MASTER OF SCIENCE
IN
APPLIED PHYSICS

HIGH POWER RADAR EFFECTS ON ANTI-SHIP MISSILES

Jeffrey A. Bennett, II-Lieutenant, United States Navy
B.S., United States Naval Academy, 1992
Master of Science in Applied Physics-December 1998
Advisors: James R. Powell, Information Warfare Academic Group
Donald Walters, Department of Physics

This report documents the susceptibilities of anti-ship missiles to high power radio frequency (RF) effects. An analytical approach to anti-ship missile vulnerabilities is developed, followed by the results of three U.S. Navy Electronic Warfare (EW) tests with fleet units.

DoD KEY TECHNOLOGY AREAS: Electronic Warfare, Directed Energy Weapons

KEYWORDS: AAW, EA, EW, HPM

FIBER LATTICE ACCUMULATOR DESIGN CONSIDERATIONS FOR OPTICAL ΣΔ DIGITAL ANTENNAS

Scott A. Bewley-Lieutenant, United States Navy
B.S., University of North Carolina State, 1991
Master of Science in Applied Physics-December 1998
Advisor: Phillip E. Pace, Department of Electrical and Computer Engineering
Second Reader: James H. Luscombe, Department of Physics

The ability to directly oversample and digitize microwave range signals at an antenna is not possible with current electronic technologies. The objective for this thesis was to design and computer model an optical sampling and digitization process using a mode-locked laser and fiber lattice accumulators. A novel fiber lattice accumulator design for integrated optical sigma-delta (ΣΔ) digital antenna technology is presented. The fiber lattice design uses phase modulation to produce the proper interference between input and recirculated/delayed optical pulses in order that they may coherently combine. In this manner, accumulation within the fiber lattice takes into account the sign of a sampled bipolar antenna signal. The fiber lattice performance is numerically evaluated within a first-order optical ΣΔ digital antenna phase coherent simulation. The initial computer simulations show promising results using lower frequency antenna signals to verify optical design feasibility and operation. Optical results closely matched all-electronic simulations. The error between the input antenna and output signals is quantified, and proves correct device performance. All results show the first-order optical ΣΔ does work and is ready for experimental construction. The significance of this device will be its usefulness in extending high resolution ΣΔ analog-to-digital conversion into the microwave signal bands.

DoD KEY TECHNOLOGY AREA: Other (Optical Analog-to-Digital Conversion of Microwave Signals)

KEYWORDS: ADC, Fiber Lattice Structures, Sigma-Delta, Directional Coupler, Oversampling, Optical ADC, Phase Coherent Modeling

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BOOST PHASE TRACKING AND TRAJECTORY BACK FITTING TECHNIQUES AGAINST THEATER BALLISTIC MISSILES

Patrick T. Britt-Lieutenant, United States Navy
B.S., United States Naval Academy, 1992
Master of Science in Applied Physics-December 1998
Advisor: Robert G. Hutchins, Department of Electrical and Computer Engineering
Second Reader: William B. Colson, Department of Physics

The continued proliferation of Weapons of Mass Destruction and ballistic missile technology pose one of the greatest threats to United States military forces today. Further complicating the mission of Theater Ballistic Missile Defense (TBMD) is the ability of each missile to carry multiple warheads or submunitions. This thesis focuses on using AEGIS ship parameters, applied to an Extended Kalman Filter (EKF), to verify accurate Boost Phase Tracking of theater ballistic missiles. A smoothing algorithm is then incorporated to further reduce the measurement error by 50 percent. The final area studied applies a Kalman back fit technique that, used in conjunction with the EKF and smoothing algorithms, can improve on current back fit to launch point origin calculations by a factor of two. These results allow AEGIS ships operating in littoral regions to be able to conduct Boost Phase Intercept (BPI), destroying a missile's entire payload with a single shot, in addition to providing rapid and accurate localization of enemy mobile and hidden missile launchers for targeting.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Kalman Filter, Smoothing, TBMD, Back Fit, Launch Point

