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13. ABSTRACT (Maximum 200 words) Accomplishments and pertinent information under the Joint Services Electronics Program (JSEP) for the reporting period September 1992 - September 1995 are summarized. The JSEP program provides the research baseline for all three military services in the expanding electronic sciences requiring interdisciplinary efforts among sub-areas of electronicst. The central theme of this research is to resolve issues that have prevented wide spread use of millimeter-wave electronics. Considered are issues that have arisen primarily due to the lack of a coherent approach between solid state (device) research and electromagnetic (circuit and component) research. The device research takes into account the electromagnetic interaction with the circuit and the system environment while the millimeter-wave integrated circuit, as the electromagnetic system, considers the interaction with the solid state devices from the outset of analysis and design. Several research areas are synergistically combined. Research in the exploration of novel material systems and devices structures benefits from device simulation efforts. Novel integrated circuit configurations that exploit the best performance from the devices are studied. The devices and circuits are then implemented into quasi-optical monolithic arrays.				
14. SUBJECT TERMS Quasi-optical technique, multiplier, nonlinear transmission line, beam control, active antenna, FDTD, Stark effect, resonant tunneling diode, quantum well, heterojunction bipolar transistor			15. NUMBER OF PAGES	
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FINAL REPORT
JOINT SERVICES ELECTRONICS PROGRAM

Research Contract AFOSR F49620-92-C-0055

For the period of September 1992 - September 1995

December 18, 1995

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(a) OVERVIEW OF ACCOMPLISHMENTS

The central theme of this program is to resolve bottleneck issues that have prevented wide spread use of millimeter-wave electronics. We consider that such bottlenecks have arisen primarily due to the lack of a coherent approach between solid state (device) research and electromagnetic (circuit and component) research. At millimeter-wave frequencies, devices and circuits cannot be analyzed, designed and tested separately due to wave interactions. Under this JSEP program, each unit interacted coherently and strongly. Although there are two units for solid state electronics and another two for electromagnetics, they worked together for several specific subjects such as quantum well devices with different aspects. Unit 1 (K. L. Wang) was concerned with the new integrable devices that were theoretically analyzed and simulated in Unit 2 (D. S. Pan). Unit 3 (T. Itoh) studied the millimeter-wave circuits in which these devices are treated as a part of the circuit in such a way that the optimum of the device capability is extracted. Under Unit 4 (N. C. Luhmann), quasi-optical configurations of the devices and circuits studied under the other units were implemented in complete systems.

Since the inception of the JSEP program at UCLA in September 1992, we have reached significant progress toward the above goal. Some of the significant accomplishments are as follows. (1) Optical control of double barrier Resonant Tunneling Diode (RTD) in which the negative resistance of the device can be externally controlled so that the initiation of the series connected RTDs may be accomplished by temporarily suppressing the negative resistance (Units 1, 2 and 3). (2) Electromagnetic simulation of the distributed gain mechanism was accomplished by incorporating the gain mechanism in the Finite Difference Time Domain (FDTD) algorithm. This technique was developed by Unit 3 with a direct impact on the device work under Units 1 and 2. (3) Stacked quantum barrier varactor frequency multiplier was invented and used in a quasi-optical system by Unit 4. The structure produced 5 W output at W band. (4) Unit 2 has discovered that the series integrated RTD's can be initiated by an injection signal at one half of the intended oscillation frequency (subharmonic oscillation). The injection signal is needed only for a short period of time and can be removed once the oscillation started. This prediction has also been demonstrated by Unit 3, by means of experiments using tunnel diodes that have the negative resistance characteristics similar to those of the RTD. During the experiment, it was found that the injection signal frequency need not be an integer fraction of the oscillation signal. (5) Coupled active antenna has been simulated by the extended FDTD. This is the first time that the microwave circuit was analyzed electromagnetically including the active devices. Unlike the standard network based approach, all the "electrically hidden" phenomena can be displayed visually as well as parametrically. Such understanding heavily relies on the device characterizations that can be provided by the solid state units while the output is useful in the system implementation work for Unit 4.

Several items on Technology Transfer have been reported in the three Annual Reports. They are: (1) Three-dimensional active integrated array antenna for which the design and structure have been provided to Hughes Aircraft. (2) Complete information on the electronically and optically activated beam control array in a quasi-optical manner has been provided to Hughes, Martin-Marietta, Northrop, Raytheon, Rockwell and TRW. (3) Electromagnetic simulation of the active integrated antenna has been transferred to Los Alamos National Laboratory with related information provided to CRAY, Research. In addition, the items (2) and (3) are now included in the proposal by Martin-Marietta for the ARPA program on MAFET (Microwave and Analog Front End Technology) under the Quasi-Optical Alliance. An extension of (3) to MMIC amplifiers is now being developed for a future CAD tool with Hughes Aircraft Company.

