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Annual Report of Investigations Carried Out Under the Director's Discretionary Fund

October 1, 1983 to September 30, 1984

28 February 1985

National Aeronautics and Space Administration

JPL

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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M.T. Chahine

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FOREWORD

The JPL Director's Discretionary Fund (DDF) was established in 1969 as one provision of the 1968 Memorandum of Understanding (MOU) between NASA and Caltech. The principal objectives of the Fund are to make possible and promote innovative and seed efforts for which program funding is not available, and to encourage collaborative work with faculty and students at Caltech and other universities. These objectives were reaffirmed when the MOU was updated and rewritten in December 1978. Since the Fund cannot provide a sustained source of support for an activity, the potential for follow-on funding (but not DDF), from either NASA or non-NASA sources, is one consideration in evaluating a task proposal for DDF support. The funding level in fiscal year 1984 for all DDF tasks was one million dollars.

This annual report comprises a set of summaries, prepared by the principal investigators, describing task objectives, progress and results or accomplishments, future outlook, and financial status for each DDF task that was active during fiscal year 1984. Credit is given to personnel who contributed to the effort. Publications and conference presentations related to the work are also listed. The individual reports are categorized as interim or final according to whether the task efforts are on-going or completed. If categorized as a final report, it will usually contain a section, "Conclusions," which may provide a brief general summary and assessment or place the results of the task in perspective relative to other developments in the field.

A partial list of new tasks to be initiated with fiscal year 1985 funds is included as information beginning on page xi. A glossary of abbreviations and acronyms, used by the task authors in their summaries, begins on page xiv. The table of contents, starting on page xviii, lists the DDF reports in sequence by their task number, which is derived from the 13-digit code assigned to account for the funds awarded to the task project.

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NEW TASKS NOT REPORTED IN THIS ISSUE

The tasks listed below are new tasks recently selected for funding from fiscal year 1985 resources. They are not described in this volume, but a status report for each will appear in the next issue of the Annual Report.

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293	High Resolution Geophysical and Planetary Physics Modeling on the Concurrent Processor Charles F. Yoder, JPL Martin A. Slade, JPL Bradford H. Hager, Caltech
294	A Solid-State Argon Counter for Gamma Ray Astronomy Allan S. Jacobson, JPL William A. Mahoney, JPL Larry S. Varnell, JPL William A. Wheaton, JPL
295	The Design of a One-Meter Class Space Coronagraphic Telescope Richard J. Terrile, JPL B. A. Smith, University of Arizona
296	Applications of the Hypercube to Convolutional Codes Fabrizio Pollara, JPL Joseph H. Yuen, JPL Robert J. McEliece, Caltech
297	Custom VLSI Chip for the Emulation of Large Neural Arrays Leslie J. Deutch, JPL
298	Circularly Polarized Array Composed of Linearly Polarized Elements John Huang, JPL
299	Concurrent Prolog for the Hypercube Architecture Brian Beckman, JPL Thomas Runge, JPL Mitchell Roth, University of Alaska

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Carl S. Guernsey, JPL
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302 Integrated Vacuum Microelectronics
Henry L. Stadler, JPL
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303 Global Oceans Model Using Computer Graphics
Minoo N. Dastoor, JPL
Wesley Huntress, JPL
Berrien Moore, III, University of New Hampshire

304 Submillimeter Schottky Mixer Using GaAs/AlGaAs Heterojunction
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305 Semiconductor-Fiberoptic Laser Gyro
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306 Integrated Optical Processors Using Compound Semiconductor Technologies
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307 Application of NMR Imaging to Non-destructive Testing of Resins and Composites
Peter Frickland, JPL
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308 Image Processing and Analysis Algorithms for the Hypercube Processor
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309 CCD Sensitivity at Extreme Ultraviolet Wavelengths
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310 Dielectric Thin Films for Ultraviolet Spectral Imaging
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312 Concurrent Computation Project
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313 Micromachined Dielectric Components for Millimeter Wave Applications
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GLOSSARY

