Omega impedance from the single shot mode up to 900 Hz. The output pulses reproducibility obtained is better than plusmn5% [J111]

"A novel UWB rugby-ball antenna for near-range microwave Radar system"

Design and performance of a monostatic ultra-wideband (UWB) microwave radar system is described in this paper. Design details are presented for a novel rugby-ball antenna and UWB resistive duplexer of the radar system. The antenna is fed through the image ground plane and backed by a reflector. Intersection of two circular areas of different radii of curvature makes up the antenna element. Antenna bandwidth is determined by upper and lower radii of curvature of the antenna element. UWB (0.1-20 GHz) voltage standing-wave ratio (percent bandwidth of 198%) was achieved, which is suitable for detection of ultrashort electric pulses. An extended time sampling method was used for the receiver section of the radar system. Analysis and performance results are described for the sampling unit and resistive duplexer. Measurement results are presented for the far-field radiation of the antenna. A comparison of range measurement was performed using the UWB antenna in a monostatic radar system with a standard trapezoidal UWB bi-static configuration. The range measurement error was improved from 3.37% to 1.59% using the present rugby-ball antenna in a monostatic radar configuration [J112]

"Ultrawideband radar imaging system for biomedical applications"

Ultrawideband (UWB) (3-10GHz)radar imaging systems offer much promise for biomedical applications such as cancer detection because of their good penetration and resolution characteristics. The underlying principle of UWB cancer detection is a significant contrast in dielectric properties, which is estimated to be greater than 2:1 between normal and cancerous tissue, compared to a few-percent contrast in radiographic density exploited by x rays. This article presents a feasibility study of the UWB imaging of liver cancer tumors, based on the frequency-dependent finite difference time domain method. The reflection, radiation, and scattering properties of UWB pulses as they propagate through the human body are studied. The reflected and back-scattered electromagnetic energies from cancer tumors inside the liver are also investigated. An optimized, ultrawideband antenna was designed for near field operation, allowing for the reduction of the air-skin interface. It will be placed on the fat-liver tissue phantom with a malignant tumor stimulant. By performing an incremental scan over the phantom and removing early time artifacts, including reflection from the antenna ends, images based on the back-scattered signal from the tumor can be constructed. This research is part of our effort to develop a UWB cancer detection system with good detection and localization properties. [J113]

"Radar Target Identification Using a “Banded” E-pulse Technique"

Resonance based radar target recognition using the extinction pulse (E-pulse) technique was first implemented

in the mid 1980s. Various derivatives of the E-pulse technique itself as well as the associated problems of identification and differentiation have been reported throughout the literature. In this paper a modified version of the E-pulse, termed the "banded" E-pulse technique is introduced as an alternative tool for target identification [J114]

"Localization via ultra-wideband radios: a look at positioning aspects for future sensor networks"

UWB technology provides an excellent means for wireless positioning due to its high resolution capability in the time domain. Its ability to resolve multipath components makes it possible to obtain accurate location estimates without the need for complex estimation algorithms. In this article, theoretical limits for TOA estimation and TOA-based location estimation for UWB systems have been considered. Due to the complexity of the optimal schemes, suboptimal but practical alternatives have been emphasized. Performance limits for hybrid TOA/SS and TDOA/SS schemes have also been considered. Although the fundamental mechanisms for localization, including AOA-, TOA-, TDOA-, and SS-based methods, apply to all radio air interface, some positioning techniques are favored by UWB-based systems using ultrawide bandwidths. [J115]

"Standards and the ultrawideband radar committee (UWBRC) of the IEEE Aerospace and Electronic Systems Society (AESS)"

{no data available} [J116]

"No place to hide [Jradar devices]"

This paper describes two innovative radar devices that can "see" through walls. These are Radar Vision built by Time Domain Corp. and the Prism 100 from Cambridge Consultants Ltd. Both rely on ultrawideband, a fairly new technology known mainly as a promising high-speed, low-power radio communications transmission technique. Both devices can detect the presence of inanimate objects through the wall, but only motion is shown to the user in the form of a moving blob of color on their built-in color screens. A version of Radar Vision, called Soldier Vision, has been commissioned by the US Army for overseas deployment. [J117]

"Measuring human body impulse response using UWB radar"

The impulse response of the human body can provide useful information of the body for medical purposes. An ultra-wideband (UWB) radar method is used to determine this impulse response. To this end, the study probed into human phantoms and the human body using discrete electromagnetic pulses. The received signal is processed primarily to extract the impulse response. The measurement result shows that impulse responses can provide information on the shape and electrical properties of the human body. [J118]

"Implementation of fully polarimetric random noise radar"

A heterodyne correlation receiver technique has been developed for coherent processing of backscatter data acquired by a radar system transmitting ultrawideband (UWB) random noise waveforms. In such a receiver, the reflected signal is correlated with a time-delayed and frequency-shifted version of the transmitted waveform, which is able to provide the phase of the reflected waveform. We describe the implementation of fully polarimetric capability in a coherent random noise radar system operating in the ultrahigh frequency (UHF) range designed for foliage penetration (FOPEN) applications. Using this implementation, the polarimetric response of various foliage targets has been characterized. [J119]

"Enhanced resolution in SAR/ISAR imaging using iterative sidelobe apodization"

Resolution enhancement techniques in radar imaging have attracted considerable interest in recent years. In this work, we develop an iterative sidelobe apodization technique and investigate its applications to synthetic aperture radar (SAR) and inverse SAR (ISAR) image processing. A modified noninteger Nyquist spatially variant apodization (SVA) formulation is proposed, which is applicable to direct iterative image sidelobe apodization without using computationally intensive upsampling interpolation. A refined iterative sidelobe apodization procedure is then developed for image-resolution enhancement. Examples using this technique demonstrate enhanced image resolution in various applications, including airborne SAR imaging, image processing for three-dimensional interferometric ISAR imaging, and foliage-penetration ultrawideband SAR image processing. [J120]