The Quasi-Optical structures being developed have recently found new applications as low cost alternative for wireless communications, at typically lower microwave frequencies such as C, S, X and Ku bands. One of these applications, the non-contact ID transponder card, was presented and demonstrated at the 1994 IEEE International Microwave Symposium. Subsequently, several industrial companies have inquired about potential productization. One of the latest was Select University Technologies, Inc. At the same time, we received an invitation from *Microwave Journal* to write an article "Quasi-optical Microwave Circuits for Wireless Applications in a feature section. The article will also appear in *Telecommunications*. Together, the total circulation is 130,000 worldwide. As soon as this article appeared, we received an inquiry from Vehicular Security Electronics, Inc. for assistance in their product of a wireless motion sensor.

In closing, this three year period has been a very rewarding experience for all of the personnel involved in this JSEP program. Significant advances have been witnessed in the basic research for understanding of many bottleneck issues and some solutions for them. Even though the emphasis of the program is of the high risk and high payoff type, emphasizing the basic research, we have found many technology transitions to industry and other organizations for further development and productization.

Tatsuo Itoh and Neville C. Luhmann, Jr.

(b) LISTING OF INVESTIGATORS

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Professor D. S. Pan	310-825-1123
Professor T. Itoh	310-206-4820
Professor N. C. Luhmann, Jr.	510-422-9787

(c) DEGREES AWARDED

Master of Science (Supervisor)

J. Y.-Y. Liao	(Luhmann)	1993
S. Y. Shu	(Luhmann)	1993
R. Hsia	(Luhmann)	1993
E. Chung	(Luhmann)	1993
W. Geck	(Luhmann)	1993
T. Liu	(Luhmann)	1993
S. Cheng	(Luhmann)	1993

Doctor of Philosophy (Supervisor)

L. Sjogren	(Luhmann)	1993
H.-X. Liu	(Luhmann)	1993
S. Khorram	(Wang)	1994
B. Toland	(Itoh)	1994
J. Lin	(Itoh)	1994
H. S. Li	(Wang)	1994
O. Boric-Lubecke	(Itoh)	1995
X. Qin	(Luhmann)	1995

(d) LIST OF JSEP PUBLICATIONS

Unit 1, "Investigation of Novel Devices and Concepts" (Prof. K. L. Wang)

I. LIST OF JOURNAL PUBLICATIONS

1. H. S. Li, Y. W. Chen, K. L. Wang, and D. Y. C. Lie, "Intersubband transitions in pseudomorphic InGaAs/GaAs/AlGaAs multiple step quantum wells," J. Vac. Sci. Technol. B, 11, 1840 (1993).
2. S. Khorram, K. L. Wang, T. Block, and D. Streit, "Carrier transport in GaAs/AlGaAs heterostructures by microwave time-of-flight technique," Appl. Phys. Lett. 63, 3491 (1993).
3. J. Jo, H. S. Li, Y. W. Chen, and K. L. Wang, "Observation of a large capacitive current in a double barrier resonant tunneling diode at resonance," Appl. Phys. Lett. 64, 2276 (1994).
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5. Y. W. Chen, H. S. Li, Z. Zhou, and K. L. Wang, "Transfer matrix analysis of waveguide phase modulator using the linear electrooptic effect of asymmetric quantum wells," J. of Appl. Phys, 76, 4903 (1994).

LIST OF CONFERENCE PROCEEDINGS

1. H. S. Li, R. P. G. Karunasiri, Y. W. Chen, and K. L. Wang, "Electron intersub-band normal incidence absorption in InGaAs/GaAs quantum wells", May/June, 1993 J. Vacuum Science Tech. B.
2. H. S. Li, L. P. Chen, Y. W. Chen, K. L. Wang, D. S. Pan, and J. M. Liu, "Dominant photogenerated valley current in a double barrier resonant tunneling diode", J. Vac. Sci. Technol. B, March/April 1994.