ABBREVIATIONS AND ACRONYMS

AAS	American Astronomical Society
ACCOS V	computer software program
AGU	American Geophysical Union
AIS	airborne imagery spectrometer
AO	announcement of opportunity
A-O	acousto-optical
AMSAT	Radio Amateur Satellite Corporation
ARMMS	autonomous redundancy maintenance management system
ASME	American Society of Mechanical Engineers
BWO	backward wave oscillator
CAD	computer aided design
CAE	computer aided engineering
Caltech	California Institute of Technology
CCD	charged-couple device
CID	charge induced device
CMOS	complementary metallic oxide semiconductor
CNES	Centre National d'Etudes Spatiales
CNR	Italian National Research Council
CNRS	Centre National AC Recherches Scientifiques
CRRES-MEB	combined release and radiation effects satellite-microelectronics package
CVD	chemical vapor deposition
CW	carrier wave
DARPA	Defense Advanced Research Projects Agency
D-C (d.c.)	direct current
DDF	Director's Discretionary Fund, JPL
DEP	density escape depth
DNA	deoxyribonucleic acid
DOD	depth of discharge
DSC	differential scanning calorimetry
DSN	Deep Space Network
EBE	element by element
ECL	emitter-coupled-logic

ECPR	electrically calibrated pyro-electric radiometer
EDM	engineering development mission
E-O	electro-optical
ESA	European Space Agency
ESD	electrostatic discharge
ESFITS	electronically scanned Fourier interference transform spectrometer
ESTEC	European Space Technology Center
FET	field effect transistor
FIR	finite impulse response
FOS	faint object spectrograph
FPI	Fabry-Perot interferometer
FTS	Fourier transform spectrometer
FY	fiscal year
GALCIT	Guggenheim Aeronautical Laboratory at the California Institute of Technology
HST	Hubble Space Telescope
IAC	Institute Administrative Council
IC	integrated circuit
IEEE	Institute of Electrical and Electronic Engineers, Inc.
IF (if)	intermediate frequency
IIR	infinite impulse response
IMPATT	impact avalanche transit time
IR	infrared
IRAS	Infrared Astronomical Satellite
JARS	JPL autonomous robot system
JEA	joint endeavor agreement
J-FET	junction-FET
JGR	Journal of Geophysical Research
JPL	Jet Propulsion Laboratory
JTF	JPL topological format
LBL	Lawrence Berkeley Laboratory, DOE
LED	light emitting diode
LO	low
LSI	large-scale integration
MASER	microwave amplification by simulated emission of radiation
MBE	molecular beam epitaxy

MGCO	Mars Geoscience and Climatology Observer
MIBB	memory interface building block
MIL	military
MIT	Massachusetts Institute of Technology
MOF	magneto-optical filter
MOU	memorandum of understanding
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NBS	National Bureau of Standards
NEC	Nippon Electric Company
NMOS	n-channel metallic oxide semiconductor
NOAA	National Oceanic and Atmospheric Administration
NOR	a functon of elements that is true if all elements are false
NRL	Naval Research Laboratory
NRO	NASA Resident Office, JPL
NSA	National Security Agency
OAST	Office of Aeronautics and Space Technology, NASA
OMCVD	organo-metallic chemical vapor deposition
ONR	Office of Naval Research
OSSA	Office of Space Science and Applications, NASA
PAT	product assurance technology
PASCAL	program applied to automatic selection and compilation of literature
PDP	program data processor
PDS	photometric data systems
PIDDP	planetary instrument definition and development program
PF	paraformaldehyde
PUMA	commercial six-degree-of-freedom manipulator
RF (rf)	radio frequency
RMS	root mean square
RO	ring oscillator
ROM	read-only memory
RT (r.t.)	room temperature
RTOP	research and technology objectives and plans
SAP	Societe d'Astronomie Populaire
SAR	synthetic aperture radar

SCF	spectrometer comparison factor
SEASAT	sea observing satellite
SEM	scanning electron microscope
SEXAFS	surface extended X-ray absorption fine structure
SMP	symbolic manipulation program
SOHO	Solar and Heliospheric Observatory
SOI	solar oscillations imager
SPIE	Society of Photo-Optical Instrumentation Engineers
SSDE	solar sail development experiment
SSP	Solar Sail Project
SSRL	Stanford Synchrotron Radiation Laboratory
ST	space telescope
STD	standard
SWG	science working group
TDA	Office of Telecommunications and Data Acquisition, JPL
TDDB	time-dependent dielectric breakdown
TWTA	traveling wave tube amplifier
TV	television
UCLA	University of California at Los Angeles
UCSB	University of California at Santa Barbara
UHV	ultra high vacuum
ULYSSES	computer program for design description and simulation
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USC	University of South Carolina
USC	University of Southern California
UV	ultraviolet
VAX	virtual address executive
VLA	very large array
VLBA	very long baseline array
VLBI	very long baseline interferometer
VLSI	very large-scale integration
XPS	X-ray photoemission
YIG	yttrium iron garnet

