REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 30, 1995

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Equipment Grant: Nonlinear Dynamics of Quasi-Optical Device Arrays

5. FUNDING NUMBERS

6. AUTHOR(S)
Dr. Robert A. York

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ECE Dept.
University of California
Santa Barbara, CA 93106

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This is a final report for an equipment augmentation under an existing Young Investigator Award. A computer workstation was purchased and used to develop Finite-Difference Time Domain (FDTD) code for analyzing planar antenna structures, which are a key element of the parent award. A new multi-shot cpw-fed antenna was developed for quasi-optical amplifier arrays as a result of this grant.

14. SUBJECT TERMS

15. NUMBER OF PAGES
5

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Nonlinear Dynamics of Quasi-Optical Device Arrays:
Equipment Augmentation

FINAL REPORT

Dr. Robert A. York

18 July 1995

U.S. Army Research Office

33098-EL-YIP

Department of Electrical and Computer Engineering
University of California at Santa Barbara
Santa Barbara, CA 93106

Approved for Public Release;
Distribution Unlimited.

STATEMENT OF THE PROBLEM

The parent award for this equipment grant is focused on the investigation of unusual nonlinear dynamics in quasi-optical oscillator arrays, developing models to predict this behavior, and performing the necessary experiments to verify the concepts. Analysis of large arrays requires the numerical integration of large sets of coupled nonlinear differential equations. This is a very computationally intensive task, even for simple arrays. In addition, several important issues have arisen that were not conceived in the original proposal, which would significantly increase this computational burden. These include limits on scanning range, scanning rates, and beamwidth (*ie.* size of the arrays), modulation, and noise analysis. Incorporating these additional models and features into our analysis package will significantly increase the complexity of the equations and hence the resulting computation.

In order to design the active antenna elements for arrays, knowledge of the impedance characteristics of the planar radiating structure is required. For well-known antennas like the microstrip patch, the open literature provides all the necessary information. However, patch antennas are not always desirable, and we have begun to explore other antennas that would be (a) more suitable for monolithic integration, and (b) provide wider bandwidth on high dielectric constant substrates. One example is the cpw-fed folded-slot antenna; this makes integration with three-terminal devices very easy, and by analogy with the complementary structure (folded-dipole) the antenna provides more bandwidth. However, there is no literature describing folded-slots on dielectric substrates.

SUMMARY OF RESULTS

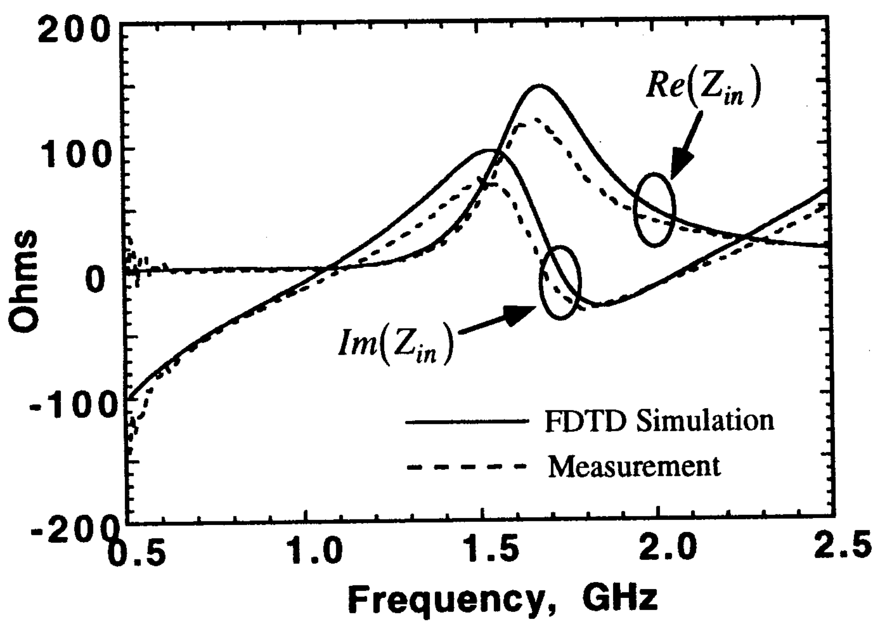
During this reporting period we have concentrated on Finite-Difference Time-Domain (FDTD) modelling of planar antenna structures. Using the HP9000-735 workstation provided under this equipment augmentation, we have developed full three-dimensional FDTD modelling capability for any passive microwave circuit structure. This program has allowed us to explore and develop cpw-fed folded-slot antennas for integrated antenna arrays [1]. These antennas are attractive due to the ease of fabrication (one mask step), easy integration with active devices, and relatively large bandwidths.

