DEPARTMENT OF PHYSICS

Thesis Abstracts

TERRAIN CATEGORIZATION USING MULTITEMPORAL INFRARED IMAGERY

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Terrain Categorization (TERCAT) in remote sensing is used extensively by the United States Military to conduct Intelligence Preparation of the Battlefield (IPB). This thesis explores the feasibility of exploiting multitemporal infrared imagery for the purpose of TERCAT. Two littoral locations were imaged multiple times from August through October 1998 using National Technical Means (NTM). Images were merged and analyzed using commercial off the shelf (COTS) technology, producing TERCAT maps of both target areas. Both supervised and unsupervised classification methods were used in this process. The TERCAT maps were compared with ground truth measurements to determine the overall classification accuracy. Accuracy levels above eighty percent were achieved. This variation on traditional change detection methods provides an alternative single-sensor approach to terrain categorization that can be utilized by the military.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Remote Sensing, Sensor Fusion, TERCAT

EVALUATION OF ALTERNATIVE COMMUNICATION SCHEMES USING ENVIRONMENTALLY ADAPTIVE ALGORITHMS

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Time-varying multipath propagation in a shallow underwater environment causes intersymbol interference in high-speed underwater acoustic (UWA) communications. Combating this effect is considered to be the most challenging task requiring large adaptive filters and increasing the computational burden at the receiver end.

This thesis presents results of an in-tank experiment and data analysis performed off-line to examine, evaluate, and compare the robustness of Time-Reversal Approach to Communications (TRAC) and the Matched Environment Signaling Scheme (MESS) in different conditions, such as noise, surface waves and range changes between the receiver and transmitter. Both methods examined can environmentally adapt the acoustic propagation effects of a UWA channel. The MESS method provides a communications solution with increased computational complexity at the receiver end but gives higher data rates and is more robust to the presence of noise, surface waves, and range changes than the TRAC method. On the other hand, the TRAC method manages to accomplish secure communications with low computational complexity at the receiver.

DoD KEY TECHNOLOGY AREA: Command, Control and Communications

KEYWORDS: Time Reversal Acoustics, Acoustic Communications, Acoustic Signal Processing, Acoustic Telemetry

PASSIVE TARGET TRACKING WITH UNCERTAIN SENSOR POSITIONS USING WAVELET-BASED TRANSIENT SIGNAL PROCESSING

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This dissertation investigates the problem of tracking a maneuvering target from passive acoustic sensors of uncertain position. A batch oriented *maximum a posteriori* (MAP) algorithm using an expanded state vector is used to accurately estimate both the sensor's location and target trajectory from the data. Three sensor motion models are developed and compared under a variety of tracking scenarios. Additional tracking improvement is achieved through the use of transient signal processing. Two new wavelet-based time difference of arrival estimation methods are developed and compared to classical techniques. Testing on a variety of transient signals demonstrates that improved performance over the classical methods is achieved. The practicality and viability of the proposed techniques is confirmed through the modification and testing of a state of the art acoustic tracking system.

DoD KEY TECHNOLOGY AREA: Sensors, Target Tracking

KEYWORDS: Target Tracking, Non-Linear Estimation, Wavelet Analysis

PREDICTION OF WIRELESS COMMUNICATION SYSTEMS PERFORMANCE IN INDOOR APPLICATIONS

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Due to a shift in the interest in wireless applications, from outdoor to indoor environments, new modeling solutions had to be designed to account for the immense complexity of the latter. Essentially, two categories of indoor propagation models prevailed until the mid-90s: the empirical and the physical models. They both predicted important characteristics of a given confined environment like the coverage area, transmitted power requirements, number and location of base stations or access points. The implementation of wireless communications systems onboard naval assets is expected to offer numerous advantages and enhance the existing shipboard communications systems. That, in turn, calls for a reliable and cost-effective means of estimating the expected link budget in such environments, especially when the infrastructure in question is yet to be built, as is the case in a ship class under development.

This thesis treats the problem of indoor propagation modeling using the Numerical Electromagnetic Code-Basic Scattering Code (NEC-BSC) and compares the predicted results obtained by this code with actual measurements performed inside a building at the Naval Postgraduate School. A number of important conclusions regarding the validity of NEC-BSC for indoor applications are being reached and some intriguing statistical results are being presented.

DoD KEY TECHNOLOGY AREA: Command, Control, and Communications

KEYWORDS: Simulation of Signal Propagation, Indoor Radio Propagation, NEC-BSC

MEASUREMENTS AND MODELING ENHANCEMENTS FOR THE NPS MINIMUM RESOLVABLE TEMPERATURE DIFFERENCE MODEL, VISMODII

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Minimum Resolvable Temperature Difference (MRTD) measurement has long been used to describe the performance of thermal imaging systems. Computer models such as U.S. Army's FLIR92, that were developed to predict the MRTD, were reported to have deficiencies in dealing with sampling and aliasing effects. The models also include assumptions regarding the observer recognition process and therefore cannot predict the MRTD of an imager that incorporates an "objective" automatic target recognition device instead of a "subjective" human observer. The Visibility Model II developed for second generation thermal imaging systems at the Naval Postgraduate School (NPS) in the mid 90s takes sampling and aliasing issues into account and makes no assumptions about the observer. Modeling enhancements in VISMODII and its extension to predict objective MRTD are proposed and tested in this thesis. A parallel thesis at the NPS has shown that aliasing effects on image appearance are fundamentally different from noise. The improved VISMODII model accounts for the fact that unlike noise, aliasing may have a visual enhancing effect and therefore may lower MRTD. Experiments were conducted to measure subjective and objective MRTD. Experimental results demonstrated that the VISMODII model successfully predicts the MRTD both for the subjective and the objective schemes.