CONTENTS

INTERIM REPORTS

and

FINAL REPORTS

SEASAT SAR ELEVATION IMAGES

Interim Report

JPL /30-00197-0-3300

Richard M. Goldstein, JPL

A. OBJECTIVE

To obtain elevation estimates for each resolution element in a set of Seasat radar images, using multiple passes of raw Seasat SAR data.

B. PROGRESS AND RESULTS

Five additional images of a part of Death Valley have been processed. They correspond to a variety of interferometer baselines, including wide separation which has the greatest sensitivity to elevation changes.

In addition, some data were collected over the Canadian Rockies by the recent SIR-B shuttle flight. (The shuttle experiment is the result of earlier work from this DDF task.)

C. FUTURE OUTLOOK

The new data will enable us to investigate the limit of elevation accuracy afforded by large baselines.

D. FINANCIAL STATUS

The DDF award to this task in FY'81 was $38.0 K. About $20 K has been expended and the remaining funds appear sufficient for us to finish the investigation of the new images.

E. PERSONNEL

Fuk L. Li and Chong-Yung Chi have processed the latest set of Seasat passes.

F. PUBLICATIONS

A paper on interferometric radar topography was given at the June 1984 meeting of the International Congress of Photogrammetry and Remote Sensing in Brazil.

A POSITION-SENSITIVE GERMANIUM DETECTOR FOR GAMMA-RAY ASTRONOMY

Interim Report

JPL 730-00225-0-3280

Allan S. Jacobson, JPL
James C. Ling, JPL
Larry S. Varnell, JPL

A. OBJECTIVES

The primary objective of this task is to develop and fabricate a position-sensitive germanium gamma-ray detector that can effectively discriminate against internal background, yet maintain the high spectral resolution and efficiency of the coaxial Ge detectors used in gamma-ray astronomy. Additional objectives include the design and construction of the test cryostat and electronics necessary for laboratory evaluation of the detector, comparison of the actual performance of the detector with predictions, and studies of the expected performance of the detector in the energetic particle environment of balloon or space flight.

B. PROGRESS AND RESULTS

Work continued at LBL (Lawrence Berkeley Laboratory) to develop their capability to fabricate conventional reversed-electrode coaxial detectors and to segment a coaxial detector. A lower grade Ge coaxial crystal was divided into two segments to verify the segmentation techniques developed with a planar detector. This test was successful and a conventional detector was made of the high-grade Ge crystal bought in April 1983. Unfortunately, this detector showed serious carrier trapping. A second crystal was obtained in exchange. Efforts are now under way to make a segmented detector from this crystal. If the conventional detector made with this crystal is good, a five-segment detector should be ready by the end of December 1984. In the meantime, the cryostat and electronics necessary for testing the segmented detector have been assembled, with many of the components resulting from innovative designs driven by the requirements of multi-detector systems.

C. FUTURE OUTLOOK

We expect the segmented detector system to be delivered to JPL in January 1985. Extensive laboratory tests are planned to measure the detector's performance and to compare this to Monte Carlo calculations. This work will be carried out under funding from a grant from the Planetary Instrument Definition and Development Program (PIDDP). Testing of the five-segment detector will be completed by June 1985. A second five-segment detector will be fabricated under the PIDDP program. A proposal has been submitted for consideration by the Defense Advanced Research Projects Agency (DARPA).

D. FINANCIAL STATUS

The total DDF funding for this task (FY 82 and FY 83) was $75,000. As of the end of October 1984, all funds have been spent, including $29,000 in a work order to LBL. Additional funds from a PIDDP grant are being used to complete fabrication and perform laboratory testing of the segmented coaxial detector.

E. PERSONNEL

Overall direction of this effort at JPL is provided by Allan S. Jacobson, Supervisor, High Energy Astrophysics Group, Section 328. The execution of the effort at JPL was carried out by James C. Ling and Larry S. Varnell.