"Dynamical evolution of the Brillouin precursor in Rocard-Powles-Debye model dielectrics"

When an ultrawide-band electromagnetic pulse penetrates into a causally dispersive dielectric, the interrelated effects of phase dispersion and frequency dependent attenuation alter the pulse in a fundamental way that

results in the appearance of so-called precursor fields. For a Debye-type dielectric, the dynamical field evolution is dominated by the Brillouin precursor as the propagation depth typically exceeds a single penetration depth at the carrier frequency of the input pulse. This is because the peak amplitude in the Brillouin precursor decays only as the square root of the inverse of the propagation distance. This nonexponential decay of the Brillouin precursor makes it ideally suited for remote sensing. Of equal importance is the frequency structure of the Brillouin precursor. Although the instantaneous oscillation frequency is zero at the peak amplitude point of the Brillouin precursor, the actual oscillation frequency of this field structure is quite different, exhibiting a complicated dependence on both the material dispersion and the input pulse characteristics. Finally, a Brillouin pulse is defined and is shown to possess near optimal (if not optimal) penetration into a given Debye-type dielectric. [J121]

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

Microwave imaging has been suggested as a promising modality for early-stage breast cancer detection. In this paper, we propose a statistical microwave imaging technique wherein a set of generalized likelihood ratio tests (GLRT) is applied to microwave backscatter data to determine the presence and location of strong scatterers such as malignant tumors in the breast. The GLRT is formulated assuming that the backscatter data is Gaussian distributed with known covariance matrix. We describe the method for estimating this covariance matrix offline and formulating a GLRT for several heterogeneous two-dimensional (2-D) numerical breast phantoms, several three-dimensional (3-D) experimental breast phantoms, and a 3-D numerical breast phantom with a realistic half-ellipsoid shape. Using the GLRT with the estimated covariance matrix and a threshold chosen to constrain the false discovery rate (FDR) of the image, we show the capability to detect and localize small ([J122]

"Ultrawideband radar special features & terminology"

UWB radar has evolved in the fifteen years since DARPA proposed the present frequency-based definition. We suggest the UWB radar definition should reflect the physical features and practical applications. We propose a revised definition: an ultra wideband radar is a radar set which has a range resolution (\Δr) much smaller than the target length L along the radiated direction. [J123]

"Theory and analysis of adaptive cylindrical array antenna for ultrawideband wireless communications"

In this paper, the principle of cylindrical array beamforming based on ultrawideband impulse (UWBI) signals is introduced. A cylindrical array antenna is composed of a number of vertically aligned and concentric circular subarrays of equal radius and equal number of array elements. Theory, analysis, and computer simulation of the cylindrical array antenna are presented based on UWBI signals with the time variation of a generalized Gaussian pulse (GGP). The radiation pattern of the cylindrical array antenna is derived in terms of the inverse Fourier transform of the radiated far-zone GGP signal. The radiation pattern results in different azimuth and elevation beam patterns such as peak amplitude pattern, peak power pattern, and energy pattern. Computer plots of these antenna patterns are generated for different design parameters such as array radius, interelement spacing distance, frequency bandwidth, and steering angle. The phenomenon of beamwidth broadening associated with electronic beamsteering is analyzed, and the resolution angle for the cylindrical array antenna is derived too. Beamforming based on UWBI signals provides a tradeoff between array dimensions, frequency bandwidth, and steering angle for achieving a high angular resolution capability in the azimuth plane as well as in the elevation plane. Such a tradeoff is attractive in practice for UWBI communications, indoor (multimedia) communications, radar, and localization systems. [J124]

"JOLT: a highly directive, very intensive, impulse-like radiator"

Ultrawideband (UWB) systems that radiate very high-level transient waveforms and exhibit operating bandwidths of over two decades are now in demand for a number of applications. Such systems are known to radiate impulse-like waveforms with rise times around 100 ps and peak electric field values of tens of kilovolts per meter. Such waveforms, if properly radiated, will exhibit an operating spectrum of over two decades, making them ideal for applications such as concealed object detection, countermine, transient radar, and communications. In this paper, we describe a large, high-voltage transient system built at the Air Force Research Laboratory, Kirtland AFB, NM, from 1997 to 1999. The pulsed power system centers around a very compact resonant transformer capable of generating over 1 MV at a pulse-repetition frequency of 600 Hz. This is switched, via an integrated transfer capacitor and an oil peaking switch onto an 85-Ω half-impulse radiating antenna. This unique system will deliver a far radiated field with a full-width at half-maximum on the order of 100 ps, and a field-range product (rEfar) of 5.3 MV, exceeding all previously reported results by a factor of several. [J125]

"Acoustooptic correlation processing in random noise radar"