DoD KEY TECHNOLOGY AREAS: Sensors, Modeling and Simulation

KEYWORDS: Minimum Resolvable Temperature Differences, Thermal Imaging System, MRTD, VISMODII

SIMULATIONS OF THE TJNAF FREE ELECTRON LASER WITH A NEGATIVE TAPER AND LASER DAMAGE STUDIES

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The Free Electron Laser (FEL) is a candidate for a future close-in weapon system that will provide a longer protective range for missile destruction. The FEL is also tunable to wavelengths that would give good atmospheric transmission and optimal target absorption characteristics at the target. This thesis describes single-mode and multimode simulation results of the Thomas Jefferson National Accelerator Facility (TJNAF) FEL operating at far infrared wavelengths. The TJNAF FEL uses inverse tapering and is driven by 34.5 MeV and 47.5 MeV energy electron pulses. Steady-state power, weak-field steady state gain, electron beam energy spread and optical spectrum widths were explored as a function of the desynchronism and tapering rate. The simulations described FEL pulse evolution and short pulse effects. The simulation results have been presented at an International Conference held at Duke University, Durham, NC in August 2000. In addition, the results of damage to Slip-cast Fused Silica samples by the TJNAF FEL, with and without the effect of airflow are analyzed. A comparison with older damage experiments was done in order to develop scaling rules in the future.

DoD KEY TECHNOLOGY AREAS: Directed Energy Weapons, Modeling and Simulation

KEYWORDS: Free Electron Laser, Undulator, Negative Taper, Close-in Weapon Systems

DEFINING MINIMUM DETECTABLE TEMPERATURE DIFFERENCE (MDT) FROM MINIMUM RESOLVABLE TEMPERATURE DIFFERENCE (MRT) IN THERMAL IMAGER PERFORMANCE MODELS

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Thermal Imaging System performance prediction is typically based on the summary performance parameter Minimum Resolvable Temperature Difference (MRT), the minimum temperature difference between bars and background that allows an observer to resolve a standard four-bar target. In operational systems, MRT may be available only as a tabulated data set. For detection of smaller, distant and unresolved targets, the appropriate measure may be the Minimum Detectable Temperature Difference (MDT) defined for a uniform square target against a uniform background.

This study addressed the calculation of MDT from data derived for the MRT curve. A transfer function was developed in terms of system engineering parameters for derivation of MDT from MRT and evaluated using three analytical thermal imager performance models. This method produced favorable results for spatial frequencies below the resolution cutoff limit. Beyond the resolution limit, a transfer function method using spatial frequency independent resolution parameters and a curve-fit method for measured MRT data that employs randomly selected constants were evaluated. These methods show promise for using MRT parameters to evaluate MDT beyond the cutoff and the curve-fit proved a good approximation for MDT data beyond the cutoff spatial frequency.

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DoD KEY TECHNOLOGY AREAS: Sensors, Modeling and Simulation

KEYWORDS: Thermal Imagers, Minimum Detectable Temperature Difference (MDTD), Minimum Resolvable Temperature Difference (MRTD)

SINKING A BODY WITH BUBBLES IN CLOSED AND OPEN ENVIRONMENTS

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The presence of bubbles in a liquid decreases the average density, and thus decreases the buoyant force on a floating body. Competing with the decrease in buoyancy is an upward drag due to the bubble motion and entrained liquid. This thesis presents investigations of the critical average density required to sink a buoyant body in water with bubbles in closed and open environments. A closed environment is where bubbles fill the container, in which case there is expected to be little if any upward flow of water at the body. An open environment is where the bubbles exist over a small cross-sectional area compared to the total cross-sectional area of the container, which models the effect of a methane eruption from the ocean floor. In this case, a substantial upward flow of water is entrained in the region of the bubbles, and a downward flow consequently occurs outside this region. Experiments for both closed and open environments are reported, where the average specific gravity of the body is varied. The closed environment data significantly deviate from a quantitative theory, and the open environment data are not in accord with a qualitative theory. Possible explanations for these deviations are offered.

DoD KEY TECHNOLOGY AREA: Other (Fluid Dynamics)

KEYWORDS: Water, Density, Specific Gravity, Volume Fraction, Bubbles, Buoyancy, Nonnewtonian Fluid

DESIGN OF A MINI THERMO-ACOUSTIC REFRIGERATOR
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A miniature thermoacoustic refrigerator is being developed for the purpose of cooling integrated circuits below their failure temperature when used in hot environments. The development of an electrically powered acoustic driver that powers the thermoacoustic refrigerator is described. The driver utilizes a flexural tri-laminar piezoelectric disk to generate one to two Watts of acoustic power at 4 kHz in 15 bar of He-Kr gas mixture. This thesis is the second of two driver development theses, which includes the information on the assembly of three drivers and their quantitative performance with a pressurized test resonator. A maximum acoustic power output of 0.5 Watt, was achieved with the third driver.

DoD KEY TECHNOLOGY AREA: Electronics

KEYWORDS: Thermo-acoustic Refrigerator, TAR, Thermo-acoustic Refrigerator Driver, Microchip Cooling

OPTIMIZATION OF MULTIPLE PLATFORM PRECISION GEOLOCATION THROUGH COMPUTER SIMULATION
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The fundamental mathematical relationships that govern Time Difference of Arrival (TDOA) geolocation suggest that to reduce the positional uncertainty in the target, the baseline between the two collectors can be lengthened. A multiple-platform precision geolocation system is modeled using Operational Performance Simulation (OPS) software and tested with various baseline lengths to determine the impact on system performance.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Space Vehicles, Command, Control and Communications, Electronic Warfare, Sensors, Modeling and Simulation

