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13. ABSTRACT (Maximum 200 words)  The principal objective of this project is to investigate problems associated with achieving the drive/read-out system complexity necessary to control a phased array antenna with optical heterodyne techniques. In particular, this work has concentrated on multi-channel microwave optical conversion. The approach has been to study the problems associated with device arrays of single sideband modulators that would be necessary to control the amplitudes and phases of all signals delivered to a phased array front end. The incorporation of our available in-house developed tools into that of already existing tools (such as MDS-Microwave Design Software) has been undertaken to design a single sideband modulator (SSBM). It was found that MESFET oscillators and the associated control lasers can be modeled by simply changing a constant in the model to give their characteristics with and with out optical injection. This is useful for injection locking of active antens for accurate and efficient phased array antenna design.				
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# FINAL PROGRESS REPORT

for Office of Naval Research  
for the period August 1992 through January 1995

## 1. **Contract Title:**

An Investigation of the Channel Crosstalk in Optical Heterodyne Controlled Phased Array Radars

## **Principal Investigator:**

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## 2. **Technical Objectives:**

The principal objective of this project is to investigate problems associated with achieving the drive/read-out system complexity necessary to control a phased array antenna with optical heterodyne techniques. In particular, this work concentrated on multi-channel microwave optical conversion.

## 3. **Approach:**

The approach has been to study the problems associated with device arrays of single sideband modulators that would be necessary to control the amplitudes and phases of all signals delivered to a phased array front end. Our approach has also focused on increasing the complexity of control by modulating only a small number of optical channels which can then be locked to a previously locked active antenna array. This approach has enabled a better understanding of the accuracy and validity of our computer aided analysis and also has allowed a greater range of device complexity to be analyzed.

## 4. **Accomplishments:**

The development of "ZOOM," a computer-aided electromagnetic analysis technique, was extended to allow analysis of more complicated electrode geometries. A greens function for electrodes on multiple dielectric layers was derived and incorporated into the program. This allows accurate modeling of realistic optical devices. Additionally, the incorporation of our available in-house developed tools into that of already existing tools (such as MDS-Microwave Design Software) has been undertaken to design a single side-band modulator (SSBM).

Potential distributions of an active antenna array (composed of a 5X5 array of oscillating field effect transistors) given by optical sampling measurements agree with theoretical calculations. These results show that the stability of the active device is determined by the near field radiation and electrode geometry within a period of an elementary cell. Additionally, it was found that the bias lines of the active array provide both the dc bias to the active device and provides a coplanar structure that supports a radiation mode.

The optical to microwave modulation transfer function has been derived for an optically injected FET (field effect transistor). The transfer function can then give the characteristics of the optically injected microwave MESFET oscillator circuit. The model can vary the injected

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power level and the amount of phase detuning between the injected signal and the free running oscillation making it possible to accurately model microwave control by optical means.

**5. Significance:**

The significance of these accomplishments are threefold. First, the CAD tools for microwave devices has been a hierarchical one, much as hierarchical tools are the ones in use in the digital and microwave circuit design areas. Here, we have used MDS CAD for the design of the higher level simulations in the design of a SSBN. Secondly, the geometry of an active antenna plays an important role in its feasibility as an effective control for complicated drive/read-out phased array system. This will enable an efficient antenna array to be constructed. Electromagnetic analyses of a realistic stacked multilayer dielectric and its associated electrode structure makes it possible to design and model the required complexity needed for multi-channel microwave optical conversion. Finally, it was found that MESFET oscillators and the associated control lasers can be modeled by simply changing a constant in the model to give their characteristics with and with out optical injection.

**6. Future Efforts:**

Future work involves trying to physically understand locked array results while simultaneously trying to modify existent software to accurately analyze optically addressed antenna elements.

**7. Publications and Presentations Partially Supported Under This Grant June 1, 1994 through February 28, 1995**

S. L. Kwiatkowski and A. R. Mickelson, "Perturbations on Effective Index of Refraction from Prism Coupling," submitted to *Appl Optics*.

P. Biernacki, H. Lee, and A. Mickelson, "Evaluation of Defect Related Diffusion in Semiconductors by Electrooptical Sampling," submitted to *Appl Optics*.