During the course of this work we learned that addition of parasitic slots to the basic folded-slot topology could provide a simple technique for impedance adjustment and bandwidth broadening [1,5]. We have developed several such "multi-slot" antennas with driving-point impedances of $50\,\Omega$, one both high and low dielectric constant substrates. Fractional bandwidths of up to 35% have been observed experimentally. The FDTD program has been crucial to this effort: the multi-slot antennas are quite complicated structures to analyze by other means. Figure 1 shows a typical result with three slots on a low-epsilon substrate, and comparison to the FDTD predictions. Figure 2 illustrates the variation of impedance with the number of slots on a high-epsilon substrate (Alumina), using measured data on a wafer probing station.

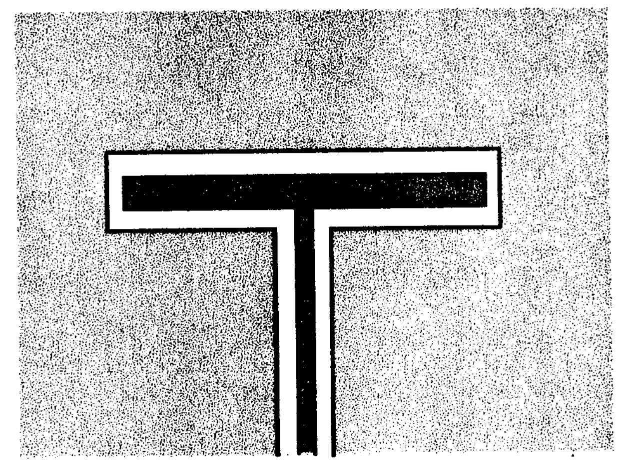
These new antennas have been integrated with active devices to form quasi-optical amplifier arrays [2,3]. A 16-element array at 10 GHz was fabricated by bonding commercial HBT gain blocks (designed at Rockwell Science Center) directly between multi-slot antennas on alumina substrate, shown in figure 3. This array provided a convincing demonstration of these new antennas, and a monolithic version at 40GHz is now under development at Rockwell using these antennas. We are due to receive this array in August of 1995 for testing.