KEYWORDS: Computer Simulation, Unmanned Aerial Vehicles, Precision Geolocation

THE NPS SMALL ROBOTIC TECHNOLOGY INITIATIVE, MAN-PORTABLE ROBOTS FOR LOW INTENSITY CONFLICT
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The Naval Postgraduate School's Small Robotic Technology (SMART) Initiative is an ongoing research effort within the Combat Systems Science and Technology Curriculum that engages in forward-looking applications of small robotic technology for military employment. The immediate goal of which is to develop a multipurpose robotic platform that is capable of hosting varied sensor packages for military research. This thesis successfully accomplished initial background research and integration of a low cost, lightweight, all-terrain, robotic vehicle to fulfill this requirement. The areas of robotic investigation

included: research and procurement of a Foster Miller Lemming tracked vehicle; the selection of a robust, network enabled, real-time microcontroller called the ipEngine; selection of Differential GPS as a highly accurate autonomous vehicle positioning technique; and the development of the ipEngine software environment for integration and testing of the microcontroller's wireless interfacing. Wireless communication tests using TCP/IP sockets, serial communication, telnet and a common Internet Web Browser validated the ability to remotely operate the vehicle under both direct and autonomous control. Ultimately, this thesis laid the foundation for follow-on NPS students to research and integrate varied robotic sensing techniques, including synthetic array seismic sonar's and chemical detection devices, and to participate in cooperative research with other military laboratories.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Electronics, Sensors, Ground Vehicles, Robotics

KEYWORDS: Robotics, Autonomous, Micro-Controller, Embedded Processor, Differential GPS, FPGA, ipEngine, Man-portable

TESTING AND DEVELOPMENT OF A SHROUDED GAS TURBINE ENGINE IN A FREEJET FACILITY

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Testing and analysis of a shrouded turbojet engine with possible application for high speed propulsion on low cost Unmanned Combat Aerial Vehicles (UCAV), Unmanned Aerial Vehicles (UAV) and missiles was the subject of this thesis. The possibility of a turbojet providing thrust at subsonic conditions and the ramjet section providing the thrust in the supersonic regime exists. The combined cycle engine (CCE) could be incorporated into a variety of applications.

The building of a new freejet facility and engine test rig at the Naval Postgraduate School enabled dynamic testing of the ongoing development of a turboramjet. The freejet facility and new engine stand performed without exception. The shrouded engine was dynamically tested in a freejet up to Mach 0.4. The engine performance measurements closely matched those predicted by a cycle analysis program, GASTURB.

Computational fluid dynamics (CFD) was used to analyze the supersonic inlet at a design point of Mach 2. The results provided by the CFD code, OVERFLOW, matched theoretical flow parameters. The intake design was slightly modified to enhance performance of shock waves in the supersonic flight regime.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles

KEYWORDS: Micro-Turbojet, GASTURB, Engine Shroud, Turboramjet, Sophia J450, Microturbine

JAVA-BASED IMPLEMENTATION OF MONTEREY-MIAMI PARABOLIC EQUATION (MMPE) MODEL WITH ENHANCED VISUALIZATION AND IMPROVED METHOD OF ENVIRONMENTAL DEFINITION

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The Monterey-Miami Parabolic Equation (MMPE) Model is a full-wave underwater acoustic propagation model that utilizes the split-step Fourier marching algorithm. Previously the MMPE model was implemented in Fortran language and ran with a simple command line interface either in a Unix or DOS command window. After the Fortran code was run, the resulting binary data output file was post-processed using Matlab routines to extract specific field data and present the results in graphical form. This approach requires the user to have installed both Matlab and Fortran compilers. The MMPE model and associated acoustic processing tools are now rewritten in the object-oriented language Java. This new version of the MMPE model built within a Windows framework is called WinMMPE. Integrating the model, the post-processing calculations and the graphics generation together with a graphic user interface has produced a more attractive tool for users. A user-friendly, efficient, and accurate full-wave acoustic propagation model with enhanced visualization can make it easier to assess the spatial transmission loss in underwater acoustic environment.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Underwater Acoustic Propagation, Acoustic Modeling, Java, Parabolic Equation, MMPE, Winmmpe, VRML, 3D, Sonar Visualization

BANDWIDTH OPTIMIZATION OF UNDERWATER ACOUSTIC COMMUNICATIONS SYSTEMS

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Current underwater acoustic communication systems operate in the frequency band of 1-10 kHz and utilize various forms of signal processing to improve data rates. In this work, the influence of the environment on long-range propagation of acoustic signals was examined over the band of 1-5 kHz. Three methods of evaluation (transmission loss, temporal coherence, and spatial coherence) were employed.

Transmission loss (TL) has been studied for many years and was included as a fundamental measure. It can be shown that TL is related to the transmission power required for a specific signal to noise ratio required for reception. Temporal coherence relates the received pressure signals as a function of time for varying bottom roughness and source motion. Similarly, spatial coherence compares the received pressure signal as a function of frequency and of depth for varying bottom roughness and source motion. Both spatial and temporal coherence evaluate the degradation of the arrival structure.

Based on the relationships observed for transmission loss, temporal coherence, and spatial coherence, it appears that the optimization of the communications bandwidth is highly dependent on the characteristics of the environment. In this study, the dominant influence on signal level and coherence appeared to be the introduction of roughness on the bottom interface. Source motion relative to this roughness (i.e. displacement) appeared to cause significant signal degradation at higher frequencies. However, Doppler effects due to source motion did not seem to appreciably influence signal coherence. Furthermore, the influence of the bottom roughness was clearly affected by the presence, or lack of, a sound channel. Specifically, if a sound channel existed which limited the amount of bottom interactions, then the source

motion (doppler or displacement) did not seem to significantly affect signal coherence. It is expected that similar conclusions would be obtained by introduction of a rough surface.

Given the conditions considered here, if the sound velocity profile generates significant bottom interactions, then the optimal frequency bandwidth appears to be the lowest possible, particularly at ranges beyond approximately 1 km. For weak bottom interacting profiles, higher frequencies that can increase data transfer rates would be optimal. The limitations of such higher frequencies would predominantly be in TL, but even this did not exhibit appreciable frequency dependence for ducted propagation.