S. L. Kwiatkowski, A. R. Mickelson, and D. R. Hjelme, "On-axis polarization coupling in y-cut titanium indiffused lithiumniobate slab waveguides," submitted to *Appl. Optics*.

A. R. Mickelson, "Rare Earth Integrated Optics," International Union of Radio Science, Boulder (CO), (Jan. 3-6, 1995).

A. R. Mickelson, "Rare Earth Doped Polymers," International Union of Radio Science, Boulder (CO), (Jan. 3-6, 1995).

J. Ma and A. R. Mickelson, "Optical Interconnects in VLSI Systems Using Polymer Waveguides and Switches," International Union of Radio Science, Boulder (CO), (Jan. 3-6, 1995).

R. Narayan and A.R. Mickelson, "Channel Waveguide Studies in Mg-Doped LiNbO<sub>3</sub>," International Union of Radio Science, Boulder (CO), (Jan. 3-6, 1995).

P. Biernacki, H. Lee and A.R. Mickelson, "Optical Sampling for Determination of Material Characteristics," International Union of Radio Science, Boulder (CO), (Jan. 3-6, 1995).

S. Lin and A. R. Mickelson, "Nd-Chelate-Doped Polymer Waveguides for Optical Amplifiers," International Union of Radio Science, Boulder (CO), (Jan. 3-6, 1995).

D. Tomic, S. Lin, W. Feng, and A. R. Mickelson, "What Limits Passive Directional Coupler Crosstalk," International Union of Radio Science, Boulder (CO), (Jan. 3-6, 1995).

W. Feng, R. B. Hooker and A. R. Mickelson, "Polymeric Electrooptic Devices," International Union of Radio Science, Boulder (CO), (Jan. 3-6, 1995).

P. Biernacki, K.Y. Cheng, D.R. Hjelme and A.R. Mickelson, 1994. "Determination of Electrode Currents from Electro-optical Sampling Measurements," in Defect Recognition and Image Processing in Semiconductors and Devices, ed. J. Jimenez, Institute of Physics Conference Series Number 135, (1994).

P. Biernacki, D.R. Hjelme, M. Yadlowsky, A.R. Mickelson, "Electro-Optical Sampling for High Frequency Electric Circuits," in Defect Recognition and Image Processing in Semiconductors and Devices, ed. J. Jimenez, Institute of Physics Conference Series Number 135, (1994).

S. Lin, W. Feng, R. B. Hooker and A. R. Mickelson, "Photo-bleached Polymeric Directional Couplers- Design, Fabrication and Evaluation," IEEE Lasers and Electrooptics Society, Boston, Oct 31-Nov 3 (1994).

S. Kwiatkowski and A. R. Mickelson, "Nearly Cut-off Modes Caused by Diffusion in LiNbO<sub>3</sub>," *Journ Appl Phys* 76, 5877-5885 (Nov. 1994).

A. R. Mickelson, "Polymers Make the OEIC Connection," *IEEE Trans Circuits and Devices* 10, #6, 8-13, (November 1994).

J. C. Chon and A. R. Mickelson, "Fabrication and Characterization of Third-Order Nonlinear Organic Polymer Composite Waveguide: A Self-Phase Modulator," *Appl Opt* (October 20, 1994)

P. Biernacki, H. Lee and A. R. Mickelson, " Noninvasive Characterization of Ohmic Contacts," IEEE Lasers and Electrooptics Society, Boston (MA), Oct 31-Nov 3 (1994).

A. R. Mickelson, "Modeling of Optically 'Assisted' Phased Array Radar," The Board of Mathematical Sciences of the National Research Council Symposium On Large Scale Structures in Acoustics and Electromagnetics, Washington, D. C., September 26-27, (1994).

S. Kwiatkowski and A. R. Mickelson, "Unexpected Characteristics of Lithium Niobate Waveguides," International Workshop on Ferroelectric Integrated Optics, Breckenridge (CO), August 17-19, (1994).

R. Narayan and A. R. Mickelson, "Characterization of Mg-doped Lithium Niobate," International Workshop on Ferroelectric Integrated Optics, Breckenridge (CO), August 17-19, (1994).

