MASTER OF SCIENCE
IN
APPLIED PHYSICS

GENETIC ALGORITHMS AS A TOOL FOR PHASED ARRAY RADAR DESIGN

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The United States Navy needs creative ways to design multi-function phased array radars. This thesis proposes that Genetic Algorithms, computer programs that mimic natural selection to arrive at innovative solutions to complex problems, would be particularly well suited to this task. The ability of a Genetic Algorithm to properly predict the behavior of an array antenna with randomly located elements was examined with encouraging results through the construction and measurement of a test array. Comparison of test data to Genetic Algorithm and Method of Moments calculations showed significant qualitative agreement in the antenna test patterns of a thin, randomly distributed array. Areas of disagreement between the test article pattern and the calculated ones were traced to systematic errors in the anechoic chamber and alignment error during antenna positioning. The final experiment to demonstrate beam steering was not completed due to lack of time and poor response of mechanical phase shifters. Despite the inability to demonstrate beam steering, the early experiments demonstrate the significant potential for using Genetic Algorithms for complex shipboard phased array radar antenna design.

KEYWORDS: Phased Array, Antenna, Radar, Radar Design, Air Search Radar, Evolutionary Computation, Genetic Programming, Genetic Algorithms, Theater Ballistic Missile Defense (TBMD), Area Air Defense, Fleet Air Defense (FAD).

RAIL EROSION AND PROJECTILE DIAGNOSTICS FOR AN ELECTRO-MAGNETIC GUN

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Rail guns will not be introduced to the Navy until there is a means of limiting rail erosion. Erosion occurs when a sliding contact loses electrical contact with the rails. Research for this thesis was centered on combating the rail erosion problem and developing a way to record the voltage drop across the rails of the Naval Post Graduate School's 4-inch Electro-Magnetic Gun. A laser was also added to the rail gun so that the projectile's velocity could be recorded as it exits the gun's barrel. Silver paste was used to coat the grooved rails, thereby establishing a strong electrical contact between the rails and projectile. Results indicate that silver paste limits erosion inflicted on both the rails and projectile, by increasing the electrical contact at the rail-projectile interface. Consistent measurements of the projectile's velocity were also obtained.

KEYWORDS: Rail Gun, Railgun, Sliding Contact, Electrical Contact, Conductive Interface, Silver Paste, Rail Erosion, Projectile Diagnostics

SCENE CLASSIFICATION USING HIGH SPATIAL RESOLUTION MULTISPECTRAL DATA

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Spectral imagery has traditionally been an important tool for terrain categorization (TERCAT). High-spatial resolution (8-meter), 4-color MSI data from IKONOS provide a new tool for scene classification. The utility of these data are studied for the purpose of classifying the Elkhorn Slough and surrounding wetlands in central California. The specific goal was to determine to what degree an existing classification map could be replicated using the 4-color imagery. The existing map was used as an input to a supervised classification process. Errors in that map required development of revised exemplar spectra sets, eliminating mixed classes. Classification was done using a spectral angle mapper and maximum likelihood classifier. Results were compared to the original classification map. Confusion matrix calculations showed agreement at the 10-20% level. This lack of agreement is attributed to errors in the original map at the relatively high resolution of IKONOS.

KEYWORDS: Remote Sensing, Multispectral, Ikonos, Landsat 7, High Resolution, Scene Classification

TEMPERATURE DEPENDENCE OF DARK CURRENT IN QUANTUM WELL INFRARED DETECTORS

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In this thesis, the I-V characteristics of a bound-to-continuum QWIP device with $Al_{0.37}Ga_{0.63}As$ barriers of 23 nm, $In_{0.1}Ga_{0.9}As$ wells of 3.6 nm, and a doping density (n_d) of 10^{18} cm^{-3} were gathered and analyzed for various temperatures. The device was cooled using a closed cycle refrigerator and the data was acquired using the Agilent 4155B Semiconductor Parameter Analyzer. Dark current in the device was qualitatively explained, then further examined using a thermionic emission model. With this model and an iterative Matlab program we were able to establish the energy levels within the well. In addition, the dark current limited detectivity (D^*) of the device was determined as a function of the temperature in the 10–170 K range. It was found that the D^* degrades beyond 80 K due to excess thermionic emission from the quantum well.

The details of the laboratory setup and test system and process are included with the intent to provide future students with simple and comprehensive procedural insight.