The detector work at Lawrence Berkeley Laboratory is under the direction of Richard H. Pehl.

F. PUBLICATIONS

The mechanical and electronic design innovations developed at LBL for the test cryostat have been described in a paper entitled "Cryostat and Electronics Development Associated with Multi-detector Spectrometer Systems" by R. H. Pehl and colleagues at LBL, to be published in IEEE Transactions on Nuclear Science, Volume 32, 1985.

BASIC LSI
DATA COMPRESSION SYSTEM

Interim Report

JPL 730-00228-0-3480

Robert F. Rice, JPL

A. OBJECTIVE

The objective of this task at inception in FY'82 was to design, fabricate, and test a custom-LSI chip that would be a basic component of a set of chips embodying all functions of a full data-compression system.

A particular set of variable-length coding algorithms was identified that would offer suitable candidates for LSI design and fabrication. These were already being implemented, or were planned for implementation, for a number of diverse applications, e.g., Voyager, Galileo, a NOAA weather satellite system, electronic mail, freeway surveillance, etc.

Initially, work focused on the design of circuits that would be "performance estimators" for the basic variable-length coding functions. While not being able actually to perform coding, these estimators can be used in adaptive coders to select which of several variable-length coding functions would perform best on a given data sequence.

As work progressed, investigations of possible design architectures revealed that, in addition to the estimator function, the basic coding functions could themselves be implemented. The overall increase in complexity was judged to be manageable, and the task was then redirected towards this more ambitious goal.

With proper interfacing, the chip(s) resulting from this expanded design goal could be imbedded within an operational JPL breadboard image data compressor developed for freeway surveillance. Replacement of a part of this system would yield an effective demonstration of JPL's ability to carry a chip-design through all the stages.

B. PROGRESS AND RESULTS

Functional operations were logically split into two chips instead of one, early in the design phase. It was also noted that a worthy demonstration satisfying the major goals of the task, could be achieved by connecting Chip 1 with the breadboard image compressor noted above. LSI design emphasis in FY'83 then focused almost entirely on achieving a successful completion and demonstration of the first of a two-chip implementation. This effort led to the successful testing of two of four "macro-cells" and to the design of interface logic ("leaf" cells) and wiring that could connect the macro cells together.

FY'84 efforts led to the fabrication and successful lab testing of the complete chip as well as modification of the existing JPL breadboard compressor to accept the chip as an integral part. However, personnel problems have jeopardized the completion of this last step. Principal designer Raymond Eskenazi left JPL before the transfer to breadboard testing could begin. At roughly the same time, a deficiency in the JPL billet allocations left the breadboard designer without a job; and this situation persisted for the last two months of FY'84.

C FUTURE OUTLOOK

The breadboard designer, O. Bruce Parham, now has an official flight project billet. Only a small amount of work remains to verify if the chip will function within the existing breadboard compressor. However, completion of this test is totally contingent on obtaining several hours of designer Eskenazi's time. This should be possible within the first quarter of FY'85.

D. FINANCIAL STATUS

The DDF award for this task was $34K in FY'82. This amount was subsequently boosted by $45K in FY'83 for a total of $79K. There remains approximately $2K to complete breadboard tests in FY'85. This should be sufficient.

E. PERSONNEL

The algorithms selected for implementation were the creation of Robert F. Rice. VLSI design efforts on this task were due principally to Raymond Eskenazi with support from Mois Navon. The implementation architecture was arrived at with the consultation of UCLA Professor Vance Tyree and JPL's Marvin A. Perlman, Robert A. Johnson, and Alan P. Schlutsmeyer. Compressor breadboard interfacing design and implementation was provided by O. Bruce Parham.

F. PUBLICATIONS

The following are recent publications dealing with the use of algorithms being implemented in this task.

R. F. Rice and J. J. Lee, "Some Practical Universal Noiseless Coding Techniques, Part II," JPL Publication 83-17. March 1, 1983.

R. F. Rice, "Mission Science Value/Cost Savings from the Advanced Imaging Communication System (AICS), JPL Publication 84-33. July 15, 1984.

COMET SAMPLE RETURN CONCEPT VALIDATION

Interim Report

JPL 730-00240-0-3130

Peter Tsou, JPL

A. OBJECTIVES

The atomized sample return concept for the collection of cometary samples was developed for the Halley Intercept Mission. The concept for dust collection is based upon the vaporization of dust upon impact with a thin diaphragm; and then the condensed volatiles are collected and returned. The objectives of this task are, first, to test in the laboratory the overall validity of this experiment concept and, second, to evaluate the efficacy of the collection process.

