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13. ABSTRACT *(Maximum 200 words)*

The principal objective of this project is to determine the most efficient means of encoding a microwave/millimeter wave signal from a patch antenna onto an optical carrier in an electro-optical substrate for subsequent optical processing of the microwave/millimeter wave signal. Our approach was to develop design models that would relate the performance of integrated electro-optic devices to the fabrication paramters used in making them and then experimentally verify their performance. From our theoretical and experimental work, it has been shown that it is feasible to build a single side band modulator for millimeter/microwave signals. Currently our efforts are in improving the design of single side band modulators, investigating alternative substrates and fabrication techniques for electro-optic devices and designing active elements to be used in conjunction with the antenna elements.

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FINAL REPORT

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A report on the progress of "Optically Driven and Optically-Controlled Integrated Millimeter-Wave Receiving Phase Arrays".

Grant No. DAAL03-88-K-0053

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Publications and Presentations Partially Supported Under This Grant Since Last Report Period

Please see the attached complete list of publications.

1. D.R. Hjelme, A.R. Mickelson, "Voltage Calibration of the Direct Electrooptic Sampling Technique," Submitted to IEEE-MTT (February 1991), see also Guided Wave Optics Laboratory Report No. 31 (April 1991).
2. S. Bundy, T. Mader, Z. Popovic, R. Ellingsen, D. Hjelme, M. Surette, M. Yadlowsky, A.R. Mickelson, "Quasi-Optical Mesfet VCO's," SPIE, Orlando, FL (March 1991). See also Guided Wave Optics Laboratory Report No. 30, (April 1991).
3. D.R. Hjelme, A.R. Mickelson, "Characterization and Modeling of MIMICs by Optical Sampling," Guided Wave Optics Laboratory Report No. 28, (April 1991).

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Professor Alan R. Mickelson
Professor David C. Chang
Walter Charczenko
Peter Weitzman
Doris I. Wu

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Theses During Project

1. H. Klotz, "An Experimental Study to Determine Fabrication Parameters for Proton Exchanged Waveguides in $LiNbO_3$", MS Thesis, University of Colorado (December 1989).
2. P. Weitzman, "Evaluation Of Electric Field Distributions, and Capacitance Of Electrode Structures Used In Integrated Optic Modulators", MS Thesis, University of Colorado (May 1990).
3. W. Charczenko, "Coupled Mode Analysis, Fabrication, and Characterization Of Microwave Integrated Optical Devices", PhD Thesis, University of Colorado (September 1990).

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Brief Outline of Research Findings

The principal objective of this project is to determine the most efficient means of encoding a microwave/millimeter wave signal from a patch antenna onto an optical carrier in an electro-optical substrate for subsequent optical processing of the microwave/millimeter wave signal.

Our approach was to develop design models that would relate the performance of integrated electro-optic devices to the fabrication parameters used in making them and then experimentally verify their performance. Where lack of agreement was observed, the models were rethought and modified to improve their predictive behavior. Such performance characteristics included modal field distributions, propagation constants, coupling coefficients of channel waveguides and coupling lengths of proton exchanged directional couplers. This information was then used to design patch antennas and integrated optical modulators using various fabrication techniques and substrates. Similar design methods were used to determine the depth of modulation of electro-optic modulators.

In order to achieve optically-controlled integrated millimeter-wave receiving phase arrays, single sideband modulation of an optical carrier by an incoming millimeter wave must be performed. Our research in this area began with the investigation of traveling wave structures used to obtain 90 degree phase shifts in millimeter wave signals. These structures consisted of slots in microstrip lines and were analyzed using a numerical (moment method) program. A theoretical model describing the interaction of a millimeter or microwave signal with an optical carrier was developed and used to determine the optical depth of modulation. A strip dipole was fabricated onto one arm of an integrated optical Mach Zender interferometer.

Modeling and fabrication of electrooptic devices in $LiNbO_3$ was then initiated. This led to the fabrication and packaging of microwave patch antennas in $LiNbO_3$ with 50 ohm microstrip feedlines. Eventually coplanar dipole antenna electrodes for electrooptic modulators were designed, modeled, fabricated and tested. It was determined that the most efficient way to couple the microwave signals to optical signals was by use of a patch antenna, amplifier and resonant electrode integrated optical modulator. Finally a patch antenna fed resonant electrode single side band integrated optical modulator was modeled, fabricated and tested.

From our theoretical and experimental work, it has been shown that it is feasible to build a single side band modulator for millimeter/microwave signals. Such devices will consist of patch antennas used as resonant electrodes for electro-optic modulators. Optical processing using such devices as Butler matrices, can be used to perform signal processing and beam forming of signals. Such techniques require gain at each antenna element and provide both transmit and receive processing. Techniques employing locked lasers can also be used for the transduction of antenna signals onto optical carriers.

A new electrode design consisting of a coplanar 3dB coupler for use in a single side band modulator is currently being tested. Our efforts will continue to pursue alternative substrates for fabrication of electro-optic devices, including $LiTaO_3$ and $LiNbO_3$. For antennas being used in the receive mode, active elements that will provide isolation from extraneous signals will be investigated.

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1. P. Weitzman, J.M. Dunn and A.R. Mickelson, "Approximate Calculation of Transmission Line Parameters of Field Distributions of Coplanar Electrodes in the Presence of A Buffer Layer", Guided Wave Optics Laboratory Report No. 22.
2. P. Weitzman, J.M. Dunn and A.R. Mickelson, "An Efficient Numerical Method For the Calculation of the Electrical Properties of Coplanar Electrodes in the Presence of a Buffer Layer", see Guided Wave Optics Laboratory Report No. 21.
3. W. Charczenko, P.S. Weitzman, H. Klotz, M. Surette, J.M. Dunn and A.R. Mickelson, "Characterization and Simulation of Proton Exchanged Integrated Optical Modulators With Various Dielectric Buffer Layers", Journal of Lightwave Technology, Volume 9, Number 1, (January 1991). See also Guided Wave Optics Laboratory Report No. 18 (May 1990).
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5. W. Charczenko, P.S. Weitzman, J.M. Dunn and A.R. Mickelson, "Characterization and Simulation of Proton Exchanged Integrated Optical Modulators with Various Dielectric Buffer Layers," OSA Annual Meeting, Boston, MA, (November 1990).
6. P. Matthews, M. Surette and A.R. Mickelson, "Characteristics of Proton-Exchanged Lithium Tantalate Waveguides," OSA Annual Meeting, Boston, MA (November 1990).
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8. W. Charczenko, M. Surette, R. Fox, S.T. Vohra, S. Asher, and A.R. Mickelson, "Comparison of Numerical Simulations to Experimental Measurements of Proton-Exchanged and Annealed Channel Waveguides and Direction Couplers in $LiNbO_3$, submitted to Applied Optics. See also Guided Wave Optics Laboratory Report No. 26 (September 1990).
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