Unit 2, "Modeling and Theoretical Exploration of Millimeter Wave Solid State Devices" (Prof. D. S. Pan)

I. LIST OF J PUBLICATIONS (*JSEP supported in whole or in part)

1. P. Man and D.S. Pan, "Analysis of Normal-Incident Absorption in P-type Quantum-Well Infrared Detectors". Appl. Phys. Lett. 61, 2799, Dec. 92.
2. P. Huang, D. S. Pan, and N. C. Luhmann, Jr. " A Microwave Measurement Technique for Characterizing the I-V relationship for Negative Differential Conductance Devices," IEEE Transactions on Microwave Theory and Tech., MTT-41(8), 1455, August, 1993.
3. P. Man and D. S. Pan " Analysis of Normal-Incident Absorption in a Proposed p-type Very-Narrow-Quantum-Well Infrared Photodetector" Appl. Phys. Lett., 64(3), 321, January, 1994.
- *4. O. Boric-Lubecke, D. S. Pan, and T. Itoh, "RF excitation of an oscillator with several tunneling devices in series," IEEE Microwave and Guided Wave Lett., Vol. 4, pp. 364-366, Nov. 1994.
- *5. O. Boric-Lubecke, D. S. Pan, and T. Itoh, "Fundamental and subharmonic excitation for an oscillator with several tunneling diodes in series," IEEE Trans. Microwave Theory Tech., vol. 43, pp. 969-976, April, 1995.
- *6. H. S. Li, L. P. Chen, Y. W. Chen, K. L. Wang, D. S. Pan, J. M. Liu, "Dominant photogenerated valley current in a double-barrier resonant-tunneling diode," Appl. Phys. Lett. Vol. 65, pp. 2999-3001, Dec. 1994.
- *7. P. Man and D. S. Pan, "Hot-carrier-temperature model for the dark current of quantum-well infrared photodetectors," Appl. Phys. Lett. Vol. 66, pp. 192-194, January 1995.
- *8. R. Sun, D. S. Pan, and T. Itoh, "Simulation of a subharmonic excitation of series integrated resonant tunneling diodes," IEEE Microwave and Guided Wave Lett., Vol. 5, pp.18-20, Jan. 1995.
- *9. C. C. Yang and D. S. Pan, "A theoretical study of an integrated quantum well resonant tunneling oscillator initiated by an IMPATT diode," IEEE Trans. Microwave Theory Tech., Vol. MTT-43, 112-118, 1995.

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1. O.B. Lubecke, D.S. Pan, T. Itoh, "Millimeter Wave Oscillators with Several Tunneling Devices in Series" presented at URSI conference, January, 1993, Boulder, Colorado.
2. C.C. Yang and D.S. Pan, "Millimeter-Wave Simulation of a Series-Integrated Resonant Tunneling Diode Including Transit Time Effect" presented in IEEE MIT-S, International Microwave Symposium, June 14-18, 1993, Atlanta.
3. O.B. Lubecke, H.S. Li, D.S. Pan, K.L. Wang, T. Itoh, "Series Integration of Quantum-Well Diodes: Millimeter Wave Oscillator Design and Excitation", XXIV The General Assembly of International Union of Radio Science, Kyoto, Japan. September 1993.

4. W. Liu and D.S. Pan, "A New Discretization Scheme for the Energy Transport Equation" presented at NASCODE IX 1993 Conference, April 6-8, 1993, Copper Mountain, Colorado.
5. B. Toland, D.S. Pan and T. Itoh, "Analysis of a Multiple Layer Traveling Wave Device," 23rd European Microwave Conference, Madrid, Spain. September 6-9, 1993.
6. Olga Boric-Lubecke, D.S. Pan, T. Itoh, "Large Signal Quantum-well Oscillator Design," 23rd European Microwave Conference, Madrid, Spain. September 6-9, 1993.
7. O. Boric-Lubecke, R. Sun, D. S. Pan and T. Itoh " Excitation of an Oscillator with Several Resonant tunneling Devices Integrated in Series Using RF source" Fifth International Symposium on Space Terahertz Technology, May 10-12, 1994, the University of Michigan, Ann Arbor, Michigan.
8. D. S. Pan and A. Man " Theoretical Analysis of P-type Quantum Well Detectors" (Invited) Second International Symposium on 2-20 um Wavelength Infrared Detectors and Arrays: Physics and Applications, October 9-14, 1994 Miami Beach, Florida.
- *9. O. Boric-Lubecke, D. S. Pan and T. Itoh, "Fast electric pulse excitation of an oscillator with several tunneling devices in series," 24th European Microwave Conference, pp. 782-787, Sept. 5-8, 1994, France.
- *10. P. Man and D. S. Pan, "Theoretical investigation of p-type optical interaction in p-type quantum well infrared detectors", (Invited paper), Proceedings of the Second International Symposium on Long Wavelength Infrared Detectors and Arrays: Physics and Applications, pp. 139-163, 199, edited by V. Swaminathan, S. Li, T.S. Faska, H.C. Liu, and F. Radpour, the Electrochemical Society.
- *11. O. Boric-Lubecke, D. S. Pan, and T. Itoh, " Oscillation amplitude and frequency limitations for an oscillator with several tunneling devices in series," 19th International conference on Infrared and Millimeter Waves, pp. 17-18, October 17-20, 1994, Sendai, Japan.