B. PROGRESS AND RESULTS

This effort consists of two tasks: hypervelocity impact tests and laboratory analyses of impacted specimens. The hypervelocity impact effort was carried out primarily at NASA Ames' vertical two-stage light-gas gun. During FY'84, 20 additional shots for the atomized concepts and 37 shots for the intact sample return were made at the Ames facility. Significant progress was made in understanding the intact sample return [Tsou et al. 1984]. Exploratory experiments were also made in three German facilities: Max Planck Institute, Ernst Mach Institute, and University of Munich. Their hypervelocity facilities are more current and have higher performance. For example, their two-stage light-gas gun can achieve 9.3 km/s for 2-mm Al projectiles vs Ames' 6.5 km/s.

Hypervelocity Impact Tests. In addition to aluminum spherical projectiles, Wellman meteorite was prepared by core drilling 1/8" cylinders, and Allende meteorite pellets were made from Allende powder and epoxy. Amazing results were discovered from low velocity intact capture by expanded polystyrene with these meteorite projectiles. Figures 1 and 2 show the Wellman recovered at 3.5 km/s and Allende recovered at 2.4 km/s, respectively. Note there is no melting but rather sheared effects.

Laboratory Analysis. Both optical and SEM microscopy was used to analyze the captured intact samples after sectioning as seen in Figures 1 and 2. For the atomized tests, condensed vapors in the simulation tests were analyzed in the SEM using energy dispersive X-ray analysis. Film thickness was quantitatively measured using X-ray thin film reduction procedures.

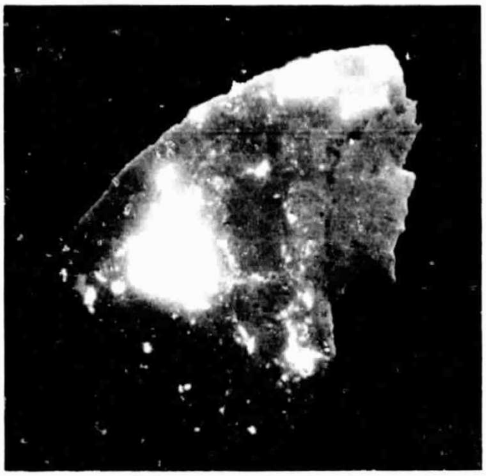

Figure 1. Captured Wellman

Figure 2. Captured Allende

Detailed X-ray analyses of condensates in the atomized concept showed that the capture efficiency increased with cell volume and decreased with increasing diaphragm thickness. Capture efficiencies of >80% were attained with optimal cell parameters. Deposited metal films on Teflon were vaporized after impacts indicating at least 100 Å of the Teflon surface was ablated away.

C. FUTURE OUTLOOK

Both the atomized and intact sample collection concepts hold very good promise. The recent interest in using ESA's GIOTTO spares for a sample return mission increased the urgency in the development of these concepts for a flight instrument. A proposal to the Planetary Instrument Definition and Development Program (PIDDP) is being prepared again for validation of these concepts, which would lead to the instrument development. It is expected that the funding environment is more favorable toward the concept this time. If it is so, the seed money provided by this DDF will have yielded quick fruits.

It is expected that the validation task will be completed in FY'85.

D. FINANCIAL STATUS

The total DDF awarded to this validation task in FY'82 and FY'83 totals $87K. As of September 30, 1984, $75K was spent.

Additional funding for the instrument development is being sought through the PIDDP program for FY'85.

E. PERSONNEL

The research is performed by Peter Tsou with bulk of the analysis performed by Donald Brownlee of University of Washington and Randy Heuser of Caltech's Electron Microprobe Laboratory. The task is directed by Arden Albee.

F. PUBLICATION

A paper titled, Experiments on Intact Capture of Hypervelocity Particles, was presented by Arden Albee at the 15th Lunar Planetary Science Conference, March 1984 [Tsou et al, 1984].

G. REFERENCE

P. Tsou, D. Brownlee, and A. Albee, "Experiments on Intact Capture of Hypervelocity Particles," 15th Lunar Planetary Science Conference, March 1984.