SOURCE DEVELOPMENT FOR A SEISMO-ACOUSTIC SONAR

Sean M. Fitzpatrick-Lieutenant, United States Navy
B.A., University of California at Berkeley, 1990
Master of Science in Applied Physics-December 1998
Master of Science in Mechanical Engineering-December 1998
Advisors: Thomas G. Muir, Chair of Mine Warfare
Steven R. Baker, Department of Physics
Anthony J. Healey, Department of Mechanical Engineering

Buried mines in the beach and surf zone hinder Naval power projection beach assault operations and endanger humans. In this research, it is demonstrated that seismic interface waves on the surface of a natural beach can be used to detect buried, mine-like objects. A seismic sonar system, employing guided interface waves known as Rayleigh or Scholte waves has been proposed for detecting shallow, buried ordnance and is the subject of an ongoing, ONR-sponsored research program at the Naval Postgraduate School. The primary purpose of this research was to develop an improved seismic source to evaluate further the concept of using a seismo-acoustic sonar to detect buried ordnance in the beach and surf zone. The developed source was based upon a linear magnetic force actuator. Additionally, testing procedures were developed for follow-on research. Seismic interface waves were generated with two, 25-lb force-controlled linear actuators operated as shakers. The waves were measured with a two-element horizontal array of three axis seismometers. Buried, mine-like objects, ranging from 71kg to 290kg, and at ranges of up to 5 meters were echo-located by visual examination of the raw, recorded seismic signal, and by the use of polarization filtering signal processing.

DoD KEY TECHNOLOGY AREA: Other (Mine Warfare and Mine Countermeasures)

KEYWORDS: Mine Warfare, Mine Detection, Buried Ordnance Detection, Seismo-Acoustic Sonar, Seismic Surface Waves, Rayleigh Waves, Scholte Waves

PERFORMANCE ANALYSIS OF IRTOOL RAY REFRACTION PROGRAM AND COMPARISON TO LWKD AND PIRAM MARINE BOUNDARY LAYER PROGRAMS

Antonios Georgopoulos-Lieutenant Junior Grade, Hellenic Navy
B.S., Hellenic Naval Academy, 1990
Master of Science in Applied Physics-December 1998
Advisors: Alfred W. Cooper, Department of Physics
David D. Cleary, Department of Physics

The prediction of mirage conditions by the IRTOOL engagement simulation program has been evaluated by comparison with experimental visible and infrared observations extracted from the MAPTIP experiment data base. IRTOOL predictions have also been compared with the LWKD and PIRAM Boundary Layer programs for identical input conditions. For sensors located above about 20 meters the values of Minimum Mirage Range and Maximum Inter-Vision Range become inconsistent and all models show similar mirage threshold performance offset internally and from the measurements by approximately 1-3 km (5-20%). This may be related to uncertainties in the temperature profiles generated from Boundary Layer models. Variations of 2-4° C in Air Sea Temperature are insufficient to account for the observed deviations.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Other (Infrared Sensors)

KEYWORDS: Refraction, Marine Boundary Layer, Temperature Profile, Mirage

AMPLITUDE MODULATION USING A NONLINEAR OPTICAL LOOP MIRROR

David S. Grennek-Lieutenant, United States Navy
B.S., United States Naval Academy, 1989
Master of Science in Applied Physics-December 1998
Advisors: Andrés Larraza, Department of Physics
H. Sarma Lakkaraju, Department of Physics, San Jose State University

The nonlinear optical loop mirror (NOLM) configuration has been studied extensively within the context of pulsed and/or quasi-CW laser sources. As such, the NOLM holds great promise in the areas of soliton switching, pulse compression and high data rate communications. However, comparatively little research has been done with CW sources. In this investigation, the theoretical properties of the NOLM are explored experimentally with the aid of a CW Nd:YAG laser operating in the infrared region. Specifically, the nonlinear effects of self-phase modulation are characterized. For a beam of sufficient intensity, its optical path through the fiber may be altered due to the dependence of the phase on intensity. Thus, two coherent beams of light of differing intensity can be made to interfere constructively or destructively even though the physical paths are identical. In the NOLM configuration, the potential result is an amplitude modulated output beam exhibiting a repetition rate several orders of magnitude greater than that of the input. Two dissimilar single-mode fibers as well as two custom-built fixed-ratio asymmetric fiberoptic couplers are utilized in the experiment. Correlation with theory is emphasized and follow-on projects are discussed.