A new technique has been developed that permits coherent processing of backscatter data acquired by a radar system transmitting ultrawideband (UWB) random noise waveforms and processing the received signals using a heterodyne correlation receiver. This technique has been used in various applications, such as Doppler estimation, polarimetry, interferometry, buried-object detection, synthetic aperture radar (SAR) imaging, inverse SAR (ISAR) imaging, foliage penetration imaging, etc. One of the major advantages of the noise radar system is its inherent immunity to external interference. In such a radar system, the correlation receiver consists of a programmable variable-delay line, a mixer followed by a lowpass filter. One drawback of this type of receiver is that it sequentially processes the target returns, thus limiting the system response time and the dynamic detection range. We have recently integrated a novel heterodyning acoustooptic (AO) time-integrating correlation receiver that uses a traveling-wave AO deflector for wideband signal processing. The transmit waveform modulates the intensity of a laser diode that is multiplied by the traveling-wave modulation produced by the AO deflector, and the correlation is time-integrated on a charge-coupled device photodetector array. The principal advantages of this AO correlation receiver are its ability to generate a large range of variable delays, as well as to perform the signal correlation operation in parallel. Compared to the conventional sequential correlation receiver using a variable stepped delay line and correlator, implementation of the AO variable-delay line and heterodyning correlator can 1) reduce the processing time and greatly increase the processing gain due to the parallel correlation mechanism and 2) greatly increase the number of range cells depending on the number of resolvable spots of the AO deflector. This results in rapid data acquisition, longer integration time on parallel detector pixels (3000 pixels), and improved SNR. It is also shown that this radar has more range gates (up to 1000), which ultimately improves the detectable range resolution. Furthermore, several field experiments performed with different target arrangements demonstrate that the acoustooptic variable-delay line and c-orrelator is able to profile various targets instantaneously and with very high SNR. [J126]

"Programmable ultrawideband signal generator for electromagnetic susceptibility testing"

Under Phase I of the Defense Advanced Research Projects Agency (DARPA) Networking in Extreme Environments (NETEX) initiative, Multispectral Solutions, Inc. (MSSI) was tasked with the development of a general-purpose, ultrawideband hardware simulator capable of reproducing a wide variety of ultrawideband (UWB) waveforms. The simulator, with UWB outputs from baseband through millimeter wave, was to be used for the purpose of electromagnetic susceptibility testing of legacy military radio, radar, and positioning systems. The ultimate goal of this portion of the Phase I program was the quantitative determination of those UWB parameters (e.g., frequency, power, pulse rate, pulse shape, dithering, etc.) which had the least impact on the operational performance of legacy designs. This describes the development of the MSSI NETEX UWB simulator (BFP1000). [J127]

"Ambiguity functions of laser-based chaotic radar"

The ambiguity functions of a newly developed laser-based chaotic radar (CRADAR) system are studied. In the CRADAR system, the chaotic waveforms can be generated either by an optically injected (OI) semiconductor laser, or a semiconductor laser with optoelectronic feedback (OEF). The ambiguity functions of the chaotic pulsation and chaotic oscillation waveforms obtained experimentally from the CRADAR system with the respective OEF and the OI schemes are examined and compared. In the cross-ambiguity functions, both types of the chaotic waveforms demonstrate their excellent capabilities in the electrical counter-countermeasures (ECCM) that civilian and military applications desire. In the auto-ambiguity functions, the chaotic oscillation waveform shows better unambiguous detection quality than the chaotic pulsation waveform that an ideal thumbtack-like ambiguity function with minimal sidelobes is found. Moreover, variations in the peak value and the full width at half-maximum of the auto-ambiguity function of the chaotic oscillation waveform along the principal axes are also investigated. By having the features of both ultrawideband radar and random signal radar, the chaotic oscillation waveform of the CRADAR system with the OI scheme is shown to possess the advantages of high range resolution, excellent ECCM capability, ideal thumbtack-like ambiguity function, and uncoupled range and range rate resolution functions. [J128]

"Rank-order filters for FOPEN target detection"

Issues associated with the radar detection of military targets that are concealed or camouflaged by forest clutter are described. The specific sensor platform can be categorized as an ultrawideband (UWB) foliage penetration (FOPEN) synthetic aperture radar (SAR). The discussion illustrates the fact that many contemporary approaches to FOPEN target detection are computationally intensive and/or require the implementation of elaborate training procedures. Alternative approaches, based the application of a set of simple rank-order filters (alternately known as order statistical or L filters), are presented. Initial results indicate impressive performance levels (in terms of

probability of detection as a function of false-alarm rate) with respect to baseline constant false-alarm rate computations. A number of avenues for future investigations are cited. [J129]

"Interference from 24-GHz automotive radars to passive microwave earth remote sensing satellites"

The automotive industry is currently considering the introduction of short-range radars (SRR) operating near 24 GHz for improving road traffic safety. SSRs are intended to observe the full azimuthal space cover around a vehicle using up to eight sensors. The sensors would operate in an ultrawideband (UWB) mode, occupying 3-5 GHz of bandwidth. Interference from SRR transmitters with passive microwave remote sensing satellites used for weather and climate monitoring could occur as the result of several coupling mechanisms, including direct coupling via the transmit antenna beam and scattering and diffraction of the transmitted signals from leading vehicles, buildings, and other nearby objects. In this study, we estimate the amount of coupling anticipated to occur from SRRs, including the direct and scattered contributions. The calculations are based on bistatic scattering measurements of a typical automobile and ray optical simulations of reflection and propagation in an urban environment. Using these calculations, the maximum allowable SRR transmitted power for interference levels acceptable for meteorological and climatological remote sensing applications are quantified. The study provides criteria for SRR operation with the Earth Exploration Satellite Service on a noninterference basis. [J130]

"Ultra-wideband radar sensors for short-range vehicular applications"

The recent approval granted by the Federal Communications Commission (FCC) for the use of ultra-wideband signals for vehicular radar applications has provided a gateway for the introduction of these sensors in the commercial arena as early as 2004. However, the rules governing the allowable spectral occupancy create significant constraints on the sensors' operation. This is further complicated by the variety of applications that these sensors are being required to fulfill. A review of the motivation for the development of these sensors is followed by a discussion of the consequent implications for waveform design and limitations on system architecture. Other practical considerations such as available semiconductor technology, packaging, and assembly techniques are reviewed, and results are presented for conventional surface-mount plastic packages illustrating their usefulness in the greater than 20-GHz frequency range. Suitable antenna technology for wide-band transmission is presented that is compliant with the specific restrictions stipulated in the FCC ruling. Finally, all of these considerations are combined with the presentation of a compatible integrated-circuit-based transceiver architecture. Measured results are presented for several critical circuit components including a +12-dBm driver amplifier for the transmitter, an RF pulse generator that can produce sub-1-ns pulses at a carrier frequency of 24 GHz, and a single-chip homodyne in-phase/quadrature down-conversion receiver that has a cascaded noise figure of less than 7 dB. All circuit components are fabricated in SiGe. [J131]