MICROFORM PUBLICATION OF THE FRANK J. MALINA AERONAUTICAL PAPERS

Interim Report

JPL 730-00247-0-1000

Judith R. Goodstein, Caltech

A. OBJECTIVES

The objective of this task is to organize and microform the scientific and personal papers of Frank J. Malina. Malina, an American rocketry pioneer (1912-1981), co-founder of the Guggenheim Aeronautical Laboratory at the California Institute of Technology [GALCIT] Rocket Research Project and the Jet Propulsion Laboratory [JPL], and Director of the Laboratory (1944-1946), left more than 25,000 items in his Paris apartment, relating to his scientific career, including personal letters with his mentor Theodore von Karman, Aerojet correspondence and documents, notes on rocket propulsion, early technical papers and reports dealing with jet propulsion and rocket projectiles (1938-1946), files from his Caltech graduate student days, and a considerable amount of manuscript material relating to astronautics, in general, and the history of JPL, in particular.

Malina played a central role in the development of rocketry in the United States from the mid-1930s through the mid-1940s, and in the development of rocket research in the North Atlantic Treaty Organization [NATO] countries later on. He also played a pivotal role in the founding of the International Academy of Astronautics and worked closely with that organization, as well as the International Astronautical Federation, for many years. Malina was an avid collector of primary source materials relating to the original GALCIT Rocket Research Project and the early history of JPL, and left his collection of letters, documents, reports, notes, manuscript material, and reprints to the Library of Congress on his death. For these reasons, Malina's scientific papers are widely regarded as one of the richest collections of original documents bearing on the history of twentieth century science and technology.

B. PROGRESS AND RESULTS

The Frank Malina microform publication project has turned a significant corner. In the course of the year, the contents of 42 manuscript boxes, representing an estimated 40,000 original records, have been microfiched at Delta Graphics in Santa Monica, a JPL contractor. The microfiche edition of the present collection consists of 491 cards, each card corresponding to and bearing the same folder number as the original folder title. To facilitate use of the microfiche collection by researchers, the master set will be stored at the JPL microfilm center. One copy will be deposited in the Caltech Archives, a second set will be given to the Malina family. Following the instructions of the family, the original records will be shipped to the Library of Congress, as soon as arrangements are completed. Work on the collection index is complete, save for the introductory material, including a chronology of Malina's life, and a description of the collection.

C. FUTURE OUTLOOK

While visiting Mrs. Marjorie Malina in Paris this summer, Daniel J. Boorstin, the Librarian of Congress, unexpectedly found additional papers stored in a gardener's shed on the property. Mrs. Malina reported this find to us and, in October 1984, the Archives received two footlockers of manuscript material, filling 12 manuscript boxes. Primarily correspondence, much of the new material complements the existing collection. The plan is to review this material, weed out extraneous or marginal documents, and organize and microfiche the rest.

About one-third of the supplemental material relates to Malina's major involvement in international astronautical activities during the 1960s and 1970s, especially the International Academy of Astronautics. Malina was a founding member and an early president of the organization.

The remainder, personal correspondence, covers the years 1938 to 1980. In many instances, these files are a continuation of files in the present collection. The letters document Malina's involvement with artists and scientists throughout the world, and over many years. Some of the intellectual and personal events revealed by the letters date back to Malina's early Caltech/JPL/Aerojet days. Some of the prominent correspondents represented in Malina's Pasadena era include Martin Sommerfield, pioneer rocket engineer, Andrew C. Haley, space law expert, and his Caltech mentor Theodore von Karman. During his years (1945-1953) at the United Nations Scientific, Educational, and Scientific Organization [UNESCO] in Paris, Malina's circle of scientists and artists became truly international. The most recent letters record his intense involvement in art and technology, in the journal he founded, Leonardo. Colleagues he exchanged letters with during the last phase of his life include the Polish polymath Jacob Bronowski, Hungarian sculptor Peter Lambda, American artist Tom George, Italian physicist Giorgio Careri, and Israeli scientists Leo Picard and Sydney Goldstein.

Although it means some months of additional work, we are confident that the supplementary material will enhance and enrich the utility of the Malina microform collection.

D. FINANCIAL STATUS

The FY82/83 DDF award for this project was $25.3K. Due to the expenses incurred relating to the additional materials received, Dr. Goodstein requested and received $13K supplemental funds to complete the task.