DoD KEY TECHNOLOGY AREAS: Command, Control, and Communications, Sensors

KEYWORDS: Fiberoptics, Nd:YAG Laser, Nonlinear Index of Refraction, Self-phase Modulation

DETECTION AND TARGET-STRENGTH MEASUREMENTS OF BURIED OBJECTS USING A SEISMO-ACOUSTIC SONAR

Patrick W. Hall-Major, United States Marine Corps
B.S., United States Naval Academy, 1986
Master of Science in Applied Physics-December 1998
Advisors: Thomas G. Muir, Chair of Mine Warfare
Steven R. Baker, Department of Physics

This thesis describes the results of field experiments in which seismo-acoustic interface (Rayleigh) waves were employed to detect and measure the target strength of mine-like test objects buried in the near-surf zone. These experiments were conducted as part of an ongoing NPS research program to develop a seismo-acoustic sonar system for the detection of buried mines in the surf and near-surf zones. An experimental seismo-acoustic sonar system, using linear force actuators as the wave source and three-axis seismometers as receivers, was deployed at a beach test site. The target strengths of two mine-like test objects, a compressed gas cylinder and a gunpowder can, were measured as a function of target mass and for various emplacement conditions, e.g., very wet sand, not very wet sand, partially buried, completely buried, completely buried and washed over for several days. Vector polarization filtering was employed to separate the reflected signal due to Rayleigh waves, for which the particle motion is elliptical, from that of body (P and S) waves, for which the particle motion is linear. The target strength was generally found to increase with increasing target mass. Typical values observed ranged from approximately –20 dB to -10 dB for target masses of 70 to 290 kg. Curiously, it was observed that the elliptical particle motion of the reflected wave was of the opposite polarity for those targets which were buried, but slightly exposed, compared to those which were completely buried. It is not known at this time whether this is due to the depth-dependent properties of Rayleigh waves, or whether it is a result of the conditions of source and target emplacement.

DoD DEY TECHNOLOGY AREA: Other (Mine Warfare and Mine Countermeasures)

KEYWORDS: Seismo-Acoustic Sonar, Seismic Surface Waves, Rayleigh Waves, Scholte Waves, Buried Ordnance Detection, Mine Detection

THE FEASIBILITY OF AN EXPLOSIVE HIGH-POWER MICROWAVE (HPM) COMBINED EFFECTS WARHEAD IN FLEET AIR DEFENSE (U)

Demetrius J. Haynie-Lieutenant, United States Navy
B.S., United States Naval Academy, 1991
Master of Science in Applied Physics-December 1998
Advisor: James R. Powell, Information Warfare Academic Group
Second Reader: Xavier K. Maruyama, Department of Physics

Recent advances in high-power microwaves (HPM) create possibilities for warfare applications and concepts previously considered only in the realm of science fiction. HPM weapon design is in the early stages in transition to fleet and battlefield employment. Advances in radiofrequency (RF) sources, prime power, pulsed power and antenna design of HPM systems and weapons developments are proceeding. One area of interest is in the use of high-power microwaves in tactical missile systems.

Conventional high explosive (HE) warhead missiles provide mission kill in most but not all engagement scenarios in current fleet defense. Aerodynamic corrections made by an anti-ship missile's electronic guidance subsystem may endure current conventional defenses, requiring modern approaches to attacking the electronics, causing "soft-kill", and mission kill. An explosively-driven HPM warhead may enhance air defense mission kill percentages across the spectrum of engagement scenarios by impeding or destroying electronic components in those missiles at longer ranges than possible by current HE warheads through blast and fragmentation effects alone.