"RC-loaded bow-tie antenna for improved pulse radiation"

In this paper, a loading technique for improving pulse radiation from bow-tie antennas is introduced. This technique allows transmission of short transient pulses with very small late-time ringing and relatively high radiation efficiency. It makes use of a combination of a constant resistive loading along the antenna and a capacitive loading with linearly increasing reactance toward the antenna ends. The constant resistive loading is applied using volumetric microwave absorbers to cover one side of the antenna and the linear capacitive loading is realized by constructing narrow slots on the antenna surface. Relatively high radiation efficiency is achieved by choosing the location of the slot nearest to the feed point in such a way that radiation from it combines constructively with radiation from the feed point. Using a 0.8-ns monocycle for excitation, the technique results in a level of late-time ringing of lower than -40 dB and at the same time the peak value of the transmitted pulse is 54% higher than that of the same antenna without loading. [J132]

"Survey of worldwide high-power wideband capabilities"

Wideband and ultrawideband (UWB) technologies have achieved notable progress in recent years, aided immeasurably by improvements in solid-state manufacturing, computers, and digitizers. As a result, wideband systems that were difficult or impossible to implement ten years ago are now being built for an increasingly wide variety of applications including transient radar, concealed object detection, mine clearing, pipeline inspections, archeology, geology, electronic effects testing, and communications. In this paper, we discuss current wideband source technology around the world as well as laboratory and test facilities. We also will briefly touch on frequency limitations of anechoic chambers, design of transmission line simulators, frequency regulation requirements for outdoor ranges, and personnel exposure limits. [J133]

"Impulse amplification in a traveling-wave Tube-I: Simulation and experimental validation"

This paper presents a new one-dimensional time-domain model to be used in the analysis of the pulse response of the helix traveling-wave tube (TWT). It incorporates a novel method of implementing the effects of waveguide dispersion in one dimension. This new model has been successfully compared to an established frequency-domain model, and both time- and frequency-domain models have been compared to the impulse response of an experimental TWT. This comparison illustrates the efficacy of this new time-domain model. [J134]

"Impulse amplification in a traveling-wave Tube-II: large signal physics"

The helix traveling-wave tube (TWT) is a vacuum electronic device which utilizes an electron beam to amplify electromagnetic waves. Although having a broad frequency gain bandwidth compared to other vacuum electron devices, the helix TWT has been used in relatively narrowband ways in its applications in communications and electronic countermeasures. Recent interest in ultrawideband (UWB) radio and radar, combined with the recent development of UWB helix TWTs, has stimulated interest in the amplification of very broadband multifrequency signals and impulses. A number of studies have been conducted on the harmonic and intermodulation effects of multiple signals in a TWT, but there has not been much investigation into impulse amplification. Utilizing a nonlinear time-domain model developed for this purpose, the response of a wideband (helix) TWT to an input Gaussian pulse is examined. Differences between the large signal response to positive and negative Gaussian inputs are examined, and it is shown that a positive impulse input yields better pulse shape preservation, higher saturation level, and possibly greater efficiency. The growth and saturation mechanisms of a positive input Gaussian are then investigated, showing distinct differences from steady-state growth and saturation mechanisms. This study indicates that the possibility of amplification of impulses in a TWT is very promising. The results and conclusions of this study generally apply to all types of TWTs with appreciable bandwidth (e.g., couple-cavity, folded waveguide). However, as the helix TWT has the largest bandwidth, it is the most interesting and is the specific TWT studied here. [J135]

"Buried small objects detected by UWB GPR"

A ground penetrating radar (GPR) using short-pulse is developed to detect small and shallow metal objects buried underground. A bistatic mode in which the GPR system uses separate transmitting and receiving antennas is applied. A modified fat dipole antenna is developed for the transmitting and receiving antennas. The prototype of the system is tested in the real environment and 2D visualization of raw data is achieved. We show that the developed system has a good ability to detect underground metal objects, and even small targets of several centimeters. [J136]

"DORT method as applied to ultrawideband signals for detection of buried objects"

The decomposition of the time reversal operator (DORT) method, originally developed in acoustics, allows detection of scatterers embedded in the probed domain and provides some very robust means for focusing an incident wave onto a given scatterer. Hence, this method is very helpful for clutter reduction. Here, it is applied to the detection of buried cylindrical objects with the help of electromagnetic ultrawideband signals. It is shown that when the set of antennas is located on a piece of line above an interface, the use of the DORT method remains simple, whatever the polarization, provided the contribution from the target can be separated from that of the interface. Using wideband signals also permits one to excite natural resonances of the buried scatterer, which can easily be extracted from the eigenvalues of the time reversal operator. Numerical examples based on a finite-difference time-domain algorithm are given. [J137]

"Generalised wideband ambiguity function of a coherent ultrawideband random noise radar"