KEYWORDS: Quantum Well Infrared Photodetector, Temperature Dependence, Dark Current, Thermionic Emission, Detectivity.

DESIGN OF A VOLTAGE TUNABLE QUANTUM WELL INFRARED DETECTOR

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The purpose of this thesis is to design a quantum well infrared detector with tunable spectral bandwidth. The tunability of the bandwidth is achieved by using the linear Stark effect for the ground to first excited

state transition in an asymmetric quantum well. The position of the absorption peak is dependent on the direction of the electric field, and therefore it can be either blue or red shifted by changing the direction of the field. If two identical asymmetric quantum wells are arranged opposite each other, we can obtain both the blue and red shift for either direction of the bias. This method can produce broader peaks with tunable bandwidths proportional to the applied field.

A program was developed to calculate the energy levels and wavefunctions of an arbitrary quantum well. The program was used to design a step quantum well capable of detecting infrared in the 8-12 *mm* band. The validity of the approach was verified by comparison with experimental data and found to have a good agreement. The designed step well was used to create a tunable bandwidth detector. The analysis showed that the bandwidth could be tuned to more than twice the peak width. The numerical simulation indicates the possibility of manufacturing a tunable bandwidth infrared detector by using step quantum wells.

KEYWORDS: Voltage Tunable, Broadband, Quantum Well Infrared Photodetector, “Staircase” Method, Transfer Matrix

TWO-COLOR PHOTODETECTOR USING AN ASYMMETRIC QUANTUM WELL STRUCTURE

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The past twenty years have seen an explosion in the realm of infrared detection technology fueled by improvements in III-V semiconductor technology and by new semiconductor growth methods. One of the fastest growing areas of this research involves the use of bandgap engineering in order to create artificial quantum wells for use in Quantum Well Infrared Photodetectors (QWIPs). QWIPs have an advantage over other infrared detectors such as Mercury Cadmium Telluride (MCT) because they have larger bandgaps and are therefore stronger and cheaper to manufacture. This thesis introduces one method of “multi-color” detection through the use of an asymmetric quantum well structure in which all energy transitions are possible. The QWIP structure in this thesis was designed to detect a laser wavelength of 1.06 μm and a wavelength in the 8-10 μm atmospheric window.

The relevance of a detector that is tuned to these wavelengths is that it can be used on military aircraft as a laser spot tracker and an infrared imager providing much greater accuracy and dependability than older systems.

KEYWORDS: Quantum Well, QWIP, Two-color Detection, Infrared Imager, Laser Spot Tracker, Transfer Matrix Method, Airy Functions

TRANSMITTING BEAM PATTERNS OF THE ATLANTIC BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*): INVESTIGATIONS IN THE EXISTENCE AND USE OF HIGH FREQUENCY COMPONENTS FOUND IN ECHOLOCATION SIGNALS

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In January 2002, time synchronized underwater pictures and echolocation signals of a free-swimming bottlenose dolphin were recorded. More than 80 experimental trial runs were recorded at the Space and Naval Warfare Center’s Marine Mammal Facility in San Diego, California. The apparatus recorded 30 underwater images per second and sonar signals up to 400 kHz. Data analysis shows wide transmitting beam patterns at frequencies lower than 135 kHz contain a majority of the energy in the echolocation signal, agreeing with previously documented work. However, further analysis shows significant energy at higher frequencies. Early in the experiment, the dolphin steered narrow high frequency signals and adjusted the energy content in those different frequencies while scanning the target. To emit these high frequency components, the dolphin changed the wave shape of the emitted sound pulse. As the experiment progressed, the animal's task became routine and the high frequency signals were noticeably absent until low frequency noise was projected into the water, at which time the high frequencies were again present in the emitted sound pulses. Resultant transmitting beam patterns provide excellent evidence of the presence of high frequency sound emissions, and also indicate how these signals are used during echolocation tasks.