This thesis will present the results of a feasibility study and conceptual design of an explosively-driven high-power microwave warhead incorporated into an existing fleet surface-to-air missile to show the advantage of an HPM combined effects radiofrequency (CERF) warhead in anti-ship missile defense (ASMD) over conventional blast-fragmentation warheads. The purpose of this study is to determine whether the technology exists today for such a weapon that can be incorporated 'form-fit-function' into an existing missile, and whether advances in this technology support development of this concept now.

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DoD KEY TECHNOLOGY AREAS: Conventional Weapons, Directed Energy Weapons

KEYWORDS: High-Power Microwaves (HPM), STANDARD Missile, Combined Effects Radiofrequency (CERF) Warhead, Anti-Ship Cruise Missile (ASCM)

ANTI-SHIP MISSILE DEFENSE AND THE FREE ELECTRON LASER (FEL)

Paul A. Herbert-Lieutenant, United States Navy
B.S., United States Naval Academy, 1989
Master of Science in Applied Physics-December 1998
Advisor: William B. Colson, Department of Physics
Second Reader: Robert L. Armstead, Department of Physics

In order to improve ship self-defense against sea-skimming missiles, several concepts, such as the free electron laser, high-power microwaves, and the Phalanx gun system are reviewed and evaluated in this thesis. Phalanx computer simulations show that Phalanx is an inadequate means of protection. High-power microwaves are found to damage electronics, but calculations show limitations due to diffraction and the possibility of shielding. This thesis evaluates several damage mechanisms caused by the free electron laser's ultra-short picosecond pulse. Theories and experiments predicting the laser damage from short picosecond pulses are reviewed and applied to the FEL weapon design. It is found that there may be a significant advantage to the ultra-short pulse format of an FEL weapon; as a result, new experiments are planned. As microwave FELs are not yet a reality, this thesis uses computer simulations to explore FEL operation for many values of the electron pulse length, peak current and cavity desynchronism in order to explain recent Thomas Jefferson National Accelerator Facility (TJNAF) experimental observations of high average power.

DoD KEY TECHNOLOGY AREA: Directed Energy Weapons

KEYWORDS: Free Electron Laser, Directed Energy Weapons

IMPROVED LASER VIBRATION RADAR

Pierre Hilaire-Lieutenant, United States Navy
B.A., Old Dominion University, 1992
Master of Science in Applied Physics-December 1998
Advisors: Robert C. Harney, Department of Physics
Donald L. Walters, Department of Physics

The Naval Postgraduate School's Physics Department is investigating the feasibility of identifying ground combat vehicles by measuring their frequency of vibrations. This thesis reconfigured an existing CO_2 laboratory laser radar system that is capable of measuring the frequencies of vibration of a simulated target into a more compact and rugged form for field testing. The optical performance of the laboratory laser radar system was also improved with a combination half-wave plate, brewster-angle plate, and quarter-wave plate. The new device was tested under laboratory conditions using a target with known frequencies of vibration and a target with a more complex frequency spectrum. Both tests involved illuminating the targets with the laser beam. The first target was a retro-reflector driven by a piezoelectric actuator vibrating at selectable known frequencies (typically 400 Hz). The second target was a 9-volt DC motor supplied with 10 volts and 13 volts respectively in order to vary its speed. The laser radar proved capable of detecting the first target's frequencies of vibrations and the more complex frequency spectrum of the DC motor.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Laser Radar, Half-Wave Plate, Brewster-Angle Plate, Quarter-Wave Plate, Acousto-Optic Modulator

INDUSTRIAL CHEMICALS AND PESTICIDES AS POTENTIAL TERRORIST WEAPONS

Mark A. Leary-Lieutenant, United States Navy
B.S., University of Washington, 1991
Master of Science in Applied Physics-December 1998
Advisor: Robert C. Harney, Department of Physics
Second Reader: Gordon E. Schacher, Department of Physics