A coherent ultrawideband (UWB) random noise radar system has been developed and field tested at the University of Nebraska-Lincoln (UNL). A heterodyne correlation technique based on a time-delayed and frequency-shifted replica of the transmit waveform is used to inject coherence within this system. The radar's combined range and range rate resolution characteristics were investigated using the generalised wideband ambiguity function. As in the narrowband random noise waveform case, range and range rate resolutions can be controlled independently, the former being inversely related to the transmit bandwidth, while the latter is inversely related to the bandwidth of the integrating filter. It is also shown that UWB waveforms are not suitable for accurate range rate estimation due to the extended Doppler-spread parameter, i.e. the product of the transmit bandwidth and the target range rate, unless the correlator is matched in the delay rate as well. [J138]

"Multipath and ground clutter analysis for a UWB noise radar"

An ultrawideband (UWB) random-noise radar operating in the 1-2 GHz frequency band has been developed and field-tested up to a 200 m range at the Environmental Remote Sensing Laboratory (ERSL) of the University of Nebraska. A unique heterodyne correlation technique based on a delayed transmitted waveform using a

photonic delay line has been used to inject coherence within this system. The performance of this radar in the presence of ground reflections is investigated analytically and experimentally, and the mitigating effects of UWB waveform on multipath-induced interference are analyzed. In addition, the ground clutter statistics, in a look-down mode, are theoretically established and experimentally verified. The performance of this radar in detecting clutter embedded targets with small radar cross section (RCS) is also experimentally examined. [J139]

"ECCM capabilities of an ultrawideband bandlimited random noise imaging radar"

Investigated here is high-resolution imaging of targets in noisy or unfriendly radar environments through a simulation analysis of the ultrawideband (UWB) continuous-wave (CW) bandlimited random noise waveform. The linear FM chirp signal was selected as a benchmark radar waveform for comparison purposes. Simulation of the recovery of various types of target reflectivity functions (TRFs) for these waveforms were performed and analyzed. In addition, electronic counter-countermeasure (ECCM) capabilities for both types of systems were investigated. The results are compared using the error between the interference (jamming)-free recovered TRF and the recovered TRF under noisy conditions as a function of the signal-to-interference/jamming ratio (SIR/SJR). Our analysis shows that noise waveforms possess better jamming immunity (of the order of 5-10 dB improvement over the linear FM chirp) due to the unique radar correlation processing in the receiver. [J140]

"Evaluation of a compound probability model with tower-mounted scatterometer data"

Six months of data from the YSCAT94 experiment conducted at the CCIW WAVES research platform on Lake Ontario, Canada, are analyzed to evaluate a compound probability model. YSCAT was an ultrawideband small footprint (≈1 m) microwave scatterometer that operated at frequencies of 2-18 GHz, incidence angles from 0° to 60°, both h-pol and v-pol, and which tracked the wind using simultaneous weather measurements. The probability distribution function of the measured instantaneous backscattered amplitude (p(a)) is compared to theoretical distributions developed from-the composite model and a simple wave spectrum. Model parameters of the resulting Rayleigh/generalized lognormal distribution probability density function (pdf) (C, a1, and a2) are derived directly from the data and are found to demonstrate relationships with wind speed, incidence angle, and radar frequency [J141]

"Prescreening during image formation for ultrawideband radar"

Standard radar image formation techniques waste computational resources by full resolving all areas of the scene, even regions of benign clutter. We introduce a multiscale prescreener algorithm that runs as part of the image formation processing step for ultrawideband (UWB) synthetic aperture radar (SAR) systems. The prescreener processes intermediate radar data generated by a quadtree backprojection image former. As the quadtree algorithm iterates, it is resolving increasingly finer subpatches of the scene. After each quadtree stage, the prescreener makes an estimate of the signal-to-background ratio of each subpatch and applies a constant false alarm rate (CFAR) detector to decide which ones might contain a target of interest. Whenever the prescreener determines that a subpatch is not near a detection, it cues the image former to terminate further processing of that subpatch. Using a small database of UWB radar field data, we demonstrate that the prescreener is able to decrease the overall computational load of the image formation process. We also show that the new multiscale prescreener method produces fewer false alarms than the conventional two-parameter CFAR prescreener applied to the completely formed image [J142]

"Time-domain imaging of objects within enclosures"

The imaging of objects within an enclosure using short electromagnetic pulses is investigated. A simulated image of a metallic cylinder within a plywood box is constructed using the numerical scattered field found by solving an integral equation. Comparison with images found experimentally shows good agreement, and the object is easily detected through the walls of the box. Multiple objects placed within the plywood box are imaged with similar clarity [J143]

"Design and applications of airborne radars in the VHF/UHF band"

The simultaneous need for ground penetration and high resolution dictates the use of frequencies less than 500 MHz for imaging ground penetrating radar (GPR) designs. It is possible to build such systems with good performance and yet not interfere with ground installations operating in the same bands. The total number of airborne GPR systems needed to saturate the market is small, (possibly less than ten), and so the buildup of noise in this spectral region occupied by these radars will be negligible. This is fortunate, since there is a clear need for such radars in such areas as humanitarian demining and unexploded ordnance (UXO) mapping. Some formal set of guidelines is needed beyond that given in Part 15 of the FCC regulations, which both recognizes the need for airborne UWB radar operations, and still protects licensed users in the band [J144]

"Time-domain sensing of targets buried under a Gaussian, exponential, or fractal rough interface"

The authors numerically examine subsurface sensing via an ultrawideband ground penetrating radar (GPR) system. The target is assumed to reside under a randomly rough air-ground interface and is illuminated by a pulsed plane wave. The underlying wave physics is addressed through application of the multiresolution time-domain (MRTD) algorithm. The scattered time-domain fields are parametrized as a random process and an optimal detection scheme is formulated, accounting for the clutter and target signature statistics. Detector performance is evaluated via receiver operating characteristics (ROCs) for variable sensor parameters (polarization and incident angle) and for several rough-surface statistical models [J145]

"Receiver operating characteristics for the coherent UWB random noise radar"