Unit 3, " Wave Interactions in Active Integrated Circuits" (Prof. T. Itoh)

LIST OF PUBLICATIONS (* JSEP Supported in whole or in part)

1. J. Lin, C.-Y. Chang, Y. Yamamoto and T. Itoh, "Progress of tunable active bandpass filter," *Annales des Telecommunications (Special Issue)*, Vol.47, No.11-12, pp.499-507, November December 1992.
2. T. Hirota and T. Itoh, "Coupling between slotlines through a conductor backing," *IEEE Microwave and Guided Wave Letters*, Vol.3, No.2, pp.40-41, February 1993.
3. S. Kawasaki and T. Itoh, "2 x 2 Quasi-Optical Power Combiner Array at 20 GHz," *IEEE Trans. Microwave Theory and Techniques* Vol. 41 No. 4 (April 1993): pp. 717-719.
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10. S. Nogi, J. Lin, and T. Itoh, "Mode Analysis and Stabilization of a Spatial Power Combining Array with Strongly Coupled Oscillators," *IEEE Trans. Microwave Theory and Techniques* Vol. 41 No. 10 (October 1993): pp. 1827-1837.
11. S. Kawasaki, and T. Itoh, "Quasi-Optical Planar Arrays with FETs and Slots," *IEEE Trans. Microwave Theory and Techniques* Vol. 41 No. 10 (October 1993): pp. 1838-1844.
- *12. T.-W. Huang, B. Houshmand, and T. Itoh, "Fast Sequential FDTD Diakoptics Method Using the System Identification Technique," *IEEE Microwave and Guided Wave Letters* Vol. 3 No. 10 (October 1993): pp. 378-380.

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- *14. J. Lin and T. Itoh, "Two-Dimensional Quasi-Optical Power-Combining Arrays Using Strongly Coupled Oscillators," *IEEE Trans. Microwave Theory and Techniques: Special Section on Space Terahertz Technology*, Vol. 42, No. 4(April1994): pp. 734-741.
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16. S. Kawasaki and T. Itoh, "Millimeter-Wave Active Integrated Antennas Utilizing Harmonics," *IEICE Trans. C-I*, Vol.J77-C-I, No.11, pp.607-616, November 1994.
17. S. Kawasaki and T. Itoh, "Optical Control of Active Integrated Antennas Using Microwave - Optical Interaction," *IEICE Trans. C-I*, Vol.J77-C-I, No.11, pp.671-678, November 1994.
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- *20. C. W. Pobanz and Itoh T, "Quasi-optical Microwave Circuits for Wireless Applications," *Microwave Journal* Vol. 38. No 1 (January 1995): pp. 64-85.
- *21. R. Sun, D.-S. Pan and T. Itoh, "Simulation of a Subharmonic Excitation of Series Integrated Resonant Tunneling Diodes," *IEEE Microwave and Guided Wave Letters* 5 1 (January 1995): pp. 18-20.
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- 2. Toland and T. Itoh, "Full wave boundary element analysis with removal of spurious modes," International Symposium on Signals, Systems and Electronics, pp.74-76, September 1-4, 1992, Paris, France.
- 3. S. Kawasaki and T. Itoh, "Active integrated antenna based on slots and FETs," International Symposium on Signals, Systems and Electronics, pp.584-587, September 1-4, 1992, Paris, France.
- 4. T. Hirota and T. Itoh, "Recent progress in filters for mobile communication systems," (Invited) International Symposium on Signals, Systems and Electronics, pp.856-858, September 1-4, 1992, Paris, France.
- 5. S. Kawasaki and T. Itoh, "Electronically and optically controlled active integrated antenna," 1992 International Symposium on Antennas and Propagation, pp.821-824, September 22-25, 1992, Sapporo, Japan.
- 6. S. Kawasaki and T. Itoh, "Quasi-optical and active antenna technology," MM92 Conference, pp.311-316, October 14- 15, 1992, Brighton, England.
- 7. S. Kawasaki and T. Itoh, "Progress of optical control of quasi-optical oscillators using MESFETs," Seventeenth International Conference on Infrared and Millimeter Waves, pp.354-355, December 14-17, 1992, Pasadena, CA.
- *8. O.Boric-Lubecke, D.S. Pan and T. Itoh, "Millimeter wave oscillators with several tunneling devices in series," National Radio Science Meeting, p.92, January 5-8, 1993, Boulder, CO.
- 9. B. Houshmand and T. Itoh, "Parameter estimation for characterization of microwave structures," National Radio Science Meeting, p.134, January 5-8, 1993, Boulder, CO.
- *10. J. Lin, and T. Itoh, "Comparison of a 4-Element Linear Array and a 2 x 2 Planar Array," Proceedings of Fourth International Symposium on Space Terahertz Technology, Los Angeles, California: March 30-April 1, 1993, pp. 94-103.
- *11. S.Kawasaki and T. Itoh, "Optical Tuning Range Comparison of Uniplanar Active Integrated Antenna Using MESFET, GaAs HEMT and Pseudomorphic HEMT," Proceedings of Fourth International Symposium on Space Terahertz Technology, Los Angeles, California: March 30-April 1, 1993, pp. 149-156.