Many commonly available chemical compounds possess a toxicity comparable to that of military chemical weapons agents, and these could potentially be used as terrorist weapons. This thesis uses a computer simulation to predict the effects of selected compounds when used in conjunction with a commercially available pesticide sprayer. Nineteen industrial chemicals and 10 pesticides were selected, along with a known military chemical warfare agent for comparison. A typical 300 gallon spray rig, including a pump and nozzle system capable of producing droplets of less than 30 microns average diameter at 30 GPM, was selected. All components are available for purchase on the open market. These values were fixed throughout all simulations, as were weather and terrain conditions. With the physical properties of the substances themselves being the only significantly varying quantities, comparison among the various substances was possible. Cumulative exposure at ground level was plotted for each substance, and each case was evaluated in terms of the known lethality of that substance. Of the 29 compounds, 8 of them were expected to result in fatalities when employed in this manner. Although the casualty rate is low, the availability of these compounds might make this an option for terrorists.

DoD KEY TECHNOLOGY AREA: Chemical and Biological Defense

KEYWORDS: Industrial Chemicals, Pesticides

SINGLE-EVENT ANALYSIS OF AlInAs/GaInAs/InP HETEROJUNCTION BIPOLAR TRANSISTORS

Todd A. Mayfield-Lieutenant, United States Navy
B.S., United States Naval Academy, 1990
Master of Science in Applied Physics-December 1998
Advisors: Todd R. Weatherford, Department of Electrical and Computer Engineering
James H. Luscombe, Department of Physics

Indium phosphide based heterojunction bipolar transistor (HBT) technology is progressing toward many areas of utility. However, there is uncertainty as to how single-event effects (SEEs) will effect this device. SEEs have a primary effect on technologies fulfilling space-based performance requirements where these phenomenon are most prevalent. The objectives of this thesis were to use the Silvaco Virtual Wafer Fabrication software to form a two-dimensional model of the Hughes AlInAs/GaInAs (HBT) grown on an InP substrate utilizing. This software can be used to design and simulate electrical properties of transistors at the submicron level. Once an adequate model was prepared, further simulations were conducted to discover the sensitivity of the device to a single event effect and the location of charge collection. The purpose of the simulations was to determine where the sensitive region of the transistor lies. Modification of the original device was required in order to simulate it with the Silvaco software. Simulation results for the modified device found that not only were the junctions critical, but charge collection in and near the sub-collector and substrate were important as well.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Manufacturing Science and Technology, Electronics

KEYWORDS: Heterojunction Bipolar Transistor, Single-Event Upsets, Indium Phosphide, Aluminum Indium Arsenide, Gallium Indium Arsenide

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TARGET DETECTION AND CLASSIFICATION AT KERNEL BLITZ 1997 USING SPECTRAL IMAGERY

Jeffrey D. Sanders-Lieutenant, United States Navy
B.S., University of Nevada, Reno, 1990
Master of Science in Applied Physics-December 1998
Advisor: Richard C. Olsen, Department of Physics
Second Reader: David Cleary, Department of Physics

Data collected from the Hyperspectral Digital Imagery Collection Experiment (HYDICE) were analyzed in this thesis to determine the feasibility of wide area detection and classification of target materials in the visible to short wave infrared region. This study used detection algorithms such as spectral angle mapper and matched filter for target detection. Parallelepiped and Maximum Likelihood routines were used to classify the image data for subsequent analyses and comparisons. Effects on data due to altitude variation of the sensor were analyzed using histograms, differencing, and principal component transforms. Data images of the Camp Pendleton airfield used for comparison analyses were obtained from two different altitudes, 5,000 feet and 10,000 feet. Results showed target detection and classification had no strong dependence on altitude.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Remote Sensing, Hyperspectral, Imagery, Target Detection, Classification, HYDICE, Littoral Radiance II, Kernel Blitz ‘97, Camp Pendleton