DoD KEY TECHNOLOGY AREAS: Command, Control, and Communications, Modeling and Simulation

KEYWORDS: Underwater Acoustic Communication, Bandwidth Optimization, Signal Coherence

ADVANCED APPLICATIONS FOR 0.53 mm LASER LIGHT

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Use of the National Ignition Facility with green light as the laser output is an intriguing option for advanced applications ranging from inertial fusion to production of compact x-ray sources. Particular attention is given to the potential use of 0.53 μm light to produce a high-energy x-ray source. This application requires the efficient generation of high-energy electrons which can subsequently produce high-energy x-rays as they transport into gold or other high Z wall. One- and two-dimensional computer simulations are used to explore high-energy electron generation by intense 0.53 μm laser light in a plasma with density near one-quarter the critical density. Significant absorption is shown to occur into high-energy electrons with an effective temperature which is reduced by the development of ion fluctuations. The results compare favorably with some recent experiments using 0.53 μm light.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Computing and Software

KEYWORDS: High Intensity Lasers, Laser-Plasma Coupling, National Ignition Facility, Fusion, Computer Simulations

RADIATION EFFECTS ON InGaAs p-i-n PHOTODIODES

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This thesis identifies, characterizes, and identifies a method to predict the dark current degradation of InGaAs p-i-n Photodiodes caused by exposure to 55 MeV protons, 12 MeV protons, and 90 MeV electrons. Experimental proton and electron fluence levels (particles/cm^2) were calculated and correlated to fluence levels for a 1 MeV neutron in silicon by equating the amount of physical damage incurred within the device. Physical damage was quantified as a displacement damage dose (D_d), which is simply the fluence level multiplied by the appropriate value for the material's non-ionizing energy loss (NIEL). Photodiodes were then irradiated and dark current data was collected. The resulting data were fitted into the three-term diode equation, and current coefficients were obtained. Proton data were used to document device performance, and to examine the relationship between fluence levels and changes in the current coefficients. Additionally, these data were used to verify that it is appropriate to use NIEL and D_d for the correlation of 55 MeV and 12 MeV protons. Electron data were also used to document device performance,

but failed to demonstrate the ability of NIEL and D_d to accurately match the predicted changes in device performance caused by 90 Mev electrons and 55 MeV protons.

DoD KEY TECHNOLOGY AREA: Electronics, Other (Radiation Effects)

KEYWORDS: Radiation, InGaAs Photodetectors

DESIGN AND DEVELOPMENT OF THE IMAGE SCANNER FOR LINEATE IMAGING NEAR ULTRAVIOLET SPECTROMETER (LINUS)

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The Lineate Imaging Near Ultraviolet Spectrometer (LINUS) is a spectral imager that works in the ultraviolet region of the spectrum, and its purpose is to study atmospheric gas plumes. This thesis project is part of an ongoing effort to field-test the first version of LINUS by mid-2001. It concentrates in the development of the ultra-precise servo system that controls the pointing/scanning system of the instrument. The closed-loop angular-position servo is controlled by a dedicated motion controller board that is installed in the host computer. Control of the servo is achieved through proportional-integral-derivative (PID) algorithms built into the hardware and firmware of the motion controller board. The servo has been designed to an angular resolution of 9 seconds of arc, and was tuned for a step of 1000 counts. Static and dynamic tests were conducted and showed that the servo is stable and accurate. The tested accuracy of the servo is well within the design goal of one half encoder count.

DoD KEY TECHNOLOGY AREAS: Chemical and Biological Defense, Environmental Quality, Sensors

KEYWORDS: Sensors, Spectral Imaging, Spectrometer, Remote Sensing

TIME DELAY ESTIMATION FOR UNDERWATER SIGNALS AND APPLICATION TO LOCALIZATION

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The problem of time difference of arrival (TDOA) is important in underwater acoustics for both passive and active sonar. Classical approaches to this problem are based on generalized cross-correlation (GCC) methods implemented in the frequency domain. After appropriate weighting of the cross spectral data in the frequency domain, an inverse discrete Fourier transform (IDFT) is performed and the peak of the resulting GCC function is located in the time domain.

This thesis shows that the cross-spectrum of the data satisfies an appropriate signal subspace model; therefore the IDFT can be replaced with a signal subspace technique such as MUSIC. The result is an enhanced ability to locate the peak. Further, application of methods such as root-MUSIC or ESPRIT produce direct numerical estimates for TDOA without the need to search for a peak. Results are presented for an extensive set of simulations using both synthetic signal data and data from a ocean acoustic propagation model (MMPE). Results are further presented for an application of the new method to target localization and tracking. In all cases results are compared using both the new methods and the classical methods.

DoD KEY TECHNOLOGY AREAS: Other (Underwater Acoustics, Signal Processing)

KEYWORDS: Time Difference of Arrival, Subspace Methods, Generalized Cross-Correlation, Localization

MODELING TOTAL DOSE RADIATION EFFECTS IN A MULTI-EDGE SOI nMOSFET

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Silicon-On–Insulator (SOI) devices provide inherent radiation-hardness for dose-rate and single-event upset effects that makes them ideally suited for radiation environments such as space. Specifically, the SOI Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET), with its many Si/SiO_2 interfaces, is normally only sensitive to total dose radiation effects. This thesis investigates how to model these effects accurately and develops a computer simulation methodology utilizing hole trapping for modeling total dose radiation effects in a SOI semiconductor device. Specifically, a commercial Technology Computer Aided Design (TCAD) application, modified to include total dose radiation effects, is used to simulate an irradiated n-channel, multi-edge SOI MOSFET. The accuracy of the model is evaluated by using the simulation data to calculate simplified radiation induced leakage currents at various radiation dosages and then comparing with experimental measured leakage currents from irradiated devices. Simulation results show that while hole trapping is a dominant mechanism in causing enhanced leakage current at lower dose levels, it cannot solely account for all the enhanced leakage that occurs in a multi-edge device at higher dose levels.