E. PERSONNEL

The work done at Caltech has been carried out by Ms. Carol Buge, the assistant archivist, Ms. Loma Sprude, the project typist, and Dr. Judith Goodstein, the principal investigator. Frank Malina's widow, Marjorie Malina, and Malina's son, Dr. Roger Malina, a staff scientist at Berkeley's Space Laboratory, assisted Dr. Goodstein in locating, sorting, and identifying family papers in Paris and in Pasadena. Technical support from JPL has been provided by J. M. Fisher, M. A. Fea, P. L. Fleming, and R. T. Chandler.

F. PUBLICATIONS

A guide to the Malina Papers, now in preparation, will be published in a limited edition in 1985, using JPL's Photo-Duplicating Division.

LINEAR INFRARED DETECTOR ARRAYS FOR SPACE ASTRONOMY

Interim Report

JPL 730-00250-0-3820

J. B. Wellman, M. Herring, G. C. Bailey, M. A. Blessinger, JPL
K. Matthews, B. T. Soifer, G. Neugebauer, Caltech.

A. OBJECTIVES

The objectives of this task are (1) to characterize the performance of multiplexed indium antimonide linear detector arrays under conditions representative of a Space Telescope (ST) infrared spectrometer experiment and (2) to acquire relevant spectral observations using a cryogenic spectrometer with the Hale telescope to demonstrate the performance of the array under conditions similar to those appropriate for the ST instrument.

The task is shared between JPL and Caltech with the Caltech investigators responsible for the majority of the effort including the development of the spectrometer and much of the low-temperature detector evaluation. JPL is responsible for providing a 128-element detector to Caltech for use in the spectrometer including supporting electronics and test data. JPL is also responsible for the evaluation of a 512-element detector. These detectors were previously developed under the imaging spectrometer project funded by NASA-OSSA.

The original proposal calls for completion of these activities on a schedule consistent with the release of a NASA AO for second-generation space telescope instrumentation. This AO has subsequently been delayed allowing a modification in the priorities for this effort.

B. PROGRESS AND RESULTS

The testing performed to date at JPL and Caltech supports the viability of the indium antimonide linear array technology in space astronomy applications. While the spectrometer has not yet been operated on the Hale telescope, the laboratory testing has yielded some impressive results. In the interim report for FY'83, a detailed discussion of detector testing was given. The principal new data at this writing is for temperatures below 46 K. The detector has now been characterized over the temperature range of 23 to 64 K. At 23 K the device is not useable because the J-FET preamp no longer operates. At 23.7 K (the lowest useable operating temperature) the performance appears to be shot-noise limited for integration times greater than 200 sec.

The major progress in FY'84 has been the checkout and integration of the spectrometer and dewar. The system has been tested with a single detector in preparation for the installation of the 128-element array. These test results show that the spectrometer resolution is very close to the original design goal and that the overall throughput is about 20%. Additional work required on the spectrometer includes reducing heat leaks in the dewar and reducing the stray radiation reaching the detector.

In addition to the spectrometer and dewar work, the hardware and much of the software for control of the array has been completed and tested.

A major problem that has delayed the completion of the spectrometer is the mechanical integrity of the dewar, particularly a cold vacuum leak. These problems now appear to be cured.

C. FUTURE OUTLOOK

The current forecast for completion of the spectrometer checkout and installation on the 5-meter telescope is the first half of 1985. All of the laboratory testing to date supports the original predictions of performance, and a successful telescope demonstration is anticipated. While the original funding has been exhausted, the Caltech team will continue their efforts utilizing other funding sources.

D. FINANCIAL STATUS

The DDF funds allocated to this task, $79.2 K in FY'83, were exhausted during FY'84. As mentioned above, the work will be continued at Caltech with support from other sources.

E. PERSONNEL

The personnel assigned to this task are as reported previously. The balance of the remaining work will be accomplished by Keith Matthews and Tom Soifer of Caltech.

F. PUBLICATIONS

A major publication supported in part by this task was "Operation of Integrating Indium Antimonide Linear Arrays at 65K and Below," presented at the August 1983 SPIE meeting in San Diego. There have been no other publications to date.