An ultrawideband (UWB) random-noise radar operating in the 1-2 GHz frequency band has been developed and held-tested at a 200 m range at the University of Nebraska. A unique heterodyne correlation technique based on a delayed transmitted waveform using a photonic delay line has been used to inject coherence within this system. The performance of this radar, assuming a point target, has been investigated from a statistical point of view by developing the theoretical basis for the system's receiver operating characteristics (ROC). Explicit analytical expressions for the joint probability density function (pdf) of the in-phase (I) and quadrature (Q) components of the receiver output have been derived under the assumption that the input signals are partially correlated Gaussian processes. The pdf and the complementary cumulative distribution function (cdf) for the envelope of the receiver output are also derived. These expressions are used to relate the probability of detection (Pd) to the probability of false alarm (Pf) for different numbers of integrated samples, and the results are analyzed [J146]

"FOPEN SAR imaging using UWB step-frequency and random noise waveforms"

The detection and identification of targets obscured by foliage have been topics of great interest. Several synthetic aperture radar (SAR) experiments have demonstrated promising images of terrain and man-made objects obscured by dense foliage, by using either linear frequency modulation (LFM) or step-frequency waveforms. We present here the methodology and results of a comparative study on foliage penetration (FOPEN) SAR imaging using ultrawideband (UWB) step-frequency and random noise waveforms. A statistical-physical foliage transmission model is developed for simulation applications. The foliage obscuring pattern is analyzed by means of the technique of paired echoes. The results of the comparative study demonstrates the ability of a UHF band UWB random noise radar to be used as a FOPEN SAR. Advantages of the random noise radar system include covert detection and immunity to radio frequency interference (RFI) [J147]

"Rigorous modeling of ultrawideband VHF scattering from tree trunks over flat and. sloped terrain"

Three electromagnetic models are employed for the investigation of ultrawideband VHF scattering from tree trunks situated over flat and sloped terrain. Two of the models are numerical, each employing a frequency-domain integral-equation formulation solved via the method of moments (MoM). A body-of-revolution (BoR) Mote formulation is applied for a tree trunk on a flat terrain, implying that the BoR axis is perpendicular to the layers of an arbitrary layered-earth model. For the case of sloped terrain, the BoR model is inapplicable, and therefore the MoM solution is performed via general triangular-patch basis functions. Both MoM models are very accurate but are computationally expensive. Consequently, the authors also consider a third model, employing approximations based on the closed-form solution for scattering from an infinite dielectric cylinder in free space. The third model is highly efficient computationally and, despite the significant approximations, often yields accurate results relative to data computed via the reference MoM solutions. Data from the three models are considered, and several examples of application to remote sensing are addressed [J148]

"Ultrawideband radar images of the surface disturbance produced by a submerged, mine-like object"

This paper describes an ultrawideband, imaging radar designed to image the fine structure of the surface disturbances caused by submerged objects and presents images of the surface wake generated by a sphere immersed in a current. The system was deployed on a research pier on the Outer Banks of North Carolina as part of the Mine Surface Effects (MISE) program, a program designed to investigate the feasibility of using microwave radar to detect submerged mines. The radar achieves extremely high range resolution, approximately 4 cm, through the use of a short pulse with a 3 dB bandwidth of 3 GHz and a center frequency of 9 GHz. Azimuthal imaging is achieved through the use of a linear array of receive antennas and a time-domain beam-forming technique. Radar images from the MISE program are presented which show the surface disturbance generated by a 91 cm-diameter sphere immersed in a 40-60 cm/s current. A surface wake is clearly visible in

the imagery, both during the low phase of the tide, when the sphere broached the surface, and during high tide, when the sphere was completely submerged. Closer examination of the imagery reveals that when the target was fully submerged, the backscatter from the wake was primarily composed of long-lived (>1.5 s), isolated echoes that translated downstream at a velocity close to that of the measured surface current. Photographs of the wake suggest that these echoes are generated by sharp-crested surface features that form where the slow moving water of the turbulent, subsurface wake impinges the surface. [J149]

"Auto-regressive filter-based E-pulse discriminating scheme"

Ultrawide-band radar target discrimination schemes have been of great interest during the last two decades. One of the most used methods is the so-called E-pulse discrimination scheme, which is based on the late-time impulse response of a target. Traditional techniques to construct the proper E-pulses require the determination of the natural frequencies as an intermediate step. Here, we present a technique that allows us to obtain the required E-pulses directly. The approach suggested is applied to two simple three-dimensional (3D) targets: a rectangular cavity and a strip with a fin [J150]

"Ultrawideband radar measurements: analysis and processing [JBook Review]"

First Page of the Article [J151]

"UWB radar detection of targets in foliage using alpha-stable clutter models"

We address the problem of detection of targets obscured by a forest canopy using an ultrawideband (UWB) radar. The forest clutter observed in the radar imagery is a highly impulsive random process that is more accurately modeled with the recently proposed class of alpha-stable processes as compared with Gaussian, Weibull, and K-distribution models. With this more accurate model, segmentation is performed on the imagery into forest and clear regions. Further, a region-adaptive symmetric alpha stable (SαS) constant false-alarm rate (CFAR) detector is introduced and its performance is compared with the Weibull and Gaussian CFAR detectors. The results on real data show that the SαS CFAR performs better than the Weibull and Gaussian CFAR detectors in detecting obscured targets [J152]

"Thinned spectrum ultrawideband waveforms using stepped-frequency polyphase codes"