DoD KEY TECHNOLOGY AREAS: Electronics, Modeling and Simulation

KEYWORDS: Electronics, Silicon-on-Insulator (SOI), Modeling and Simulation, Radiation Hardened

SIMULATIONS OF THE TJNAF FEL WITH A TAPERED UNDULATOR AND EXPERIMENTAL RESULTS OF LASER DAMAGE

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The modern maritime battlefield is dominated by the new generation of sea-skimming, high-speed, stealthy and highly agile anti-ship missiles. Anti-ship cruise missile technology continues to evolve, overcoming the performance of the existing ship self-defense weapon systems. The Free Electron Laser (FEL) could be the ultimate speed-of-light hard kill weapon system, offering unique features such as tunability, high power, pinpoint accuracy and infinite magazine. Multimode computer simulations were used to explore the operation of the Thomas Jefferson National Acceleration Facility (TJNAF) FEL with untapered and positively tapered undulator. The final steady state power, the steady state gain and the electron energy spread as a function of desynchronism were determined for both 34.5 Mev and 47.5 Mev electron beam energies.

This thesis also includes an experimental study of damage induced to Polyimide Fiberglass and F2 Epoxy samples, by the TJNAF FEL. Irradiations of the samples were conducted changing various parameters, such as the wavelength, average power, pulse repetition frequency, cross wind and spot size in order to explore the damage mechanism. At this stage of evolution, TJNAF FEL is capable of 500 W output average power, and in order to achieve the required intensity of 10 kW/cm^2 the beam was focused to a small radius. Scaling guidelines were developed in order to predict the damage caused by a high power laser over a large area.

DoD KEY TECHNOLOGY AREAS: Directed Energy Weapons, Modeling and Simulation

KEYWORDS: Free Electron Laser, Ship Self-Defense, Tapered Undulator, Laser Damage Experiments

SIMULATION OF DARMSTADT FREE ELECTRON LASER AND A COMPARISON OF HIGH GAIN FREE ELECTRON LASERS
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Second Reader: Robert L. Armstead, Department of Physics

The Free Electron Laser, with its wavelength tunability unlike any other laser, may be used in numerous future applications. These applications range from high energy laser weapons to surgical lasers for medical use. This thesis covers three separate topics concerning the FEL: the height of the separatrix for a tapered undulator, use of dimensionless parameters in a simple model and description for several high gain free electron lasers, and simulations of the Darmstadt free electron laser. The first topic yielded a formula for the separatrix height. The second topic utilized data from the proposed LCLS and TESLA x-ray lasers, the Electron Laser Facility at Lawrence Livermore Labs and the Free Electron Laser experiments at the Massachusetts Institute of Technology to develop dimensionless parameters for use in a simple model. For the last topic desynchronism curves for seven tapers were computed and gave expected results.

DoD KEY TECHNOLOGY AREAS: Directed Energy Weapons, Modeling and Simulation

KEYWORDS: Free Electron Laser

FREE ELECTRON LASER DEVELOPMENT FOR DIRECTED ENERGY
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Dissertation Supervisor: William B. Colson, Department of Physics

This dissertation investigates power requirements for a Free Electron Laser to burn through various missile radome materials. It also includes computer simulation results for several FEL system configurations designed to achieve maximum power while maintaining strict energy spread constraints.

The method used to determine power requirements to burn through materials was to use the Thomas Jefferson National Accelerator Facility's Free Electron Laser to conduct material damage experiments. As the laser was improved and increased in power, the laser spot sizes on the target materials were increased while maintaining a constant irradiance. The key results from these experiments included determining minimal spot sizes that can be used for future experiments, and validation that an irradiance level of 10 kW/cm^2 can burn through most missile radome materials in a few seconds.

The computer simulations involved changing various parameters of an FEL such as electron energy levels, pulse lengths, magnetic field strengths, desynchronism, as well as several other parameters, to determine the best possible configuration to achieve the desire power levels and energy spread requirements for development of a megawatt size FEL. The results indicate that for the proposed designs, both the required power and the required energy spread limit can be met.

DoD KEY TECHNOLOGY AREAS: Directed Energy Weapons, Materials, Processes and Structures, Modeling and Simulation

KEYWORDS: Free Electron Laser, Laser Damage, Anti-Ship Cruise Missiles

EFFECTIVENESS OF MODELING A HIGH POWER RADIO FREQUENCY (HPRF) WEAPON SYSTEM (U)

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The objective of this research was to model the electromagnetic output of a proposed High Power Radio Frequency (HPRF) weapon system. The antenna data was generated using GNEC, a method of moments computational electromagnetic code. The impulsive excitation and resultant transient near-fields were modeled using electrical circuit analysis and inverse Fast Fourier Transformation programmed in MATLAB 5.3. The peak amplitudes and waveforms were the primary focus of this study.

DoD KEY TECHNOLOGY AREAS: Electronic Warfare, Directed Energy Weapons, Modeling and Simulation

KEYWORDS: Electronic Warfare, Directed Energy Weapons, Antenna Design, Antenna Modeling, Electromagnetic Simulation

CONSTRUCTION AND TESTING OF A MODERN ACOUSTIC IMPEDANCE TUBE

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Second Reader: Thomas J. Hofler, Department of Physics

The acoustic impedance of a material describes its reflective and absorptive properties. Acoustic impedance may be measured in a wide variety of ways. This thesis describes the construction and testing of an acoustic impedance measurement tube which employs modern Fourier Transform techniques. Two methods are employed for acoustic impedance measurement using this apparatus. One technique uses a two-microphone continuous excitation method and the other uses a single microphone transient excitation method. Simple acoustic theory is used to derive equations for both methods. MATLAB computer programs are developed using these equations, to provide graphical results of acoustic impedance measurements over a frequency range for a given material, from raw data. A procedure is subsequently developed for using this apparatus to make acoustic impedance measurements. The performance of this device is evaluated by making measurements utilizing both methods on three sample materials and also with the end of the tube open to the atmosphere (referred to as an open tube measurement). The open tube measurements are compared with theoretical values. The results using both approaches compared favorably with the open tube theoretical values. Additionally both approaches agreed reasonably well with each other for the three sample materials. Performance at frequencies below 500 Hz, however, yielded deficient results, indicating a need for development of a filter for better accuracy.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Acoustic Impedance Measurement, Acoustic Impedance Tube, Reflection