UCSB University of California, Santa Barbara

Comparison Between Measurement and FDTD Simulation Results



Thickness = 0.787mm $\varepsilon_r = 2.2$

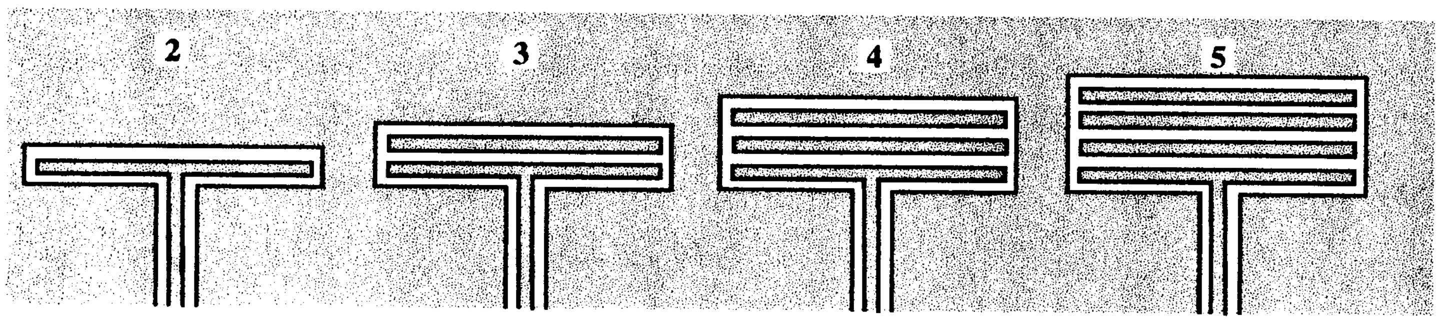


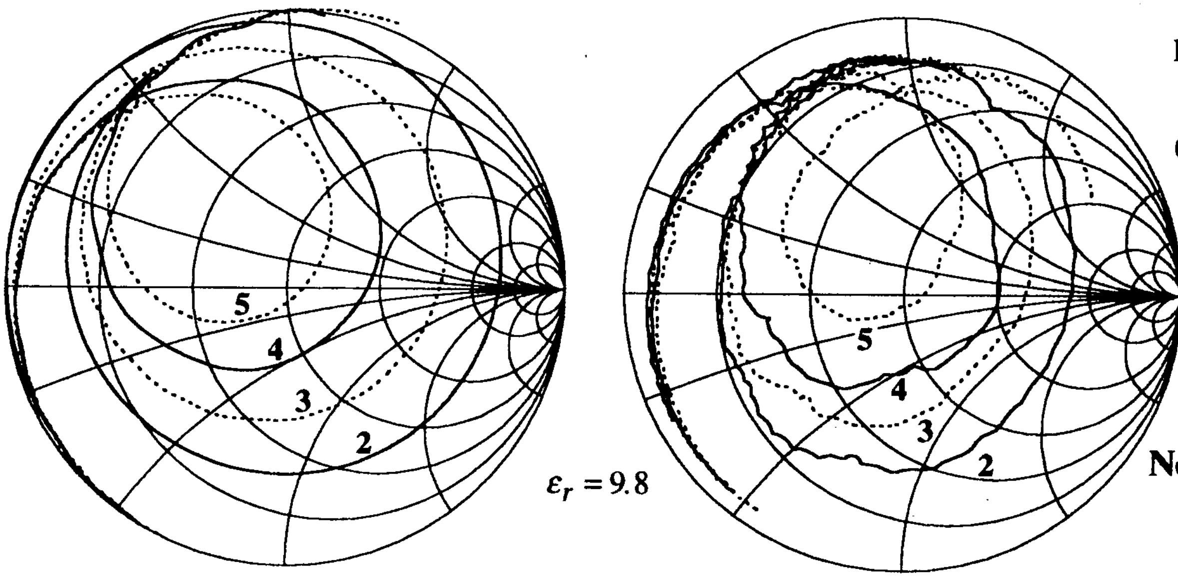
- **Excellent agreement between simulation and measurement.**
- **Great flexibility of analyzing different circuit configurations.**

Fig 1

UC SB
University of California, Santa Barbara

Impedance Scaling Using Multiple-Slot Antennas





$\varepsilon_r = 9.8$

FDTD simulation **Measurement**

Frequency Range :
5 GHz to 15 GHz
0.635 mm Alumina substrate

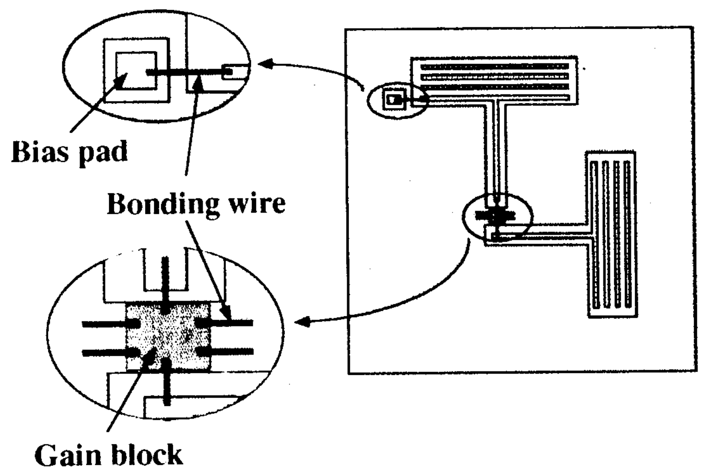
Notes :

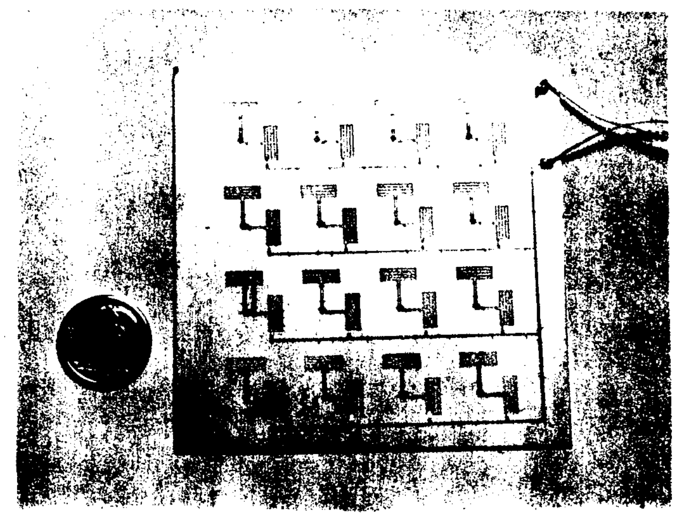
The resonant frequencies of these four antennas are about the same.