An ultrawideband (UWB) radar can interfere with external RF sources because of the mutual occupancy of the same frequency band. A stepped-frequency polyphase code (SFPC) waveform is proposed as a generic UWB waveform whose interference with the external RF sources is significantly reduced. The subpulses of the individual stepped-frequency (SF) pulses are phase coded using small phase perturbations. This results in a waveform which places nulls at the frequency locations of the external RF sources. Because the phase perturbations are small, a mismatched filter which uses the unperturbed pulses (no phase modulation) as a reference signal results in a simple receiver design and a small mismatch loss on receive. Furthermore, the proposed methodology also has application to narrowband or wideband radars [J153]

"Polarimetric SAR imaging of buried landmines"

If the fields incident on a buried body of revolution are polarized vertically or horizontally (relative to the ground), the backscattered fields are exclusively copolarized (i.e., there are no cross-polarized backscattered fields). After substantiating this theoretically, measured ultrawideband (UWB) synthetic aperture radar (SAR) data are used for corroboration, considering real, buried landmines that approximate bodies of revolution [J154]

"Ultra-wideband radar using Fourier synthesized waveforms"

Traditional methods of ultra-wideband (UWB) radar signal generation suffer from several disadvantages such as low antenna radiation efficiency and lack of accurate control of signal parameters like pulse shape, pulse repetition interval (PRI), and its spectrum. UWB signals can be generated by expanding the desired radar waveform in a Fourier series and then synthesizing the waveform by generating the individual terms in the expansion from harmonically related oscillators. Signals thus produced overcome the disadvantages of traditional methods of UWB signal generation. Fourier series based method for generation of complex amplitude coded waveforms is developed which can be used to generate time domain equivalent of Barker and other codes for application in radar and communication areas. In radar applications, these coded waveforms, with accurate and stable waveform parameters, shall allow pulse compression and coherent integration. The additional processing gain provided by these operations reduces the need for high peak power in radar transmitters which is one of the bottlenecks in the implementation of operational UWB radars. This paper also describes a UWB radar concept which incorporates Fourier synthesized waveforms. Related digital signal processing issues are also

discussed [J155]

"Moving target detection in foliage using along track monopulse synthetic aperture radar imaging"

This paper presents a method for detecting moving targets embedded in foliage from the monostatic and bistatic synthetic aperture radar (SAR) data obtained via two airborne radars. The two radars, which are mounted on the same aircraft, have different coordinates in the along track (cross-range) domain. However, unlike the interferometric SAR systems used for topographic mapping, the two radars possess a common range and altitude (i.e., slant range). The resultant monopulse SAR images are used to construct difference and interferometric images for moving target detection. It is shown that the signatures of the stationary targets are weakened in these images. Methods for estimating a moving target's motion parameters are discussed. Results for an ultrawideband UHF SAR system are presented [J156]

"RFI suppression for ultra wideband radar"

An estimate-and-subtract algorithm is presented for the real-time digital suppression of radio frequency interference (RFI) in ultrawideband (UWB) synthetic aperture radar (SAR) systems used for foliage- and ground-penetrating imaging. The algorithm separately processes fixed- and variable-frequency interferers. Excision of estimated targets greatly reduces bias in RFI estimates, thereby reducing target energy loss and sidelobe levels in SAR imagery. Performance is demonstrated on data collected with the Army Research Laboratory's UWB rail SAR. [J157]

"P-3 ultra-wideband SAR: description and examples"

Under the Advanced Research Projects Agency (ARPA)/ASTO sponsorship, through a contract from the Naval Air Warfare Center (NAWC), the Environmental Research Institute of Michigan (ERIM) has developed an ultrawideband (UWB) very high frequency (VHF)/ultrahigh frequency (UHF) fully polarimetric airborne synthetic aperture radar (SAR) for studying the detection of foliage-obscured objects. The radar is installed in the NAWC P-3 testbed aircraft and takes advantage of existing ERIM-built multimode, fully-polarimetric X/L/C-band SAR hardware. This paper describes the radar and presents some examples of its capabilities including polarimetric imagery and two-pass interferometric surface height estimates [J158]

"Signal analysis by means of time-frequency (Wigner-type) distributions-applications to sonar and radar echoes"

Time series data have been traditionally analyzed in either the time or the frequency domains. For signals with a time-varying frequency content, the combined time-frequency (TF) representations, based on the Cohen class of (generalized) Wigner distributions (WD's) offer a powerful analysis tool. Using them, it is possible to: (1) trace the time-evolution of the resonance features usually present in a standard sonar cross section (SCS), or in a radar cross section (RCS) and (2) extract target information that may be difficult to even notice in an ordinary SCS or RCS. After a brief review of the fundamental properties of the WD, we discuss ways to reduce or suppress the cross term interference that appears in the WD of multicomponent systems. These points are illustrated with a variety of three-dimensional (3-D) plots of Wigner and pseudo-Wigner distributions (PWD). The plots are all obtained from an extensive analysis we have made over the years of the resonance acoustic echoes backscattered by a variety of elastic shells submerged in water, when they are excited by various types of incident pressure waves, including the short pulses generated by explosive charges. We also review studies we have made of the echoes returned by conducting or dielectric targets in the atmosphere, when they are illuminated by broadband radar pings. These short incident pulses are used to analytically model the performance of ultrawide band (UWB) radars, often called impulse radars. A TF domain analysis of these impulse radar returns demonstrates their superior information content [J159]

"Reconnaissance with slant plane circular SAR imaging"

This paper presents a method for imaging from the slant plane data collected by a synthetic aperture radar (SAR) over the full rotation or a partial segment of a circular flight path. A Fourier analysis for the Green's function of the imaging system is provided. This analysis is the basis of an inversion for slant plane circular SAR data. The reconstruction algorithm and resolution for this SAR system are outlined. It is shown that the slant plane circular SAR, unlike the slant plane linear SAR, has the capability to extract three-dimensional imaging information of a target scene. The merits of the algorithm are demonstrated via a simulated target whose ultra wideband foliage penetrating (FOPEN) or ground penetrating (GPEN) ultrahigh frequency (UHF) radar signature varies with the radar's aspect angle [J160]