ENERGETIC ELECTRON GENERATION BY FORWARD STIMULATED RAMAN SCATTERING USING 0.35 AND 0.53 MICRON LASER LIGHT IN A PLASMA

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This research investigates the use of high-powered lasers to produce 50-100 keV x-ray sources for applications for programs such as Stockpile Stewardship and nuclear weapons effects testing (NWET). To produce these x-ray sources requires irradiating targets with intense laser light to efficiently generate high-energy electrons. Stimulated Raman scattering (SRS) of intense laser light produces electron plasma waves, which in turn generate high-energy electrons. To make a high-energy x-ray source, the maximization of this laser-driven instability is desired. Using computer simulations, we show that forward SRS can grow by using a combination of frequency-tripled and a "seed" beam of frequency doubled laser light in a plasma of the appropriate density. Electron plasma waves with a high phase velocity are produced, which trap electrons and accelerate them to high energy. These energetic electrons will in turn generate high energy x-rays via collisions with nearby dense material. By adjusting the angle between the 0.35 μm and 0.53μm laser beams, the characteristic temperature of the heated electrons (and the x-rays) can be varied. We show one and two-dimensional simulations and illustrate the important role that laser-driven ion fluctuations play.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Other (Stockpile Stewardship Program, Nuclear Weapons Effect Testing)

KEYWORDS: Laser-Plasma Interactions, Stimulated Raman Scattering, Plasma Instabilities

SIMULATION OF AN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING BASED UNDERWATER COMMUNICATION SYSTEM USING A PHYSICS BASED MODEL FOR THE UNDERWATER ACOUSTIC SOUND CHANNEL

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The primary thrust of this thesis is the development of a computer-based simulation of an Orthogonal Frequency Division Multiplexing (OFDM) based underwater acoustic communication system. The product will support the testing and evaluation of various digital signal processing algorithms applicable to underwater acoustic communication systems using OFDM as well as the study of the effects of the acoustic channel and communication system factors on the key parameters of the system such as bit error rate, received signal to noise ratio, frequency band of employment and overall system bit rate. The underwater acoustic sound channel is modeled using a physics based parabolic equation approximation. The simulation models the key components in the transmitter and receiver that contribute to the overall performance of the system. The results of the thesis provide expected values for system performance in terms of bit rate, bit error rate and received SNR for given frequency bands and are validated through comparison to theoretically derived expectations and to ocean testing of OFDM underwater communication systems.

DoD KEYTECHNOLOGY AREAS: Other (Underwater Acoustics)

KEYWORDS: Orthogonal Frequency Division Multiplexing, OFDM, Underwater Acoustic Sound Channel

TERRAIN CATEGORIZATION USING MULTITEMPORAL SYNTHETIC APERATURE RADAR (SAR)

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Multitemporal synthetic aperture radar (SAR) imagery is exploited for the purpose of Terrain Categorization (TERCAT). This thesis explores using SAR data from National Technical Means (NTM) to construct detailed TERCAT maps. Two littoral military locations were imaged multiple times over a three-month period. These images were registered to each other and combined to form multi-band composite images. Unsupervised and supervised classification techniques were then used to construct TERCAT maps of the two littoral military locations. The unsupervised and supervised classification techniques used unique spectral elements in the multi-band composite images to assign each pixel in the composite images to a terrain class. The TERCAT maps were compared with ground truth measurements to determine the overall categorization accuracy with good results. The military utility of the TERCAT techniques and products was explored with an emphasis on the intelligence value.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Remote Sensing, Sensor Fusion, TERCAT

TARGETING AND FIRE CONTROL SYSTEM ANALYSIS OF THE NEW TURKISH ATTACK HELICOPTER "THE AH-1Z KINGCOBRA"

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Alfred W. Cooper, Department of Physics

In May of 1997, the Turkish Military issued a Request for Proposal for the purchase of 145 attack helicopters. Turkey has chosen Bell Helicopter's KingCobra as its attack helicopter. The major difference between the USMC version of AH-1Z and the Turkish version KingCobra is the Targeting and Fire Control System. Bell Helicopter Textron has chosen Lockheed Martin to develop and build a new targeting system, the Target Sight System (TSS). The TSS will contain Lockheed Martin's 3-5μm midwave staring array FLIR. On the other hand, the Turkish Secretariat for Defense Industries (SSM) has chosen Aselsan ASELFLIR-300T that contains an 8-12μm longwave scanning second-generation FLIR.

A comparison of range performance for these two systems has been made using the TAWS Field Performance Model. Since the physical parameters on these specific FLIRs are proprietary, the FLIR92 Simulation Mode is used to generate performance parameters. These parameters are expected to represent the general characteristics of the two systems. The resultant data is used in the TAWS Field Performance Model to predict the range performances.

The results have showed that the staring array midwave FLIR has longer ranges in the scenarios given in this thesis. This may not represent the real performance of the systems.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Sensors, Other (Thermal Imaging Systems)

KEYWORDS: Thermal Imaging Systems, Targeting, Fire Control Systems, Forward Looking Infrared, FLIR, TAWS, KingCobra, Attack Helicopter, Infrared

EXPERIMENTAL USE OF THE LAWRENCE LIVERMORE DEVELOPED MICRO-POWER SHORT PULSE RADAR TO EXTRACT LOW AMPLITUDE MODULATION SIGNALS CORRESPONDING TO HUMAN HEART RATES

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Detecting a living person buried in rubble or concealed in buildings has far reaching search and rescue as well as military applications. This thesis developed a filter from a catalog of close range impulse response signals that were acquired using Micro-power Short Pulse Radar developed at Lawrence Livermore National Laboratory.