KEYWORDS: Biosonar, *Tursiops Truncatus*, Bottlenose Dolphin, Mine Detection

ATMOSPHERIC TURBULENCE COMPARISON USING MM5 AND COAMPS MESOSCALE MODELS

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Modeling atmospheric optical turbulence is critical to the use of high energy lasers in military applications. The MM5 Version 3.3 and COAMPS version 2.0.15 mesoscale numerical models were evaluated using the Tjernström (COAMPS and MM5) and Deardorff (COAMPS) turbulence algorithms. The model predicted C_n^2 profiles were compared against thermosonde launch data that were collected from 18 through 25 October 2001 at Vandenberg Air Force Base by the Air Force Research Laboratories (AFRL). Preliminary results indicated that the initial thermosonde profiles were an order of magnitude below previously received data. Following NPS recommendations, the AFRL investigated and found a calibration error and developed a recalibration procedure that permitted a meaningful comparison for the balloon data. At low altitudes (0-5 km) MM5 and COAMPS were comparable, with the first kilometer being the most difficult for the models to predict accurately. In the upper-levels (0-20 km) COAMPS provided reasonable results at 3 and 6-hour forecast times, but became inconsistent at longer time intervals. MM5 and COAMPS results were similar when configured with the same input data fields, and horizontal and vertical resolution. Both models had difficulty predicting accurate turbulence above 12 km, which likely represents problems in the turbulence algorithm.

KEYWORDS: Optical Turbulence, Atmospheric Turbulence, Tjernström, Deardorff, COAMPS, MM5, Forecasting, Thermosonde, Mesoscale

PERFORMANCE MEASUREMENTS OF A MINI THERMOACOUSTIC REFRIGERATOR AND ASSOCIATED DRIVERS

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A miniature Thermoacoustic refrigerator is being developed to cool integrated circuits – which must sometimes operate at high temperatures nearing the upper threshold of their tolerance – to temperature spans more within the circuits' tolerable limits, without the need of the chemicals of a traditional refrigerating system. The development of an electrically powered acoustic driver that powers the thermoacoustic refrigerator is described, as well as different schemes to improve its delivered acoustic power. 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. Two different drivers are tested on a pressurized test resonator, and their quantitative performance is analyzed. The analysis of the drivers' performance indicates one power-improvement scheme may be faulty, while data taken before the second broke indicates its design may be beneficial to power-improvement. Tests are also conducted using a refrigerating resonator; these first attempts to meet design criteria of temperature span and cooling power are unsuccessful, but the results obtained – including a thermodynamic coefficient of performance (COP) 13.1% below the modeled ideal value for the given data set – with less-than-ideal acoustic power delivered to the resonator signal suggest continued research is worthwhile.

KEYWORDS: Thermoacoustic Refrigerator, TAR, Thermo-Acoustic Refrigerator Driver, Microchip Cooling

ION DENSITY FLUCTUATIONS IN PLASMA AND THEIR EFFECTS ON HOT ELECTRON GENERATION

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In this thesis, high-energy electron generation by stimulated Raman scattering of intense laser light is investigated in computer simulations. These high-energy electrons can be used to produce a high-energy x-ray source for Nuclear Weapons Effects Testing. The simulation results are compared with actual experiments conducted at the Atomic Weapons Establishment in the United Kingdom. The simulations show that the heated electron temperature is significantly lowered and the frequency spectrum of the scattered light is broadened by strong ion density fluctuations in the plasma. These density fluctuations are produced when the Raman scattered light undergoes Brillouin backscattering. Interactive Data Language is also used to analyze the spectrum of Raman scattered light in some recent experiments with the OMEGA laser at the University of Rochester.

KEYWORDS: Laser-plasma Interactions, Stimulated Raman Scattering, Plasma Instabilities, Ion Density Fluctuations

NONLINEAR OSCILLATION OF A TRIATOMIC MOLECULE

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Due to nonlinearity in the coupling, one of the vibrational modes of a straight symmetric triatomic molecule can be unstable for amplitudes greater than a threshold value. The instability is due to the mode parametrically exciting another mode. The threshold amplitude decreases if the difference of the frequency of the two modes is reduced. We consider the simplest case of a symmetric rectilinear molecule where the coupling has a cubic nonlinearity in addition to a linear restoring force. Approximate analytical results are in good agreement with numerical simulations of the exact equations of motion, although in some cases the actual behavior fundamentally deviates from the perturbative theory. Two physical demonstrations of the instability are described, where the apparatus are a system of gliders coupled by springs and magnets on an air track. Possible quantum mechanical implications are discussed. This work is a fundamental generalization of the parametric instability of two linearly coupled nonlinear oscillators that was reported in a previous investigation.

KEYWORDS: Parametric Excitation, Nonlinear Oscillations, Symmetric Rectilinear Triatomic Molecule, Nonlinear Coupling, Triatomic Molecule.