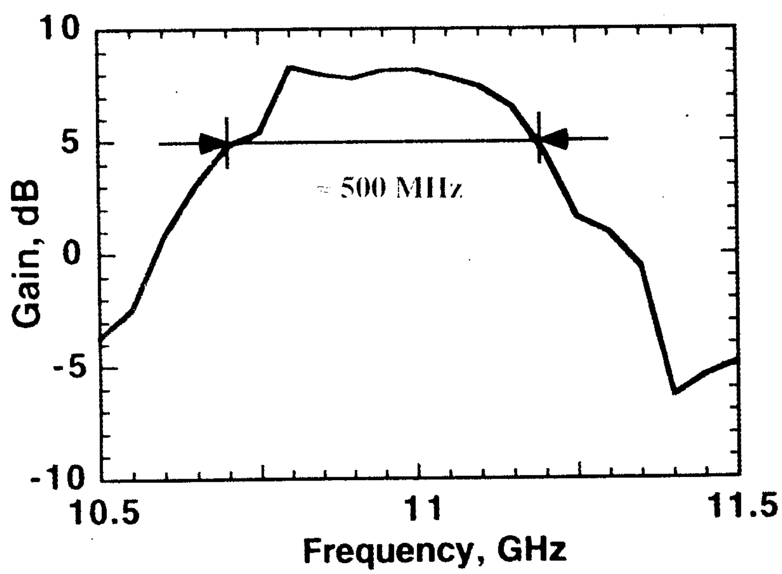
Fig 2

UC SB
University of California, Santa Barbara

4 x 4 HBT Amplifier Array







- 4x4 HBT array @ 10 GHz
- 0.635 mm Alumina substrate
- 50 Ω five-slot antennas, no matching
- 8 dB gain with ≈ 5 % bandwidth

Fig 3

List of Publications:

Journal Papers (listed chronologically)

1. H.-S. Tsai and R.A. York, "FDTD analysis of folded-slot and multiple slot antennas on thin substrates", to appear in *IEEE Trans. Antennas & Prop.*, October 1994.
2. H.-S. Tsai and R.A. York, "Multi-slot 50 Ω antennas for quasi-optical circuits", *IEEE Microwave Guided Wave Lett.*, vol. 5, no. 6, pp. 180–182, June 1995.
3. H.-S. Tsai and R.A. York, "FDTD Analysis of Planar CPW Circuits with Berenger's PML Boundary Condition", submitted to *IEEE Microwave Guided Wave Lett.*, July 1995.

Conference Papers (listed chronologically)

4. H.-S. Tsai and R.A. York, "Experimental and theoretical investigations of folded-slot antennas for quasi-optical arrays", *IEEE Antennas and Propagation Society Symposium Digest*, pp. 1518–1521, (Seattle), June 1994.
5. H.-S. Tsai and R.A. York, "Quasi-optical Amplifier Array using Broadband Antennas", *1994 International Conference on Millimeter-waves and Far-Infrared science and Technology* (Guangzhou, China), Sept 1994.
6. H.-S. Tsai, P. Liao, J.J. Lynch, A. Alexanian, and R.A. York, "Active Antenna Arrays for Millimeter-wave Power-Combining", *1994 International Conference on Millimeter-waves and Far-Infrared science and Technology* (Guangzhou, China), pp. 371–374, Sept 1994.
7. N. Cheadle and R.A. York, "Design and Calibration of a Wide-band FMCW Imaging Radar", *28th Annual Asilomar Conference on Signals, Systems, and Computers*, Oct 1994.
8. H.-S. Tsai and R.A. York, "Quasi-optical amplifier array with direct integration of MMIC and 50Ω antennas", *1995 IEEE MTT-S International Microwave Symposium* (Orlando), pp. 593-596.
9. H.-S. Tsai and R.A. York, "Applications of planar multiple slot antennas for impedance control, and analysis using FDTD and with Berenger's PML method", *1995 IEEE Antennas and Propagation Society Symposium* (Newport Beach, CA), pp. 370–373.