Utilizing matched filtering techniques, low amplitude modulations signals corresponding to the human heart were extracted from return signals out to 40 feet. Human heart signals were extracted from return signals in air and through different materials. The matched filter output of the signal compared with the noise was then used to develop detection probabilities and performance characteristics based on range and material.

DoD KEY TECHNOLOGY AREA: Human-Systems Interface

KEYWORDS: Human Heart Signals, Human Heart Rates, Micro-Power Short Pulse Radar

EXPLOITATION OF NATIONAL SENSORS FOR TERRAIN CATEGORIZATION (U)

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Abstract is classified.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Sensors, Other (Intelligence, Indications and Warning (I&W))

KEYWORDS: Sensor Fusion, Multispectral Imaging, Imagery Intelligence, TERCAT

DETONABILITY OF HYDROCARBON/AIR MIXTURES USING COMBUSTION ENHANCING GEOMETRIES FOR PULSE DETONATION ENGINES

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This research studied combustion enhancing geometries and shock reflection on generating a hydrocarbon/air detonation wave in a combustion tube. Ethylene was used as a baseline fuel to determine the preferable geometries. Propane was then used in later testing because of its combustion similarities with heavy hydrocarbon fuels such JP5, JP8, and JP10. Three criteria were used to measure the effectiveness of the combustion enhancing geometries: ability to generate a detonation, wave speed, and time for shock formation. The evaluated geometries included flow-restricting orifice plates and a Schelkin spiral. The shock reflection was accomplished by a vertical fence (large orifice) placed in the last fourth of the tube length. The optimum geometry was found to be the orifice plate used in conjunction with the

spiral. Detonations occurred when using ethylene in this configuration, but did not develop when using propane. Because propane's overall reaction rate is slower than that of simpler fuels, more large- and small-scale turbulence to further enhance combustion needs to be generated to create a detonation wave in a short distance when using complex hydrocarbons, such as propane.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Detonation, Pulse Detonation Engine, Deflagration to Detonation Transition, DDT

ADVANCEMENTS IN BURIED MINE DETECTION USING SEISMIC SONAR

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Buried mines continue to disrupt the U.S. ability to project naval power ashore, conduct amphibious assaults, and wage land campaigns. This thesis describes advances in the development of a seismic sonar research tool that resulted in the successful detection of a Mk-63, 1000 lb, mine shape and a M-19, 20 lb, anti-tank mine. This seismic sonar research investigates the concept of using echo returns of a particular seismic interface wave, known as a Rayleigh wave, to detect buried mines. Rayleigh waves are unique in that they have elliptical particle motion that allows one to use vector polarization filtering to separate Rayleigh wave target reflections from other body waves with linear particle motion. A new source design employed in an array of seven elements has been shown to form a narrow beam of Rayleigh wave energy in a sand medium at the navy beach test site. This source beam, coupled with the receiver beam formed by an array of five three-component seismometers has provided a successful bi-static seismic sonar configuration. Signal to noise ratios of 21 dB for the Mk-63 mine shape, and 9 dB for the M-19 anti-tank mine were observed in the target echoes. These experimental results suggest that the seismic sonar is a very promising concept for buried mine detection.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: Mine Warfare, Buried Mine Detection, Seismic Sonar, Surface Waves

PSPICE MODELING AND PARAMETRIC STUDY OF MICROBOLOMETER THERMAL DETECTORS

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The operation of a bolometer thermal sensor is analogous to that of a charging capacitor in a generic RC circuit. As such, circuits containing bolometers can be analyzed with standard circuit simulation programs such as PSPICE. This thesis deals with the development of a bolometer model by using PSPICE with the aid of Analogue Behavior Modeling (ABM) capability, which allows the user to program circuit components with basic mathematical functions. The predictions of the model were found to be in good agreement with the reported data of an experiment previously conducted, which demonstrates the accuracy of the model. The model was used to design a self-heating compensated thermal sensor with enhanced signal integration capability to improve the signal-to-noise ratio. We believe the model can be used to analyze any circuit containing bolometers to optimize the performance.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Microbolometer, Bolometer, Thermal, Sensor, PSPICE, Computer Modeling, Thermal Imaging

EXPERIMENTAL STUDIES OF TWO-WAY SINGLE ELEMENT TIME-REVERSAL IN A NOISY WAVEGUIDE

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As the United States Navy considers operation closer to shore, it must account for the impact of shallow water ocean environments on the performance of active sonar. Multi-path propagation and high ambient noise in these areas pose a unique detection challenge for current sonar systems. A possible solution for this problem involves the use of processing that is actually enhanced by multi-path propagation, and can perform in the presence of in-band noise. Time-Reverse Acoustics (TRA) has been used with many transducer elements to focus acoustic energy in a very small region. Used as a single element active sonar, it can focus the return of an active pulse at the receiver location.

To test the performance of a TRA-based sonar in the presence of noise, ultrasonic signals were used in a laboratory waveguide, so that the scale of wavelength to water depth approximates a shallow channel with a flat, lossy bottom. Several sequences of a traditional sinusoidal pulse and the time-reversed reception were performed with varying noise levels. The gain in detection signal-to-noise ratio (SNR) was on average 7.3+0.8dB using TRA. Further, the TRA processing provided a noticeable detection when noise had completely obscured the reception of the initial pulse.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Time Reverse Acoustics, Active Sonar, Signal-to-Noise Ratio (SNR), Waveguide

APPLICATIONS OF LARGE AMPLITUDE BROADBAND ACOUSTIC NOISE TO ACOUSTOPHORESIS

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Theoretical results show that the drag on a resonant object can be modified by the presence of homogeneous, broadband acoustic noise, when the band overlaps the object's resonance width. While the results constitute an acoustic analog to the Einstein-Hopf drag on an oscillating dipole in the presence of electromagnetic fluctuations, an important difference is that band limited acoustic noise can reduce the drag when the lower frequency of the spectrum coincides with the resonant frequency of the resonator. Experimental evidence of the increased drag on a bubble is shown. Both increased and reduced drag on aerogel spheres configured as the bob of a parametrically driven pendulum are reported. Applications to separation processes, in particular a design that can be used for extraction of water in both fuel and lubrication oil systems and extraction of oil in bilge water, are suggested.