"Foliage penetration experiment"

This series papers describes analyses of a foliage penetration experiment undertaken by MIT Lincoln Laboratory to assess the ability of synthetic aperture radar (SAR) to detect targets under trees. Data were taken using the NASA/JPL UHF, L-, C-band fully polarimetric SAR over a forested area in Maine in July 1990. Future experiments are planned to measure the polarimetric properties of clutter and targets using the latest ultrawideband sensors with submeter resolutions and fully polarimetric data collection capabilities. [J161]

"Scattering center analysis of radar targets using fitting scheme and genetic algorithm"

Development of successful radar target discrimination schemes using ultrawideband signatures hinges on an accurate understanding of the scattering behavior of complex radar targets. Since it is very difficult to calculate the scattered field of complex targets theoretically, a mathematical model (Altes (1976) model) representing scattering center impulse response has been developed to describe the scattered field. The extraction of temporal positions, pulse responses, and transfer functions of target scattering centers is demonstrated using artificially created and measured responses. Two different scale aircraft models (B-58 and B-52) are utilized. The fitting scheme based on the least squares method is quite satisfactory but its accuracy deteriorates when the overlapping of scattering-center pulse responses is severe. To overcome this problem a genetic algorithm is used to improve the results. While the genetic algorithm gives much better accuracy, it consumes much more computer time due to its global nature and lack of derivative information. The purpose of this analysis is to provide a method to reduce data storage for ultrawideband signatures in target discrimination [J162]

"Dependence of the normalized radar cross section of water waves on Bragg wavelength-wind speed sensitivity"

Measurements of the normalized radar cross section (σ°) made by the YSCAT ultrawideband scatterometer during an extended deployment on the Canada Centre for Inland Waters (CCIW) Research Tower located at Lake Ontario are analyzed and compared with anemometer wind measurements to study the sensitivity of σ° to the wind speed as a function of the Bragg wavelength. This paper concentrates on upwind and downwind azimuth angles in the wind speed range of 4.5-12 m/s. While YSCAT collected measurements of σ° at a variety of frequencies and incidence angles, this paper focuses on frequencies of 2.0, 3.05, 5.30, 10.02, and 14.0 GHz and incidence angles within the Bragg regime, 30-50°. Adopting a power law model to describe the relationship between σ° and wind speed, both wind speed exponents and upwind/downwind (u/d) ratios of σ° are found using least squares linear regression. The analysis of the wind speed exponents and u/d ratios show that shorter Bragg wavelengths (Λ<4 cm) are the most sensitive to wind speed and direction. Additionally, vertical polarization (V-pol) σ° is shown to be more sensitive to wind speed than horizontal polarization (H-pol) σ, while the H-pol u/d ratio is larger than the V-pol u/d ratio [J163]

"Ultrawideband microwave-radar conceptual design"

This paper outlines the special considerations that characterize the design of an UWB radar for the detection of low-altitude missiles over the sea. It discusses the factors which enter into the choice of frequency, and the selection of the transmitter, antenna, and receiver. Reviewed are signal processing issues concerning detection of UWB signals in noise and clutter, nondoppler MTI based on the pulse-to-pulse change in range due to target motion, measurement of target height based on multipath time delay, and target recognition. As the investigation progressed, the authors became disappointed with the available UWB technology, but encouraged about the potential advantages of UWB for this application. The chief limitation of UWB radar that must be overcome before applications are viable is its poor electromagnetic compatibility (EMC) [J164]

"Resolution of a phase ambiguity in a calibration procedure for polarimetric radar systems"

A cross-pol/co-pol phase ambiguity in a previously published calibration procedure for polarimetric radar systems is discussed. The original procedure is modified to resolve the ambiguity while still retaining insensitivity to calibration target orientation. The modified form is then generalized and applied to an ultrawideband radar system for which the ambiguity in the original procedure is particularly evident [J165]

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

An ultrawideband radar system is described which has the capability of making pulse-to-pulse polarimetric measurements of the dynamic water features responsible for radar backscatter from the sea. The fast risetime voltage step produced by a Tektronix time-domain reflectometer (TDR) is used to excite a 6-12-GHz amplifier, producing a short (15 cm) radar pulse, A pair of 2- to 18-GHz antennas and appropriate pulse-to-pulse transmit and receive switching capability allows the collection of four consecutive equivalent-time-sampled pulses, one for

each combination of the linear transmit and receive antenna polarizations. A polarimetric scattering matrix is then obtained at a sequence of frequencies across the 6-12-GHz band through the Fourier transform of each of the four waveforms and the application of an ultrawideband, polarimetric calibration procedure. The effect of motion on the computed scattering matrix is discussed and quantified, as this is an important consideration for polarimetric investigations of the water features responsible for radar sea scatter, A technique is then presented which compensates for the effects of target translation during the sampling interval. Scattering measurements of several rigid targets and of small breaking waves in a wave tank are used to illustrate the unique capabilities of this system and its applicability to sea scatter studies [J166]

"The UWB (impulse) radar caper or `punishment of the innocent'"

The author describes his experiences chairing a panel to review ultrawideband (UWB), or impulse, radar. The panel's report pointed out the fallacies in the proposals of the extremists pushing the rapid development of such a radar, noted the very good work of the real contributors, and made several recommendations. Pressure from the extremists led to an investigation by the Inspector General of the US Department of Defense of the panel and its members. That investigation found no basis for the allegations and concluded that the panel's report was credible and the panel balanced [J167]

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