- *12. J. Lin, S. Kawasaki, and T. Itoh, "Optical Control of MESFETs for Active Filter and Active Antenna," Proceedings of MIOP '93, Sindelfingen, Germany: May 25-27, 1993, pp. 348-352.
- 13. Niu, D.-C., T. Yoneyama, and T. Itoh, "Measurement of NRD-Guide Leaky Wave Coupler in Ka Band," IEEE MTT-S International Microwave Symposium Digest, Atlanta, Georgia: June 15-17, 1993, pp. 1207-1210.
- 14. Y. Liu, T. Hirota, and T. Itoh, "Coupling Phenomena in Conductor-Backed Slotline Structure," IEEE MTT-S International Microwave Symposium Digest, Atlanta, Georgia: June 15-17, 1993, pp. 1203-1206.
- *16. T. W. Huang, B. Houshmand, and T. Itoh, "The FDTD Diakoptics Method," IEEE MTT -S International Microwave Symposium Digest, Atlanta, Georgia: June 15-17, 1993, pp. 1435-1438.
- *17. J. Lin, and T. Itoh, "A 4 x 4 Spatial Power-Combining Array with Strongly Coupled Oscillators in Multilayer Structure," International Microwave Symposium Digest, Atlanta, Georgia: June 15-17, 1993, pp. 607-610.
- 18. A. M. Tran and T. Itoh, "Analysis of Microstrip Line Coupled Through an Arbitrarily Shaped Aperture in a Thick Common Ground Plane," IEEE M77-S International Microwave Symposium Digest, Atlanta, Georgia: June 15-17, 1993, pp. 819-822.
- *19. S. Kawasaki and T. Itoh, "Optical Control on 2-Element CPW Active Integrated Antenna Array with Strong Coupling," I 993 IEEE AP-S Symposium Digest, Ann Arbor, Michigan: June 28 - July 2, 1993, pp. 1616-1619.
- *20. J. Lin, T. Itoh, and S. Nogi, "Mode Switch in a Two-Element Active Array," 1993 IEEE AP-S Symposium Digest, Ann Arbor, Michigan: June 28 - July 2, 1993, pp. 664
- *21. T. W. Huang, B. Houshmand, and T. Itoh, "The FDTD Wide-Band Absorbing Boundary Conditions for the Excitation Plane," 1993 IEEE AP-S Symposium Digest, Ann Arbor, Michigan: June 28 - July 2, 1993, pp. 2-5.
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- 23. J. Lin, S. Kawasaki, and T. Itoh, "Quasi-Optical Linear Arrays," Proceedings of PIERS '93, Pasadena, California: July 12-16, 1993, p. 834.
- 24. B. Houshmand, T.W. Huang, and T. Itoh, "Efficient Analysis of Planar Microwave Structures by FDTD Diakoptics and Parameter Estimation," Proceedings of PIERS '93, Pasadena, California: July 12-16, 1993, p. 369.
- 25. M. C. Wu, and T. Itoh, "Ultrafast Photonic-to-Microwave Transformer (PMT)," Proceedings of LEOS Summer Topical Meeting on Optical Microwave Interactions, Santa Barbara, California: July 19-21, 1993, pp. 63-64.
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27. S. Kawasaki and T. Itoh, "Topology of Active Integrated Antenna," Proceedings of XXIVth URSI General Assembly, Kyoto, Japan: August 23 - September 3, 1993, p.133.
28. S. Kawasaki, and T. Itoh, "Optical Control of 2-Element Uniplanar HEMT Active Integrated Antenna Array," Proceedings of XXIVth URSI General Assembly, Kyoto, Japan: August 23 - September 3, 1993, p. 567.
- *29. O. Boric-Lubecke, et al., "Series Integration of Quantum-Well Diodes: Millimeter Wave Oscillator Design and Excitation," Proceedings of XXIVth URSI General Assembly, Kyoto, Japan: August 23 - September 3, 1993, p. 174.
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