DoD KEY TECHNOLOGY AREAS: Other (Acoustics)

KEYWORDS: Acoustic Noise, Acoutophoresis

FEASIBILITY OF PARAMETRIC EXCITATION OF ACOUSTIC RESONATORS

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This thesis examines the feasibility of parametrically exciting a mode of an acoustic resonator. Such excitation may result in substantially larger amplitudes than by direct excitation, and would thus be useful in acoustic evices that require high-amplitude standing waves. Parametric excitation of a mode occur if the natural frequency is modulated at twice its value, and if the drive amplitude is above a threshold value due to dissipation. It is theoretically shown to be possible to excite the fundamental longitudinal mode of a pipe of any length filled with sulfur hexafluoride if the length is modulated with an Eletrovoice EVX-150A driver. For carbon dioxide, excitation is predicted to occur if the pope is longer than 1.2 meters. Also investigated is parametric excitation of the fundamental radial mode of a cylindrical cavity by modulating the height and thus the temperature. In this case, no driver was found to be capable of exceeding the threshold, regardless of the gas. Use of an electromagnetic wave source to modulate the temperature was also considered as a mans of parametriclly exciting the fundamental radial mode. Preliminary investigations show that sufficient heat conduction cannot occur over an acoustic cycle, indicating that this method is infeasible.

DoD KEY TECHNOLOGY AREA: Other (Acoustics)

KEYWORDS: Parametric Excitation, Acoustic Resonator, Acoustics

MODELING SECOND GENERATION FLIR SENSOR DETECTION RECOGNITION AND IDENTIFICATION RANGE WITH POLARIZATION FILTERING

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The influence of polarization filtering on maximum detection, recognition, and identification ranges of a generic second generation FLIR sensor is examined with a computational model. The scenario studied represents a second generation FLIR sensor mounted on an aircraft in level flight at 300m approaching a ship target. The target ship radiant signature is modeled with an advanced infrared signature prediction program, MuSES (Multi-Service Electro-Optic Signature). A weather file representative of Midlatitude Summer at sea conditions was utilized. Polarized sea background and path radiance calculations are performed with a polarized version of the SEARAD Radiance and Propagation Code. Results showed that there is an improvement in maximum range of the sensor for detection, recognition, and identification tasks when a horizontal filter is included, provided that the target does not have a negative degree of polarization. For detection task the improvements were found to be 33.48%, 35.65%, and 39.78% when the target has 0%, +2%, and +8% degree of polarization respectively. A better modeling of Apparent Temperature Difference (ATD) calculation is also developed. To improve the model use of polarized target model is recommended.

DoD KEY TECHNOLOGY AREAS: Sensors, Modeling and Simulation

KEYWORDS: Thermal Imaging Systems, Minimum Resolved Temperature Difference, Polarization Filters

APPLICATION OF THE ROBUST SYMMETRICAL NUMBER SYSTEM TO HIGH RESOLUTION DIRECTION FINDING INTERFEROMETRY

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This research has examined the benefits of using the Robust Symmetrical Number System (RSNS) to resolve ambiguities in phase sampling interferometry. A compact, high resolution direction finding antenna architecture based on the RSNS was developed to demonstrate experimentally the elimination of phase errors using a minimum amount of hardware. Previous work has determined that phase errors in the system will degrade the system performance. Several improvements were made to the original RSNS prototype antenna to provide enhanced performance. Adding isolators and supplementing the ground plane with copper tape (between the antenna elements), a reduction in the mutual coupling effects was accomplished. Mounting the microwave components on a brass plate also reduced errors contributed by vibrations and temperature. Tailor cutting all semi-rigid coaxial lines also helped reduce the number of connectors required to assemble the microwave circuit, also a source of phase errors. Matching the front-end amplifiers in each amplification stage rather than matching the characteristics of two cascaded amplifiers in each signal line has reduced relative phase errors between channels as well as matching the power outputs of the amplifiers. Two printed circuit boards were designed and built for the RSNS signal processor. The printed circuit boards provide a decrease in the electrical noise floor over the original design (assembled on breadboards). The new design has reduced the phase errors that were present in the first prototype system. The RSNS signal processing technique is able to provide a high-resolution phase sampled direction finding capability with an angular resolution of 1.9 degrees by using only three receiving elements (two interferometers).

DoD KEY TECHNOLOGY AREAS: Sensors, Electronic Warfare

KEYWORDS: Robust Symmetrical Number Systems, Optimum Symmetrical Number Systems, Phase Sampling Interferometry, Direction Finding, Ambiguity Resolution

NETWORK DEFENSE-IN-DEPTH: EVALUATING HOST-BASED INTRUSION DETECTION SYSTEMS

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As networks grow, their vulnerability to attack increases. DoD networks represent a rich target for a variety of attackers. The number and sophistication of attacks continue to increase as more vulnerabilities and the tools to exploit them become available over the Internet. The challenge for system administrators is to secure systems against penetration and exploitation while maintaining connectivity and monitoring and reporting intrusion attempts.

Traditional intrusion detection (ID) systems can take either a network or a host-based approach to preventing attacks. Many networks employ network-based ID systems. A more secure network will employ both techniques. This thesis will analyze the benefits of installing host-based ID systems, especially on the critical servers (mail, web, DNS) that lie outside the protection of the network ID system/Firewall. These servers require a layer of protection to ensure the security of the entire network and reduce the risk or attack.

Three host-based ID systems will be tested and evaluated to demonstrate their benefits on Windows 2000 Server. The proposed added security of host-based ID systems will establish defense-in-depth and work in conjunction with the network-based ID system to provide a complete security umbrella for the entire network.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Network Security, System Security, Intrusion Detection, Intrusion Detection System, Defense-in-depth