D. Tomic and A. R. Mickelson, "What Limits Passive Directional Coupler Crosstalk," International Workshop on Ferroelectric Integrated Optics, Breckenridge (CO), August 17-19, (1994).

A. R. Mickelson, "Heterodyne Phased Array," Workshop on Optically Controlled Phased Array Antenna Systems for Military Communications-on-the-Move, CECOM, Fort Monmouth (NJ), July 6, (1994).

A. R. Mickelson, "Electro-Optic Polymers for Circuit Interconnect Structures," ISHM Advanced Technology Workshop on Optoelectronics, Aspen (CO), April 15-17, (1994).

P. S. Weitzman, J. M. Dunn and A. R. Mickelson, "Approximate Calculation of Transmission Line Parameters and Field Distributions of Coplanar Electrodes in the Presence of a Buffer Layer," *Electromagnetics* (March 1994).

K.Y. Chen, S. Buchheit, and A.R. Mickelson, "Evanescent Current Modes in Active Antenna," International Union of Radio Science, Boulder (CO), (Jan. 5-8, 1994).

K.Y. Chen and A.R. Mickelson, Transistors "Oscillators as Van Der Pol Oscillators," International Union of Radio Science, Boulder (CO), (Jan. 5-8, 1994).

S.J. Buchheit and A.R. Mickelson, "Electromagnetic Modeling of Active Circuits," International Union of Radio Science, Boulder (CO), (Jan. 5-8, 1994).

S.M. Genco and A.R. Mickelson, "Optically Induced Effects in Microwave Mesfets: Experiments and Analysis," International Union of Radio Science, Boulder (CO), (Jan. 5-8, 1994).

M. Popovic, S.L. Kwiatkowski, and A.R. Mickelson, "Characterization of X-Cut LiNbO<sub>3</sub> Planar Waveguides," International Union of Radio Science, Boulder (CO), (Jan. 5-8, 1994).

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L. E. Rohlev and A.R. Mickelson, "Microwave Characterization of Nonlinear Optical Polymers," International Union of Radio Science, Boulder (CO), (Jan. 5-8, 1994).

R. Narayan and A.R. Mickelson, "Analysis of Travelling Wave Electrodes in Integrated Optical Devices," International Union of Radio Science, Boulder (CO), (Jan. 5-8, 1994).

Indra Januar and Alan R. Mickelson, "Characteristics of S-Shaped Waveguide Structures by the Annealed Proton Exchange Process in LiNbO<sub>3</sub>, *IEEE JLT*, 11 (Dec. 1993).

M. J. Yadlowsky and A. R. Mickelson, "Distributed Loss and Mode Coupling and Their Effect on Time-Dependent Propagation in Multimode Fibers," *Journal of Applied Optics*, 32, 6664-6677, (November 1993).

S.L. Kwiatkowski, D.R. Hjelme, K.H. Wagner and A.R. Mickelson, "Polarization Coupling in Y-Cut Titanium In-Diffused Lithium Niobate Planar Waveguides," IEEE Lasers and Electro-Optics Society, San Jose, (CA), Nov. 15-18, 1993).

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P. Biernacki, K.Y. Cheng, D.R. Hjelme and A.R. Mickelson, "Determination of Electrode Currents from Electro-optical Sampling Measurements," Fifth International Conference on Defect Recognition and Image Processing in Semiconductors and Devices, Santander, Spain, (Sept. 6-10, 1993).

P. Biernacki, D.R. Hjelme, M. Yadlowsky, A.R. Mickelson, "Electro-Optical Sampling for High Frequency Electric Circuits," Fifth International Conference on Defect Recognition and Image Processing in Semiconductors and Devices, Santander, Spain, (Sept. 6-10, 1993).

M.R. Surette, D.R. Hjelme and A.R. Mickelson, "An Optically Driven Phased Array Antenna Utilizing Heterodyne Techniques," *IEEE JLT*, 11, 1500-1509 (Sept. 1993)

V. Radisic, D. Hjelme, A. Horrigan, Z. Popovic, and A. Mickelson, "Experimentally Verifiable Modeling of Coplanar Waveguide Discontinuities," Special Issue on Modeling and Design of Coplanar Monolithic Microwave and Millimeter-Wave Integrated Circuits, *IEEE Trans on Microwave Theory and Tech*, 41, 1524-1533 (September 1993).

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Dag Roar Hjelme, Michael John Yadlowsky, and Alan Rolf Mickelson, "Two-Dimensional Mapping of Microwave Potential on MMIC's Using Electrooptic Sampling," *IEEE Trans. on Microwave Theory and Tech.*, MTT41, 1199-1158 (June/July 1993).

K. Y. Chen, P. Biernacki, A. R. Mickelson and Z. B. Popovic, "Optical Measurements of Microwave Grid Oscillator Power Combiners," IEEE MTT-S International Symposium, Atlanta (GA), (June 15-17, 1993).

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J. Chon, P. Comita, W. Fleming, J. Swalen, G. Bjorklund and A. R. Mickelson, "Optical Channel Waveguiding Devices in Poled NLO Polymers," MRS Spring Meeting, (April 12-16, 1993), Paper J5.9.

H. F. Jordan, A. R. Mickelson, B. VanZeghbroeck, and I. P. Januar, "Stored Program Optical Computer, Its Demonstration and Integration," Invited Paper, OSA Topical Meeting on Photonics in Switching, (March 15-17, 1993).

K.Y. Chen, P. Biernacki, Z.B. Popovic, and A.R. Mickelson, "Current and Field Distribution Across a 25-HEMT Grid Oscillator," National Radio Science Meeting, URSI, Boulder (January 1993).

D.R. Hjelme, V. Radisic, Z.B. Popovic, and A.R. Mickelson, "Experimentally Verifiable Modeling of Parasitics in Coplanar Waveguide", National Radio Science Meeting, URSI, Boulder (January 1993).

S.L. Kwiatkowski, D.R. Hjelme, and A.R. Mickelson, "Optical Waveguide Lenses for Integrated Optical Components," National Radio Science Meeting, URSI, Boulder (January 1993).

L.E. Primas, V. Jevremovic, A.R. Mickelson, and Z. Popovic, "Microwave Characterization of Polymeric Materials for Electro-Optic Devices," National Radio Science Meeting, URSI, Boulder (January 1993).

S.M. Genco, J. Buetow, Z. Popovic, and A. Mickelson, "Enhanced SNR and Stability of Microwave MESFET Oscillators via Optically Injected Signals," National Radio Science Meeting, URSI, Boulder (January 1993).

S. Yang and A. R. Mickelson, "Coupling Mechanisms and Transfer Functions of Optical Fiber Devices," *Applied Optics*, 31, 7587-7596 (December 20, 1992).

P.J. Matthews and A.R. Mickelson., "Instabilities in Annealed Proton Exchange Waveguides in Lithium Tantalate," *Journ. Applied Physics*, 71 pp. 5310-5317, (Nov. 1992)

D.R. Hjelme and A.R. Mickelson, "Voltage Calibration of the Direct Electrooptic Sampling Technique," *IEEE Micro. Theory and Tech*, 40, 1941-1950, (October 1992)

I. Januar, R. J. Feuerstein, A. R. Mickelson and J.R. Sauer, "Wavelength Sensitivity in Directional Couplers," *Jour. Lightwave Tech.*, 10, 1202-1209 (September 1992).

M.J. Yadlowsky, D.R. Hjelme and A.R. Mickelson, "Power Coupling and Time-Dependent Radiative Transfer in Guided Wave Systems," *Journ. Opt. Soc. Am A* 9, 1306 (August 1992).

#### **Theses During Project:**

L. Rohlev, Ph.D., "Characterization of Optical Polymers for Multilayered Electrooptic Devices."

S. Genco, Ph.D., "Characterization of Microwave MESFET Circuits under Laser Illumination: Applications to Phased Array Radar, Microwave Communications, and Digital Clock Control."

K. Chen, Ph.D., "Active Antennas with Periodic Structures."

#### **8. Participants:**

Professor Alan R. Mickelson  
Kuang Yi Chen  
Raghu Narayan  
Sheryl Genco  
Lori Rohlev