INVESTIGATION OF MIXED ALLOY SILICIDES
FOR IR DEVICES*

Interim Report

JPL 730-0258-0-3460

James K. Liu, JPL

and

GROWTH OF EPITAXIAL $Hg_{1-x}Cd_xTe$ THIN FILMS
by OMCVD FOR INFRARED DETECTOR APPLICATIONS*

Interim Report

JPL 730-00279-0-3460

Solomon Zwerdling and Ke-Li Wang, JPL

A. OBJECTIVES

The principal objective of these tasks is to investigate the spectral and electrical properties of mixed ternary silicide thin films of appropriate metal alloys formed on silicon substrates for infrared detector device applications. The work is based on the concept that by forming a mixed silicide as a Schottky barrier metal-like electrode, one could continuously vary the barrier height for photo-excited charge carriers by changing the alloy ratios and, thus, controllably vary the long-wavelength response cut-off of the detector. The study seeks to analyze spectral reflectance and/or transmittance measurements of the silicide films and interpret any wavelength-dependent structure, as well as to evaluate such other pertinent optical properties as refractive index and absorption coefficient.

B. PROGRESS AND RESULTS

Initial efforts were directed toward the fabrication of platinum, palladium, molybdenum, and iridium silicides on silicon substrates by evaporation and deposition of thin metal films onto Si substrate wafers, followed by heat treatment at suitable temperatures for silicides to form as thin layers. This fabrication effort was collaboratively undertaken by the research group at Caltech, under the direction of Professor Marc-A. Nicolet, by means of a work order arrangement and the transfer of $16K in obligation authority. The Caltech effort was performed under JPL Work Order 61542, which is entitled "Formation of Ternary Silicides for IR Applications." A midterm report from Prof. Nicolet dealing with a study of hexagonal $MoSi_2$ is attached. The formal Caltech research effort was completed as of 30 September 1984, although informal sample preparation assistance is continuing. The results of the second half of the effort

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*This report combines two DDF tasks having related objectives. The unusual circumstances are described in Section G, "Remarks."

are being analyzed and a final report is being prepared. Based on this work, an article has been submitted by Prof. Nicolet's group for publication in the IEEE Transactions on Electron Devices entitled "An Improved Forward I-V Method for Non-Ideal Schottky Diodes with High Series Resistance," by C. D. Lien, F. C. T. So, and M-A. Nicolet. A second paper, entitled "Electrical Properties of $MoSi_2$," has also been prepared for publication.

In JPL Section 346, two spectrophotometers are in operation for performing spectral measurements on the silicides through the visible and the infrared wavelength regions (0.38 to 25 μm). Samples of palladium, platinum, and nickel silicide are being measured in the latter region, and more samples are being prepared at Caltech under different controlled conditions for these studies. The preparation of the interesting compound, iridium silicide, is also being undertaken for this study. The reason is because on p-type Si of moderately heavy doping, iridium silicide provides the basis for a silicon compatible Schottky diode infrared detector currently with the lowest barrier energy available and, therefore, the longest cut-off wavelength (~8 μm) compared to the silicides of other commonly used metals such as platinum and palladium, which have cut-off wavelengths not exceeding 6.5μm.

C. FUTURE OUTLOOK

Experiments are continuing involving the fabrication of single-metal silicide samples on silicon substrates and the measurement of their reflectance spectra (and the transmittance spectra when feasible). These measurements constitute a search for spectral features that can give a clue to the generation and behavior of photo-excited "hot" carriers in the silicide, which are the basis for the output signal of the silicide-silicon detector. Prof. Nicolet's group will also be asked to attempt the preparation of a mixed alloy silicide of iridium and palladium on p-type Si, using an ion mixing procedure to create a uniform and homogeneous alloy of these silicides. If such material fabrication is possible, spectral studies will be made to examine and analyze the features of the reflectance (and transmittance) in the wavelength range 0.37-10.0 μm and beyond.

D. FINANCIAL STATUS

The DDF award for FY'83 for the task "Investigation of Mixed Alloy Silicides for IR Devices" was made to Dr. James K. Liu in December 1982 for $50K. It was assigned JPL Account 730-00258-0-3410 (later changed to -3460). The actual obligations to 21 October 1984 are $50,957, and the actual costs are $45,017. There are no funds remaining in this account for further obligations.

The DDF award for FY'84 for the task "Growth of Epitaxial $Hg_{1-x}Cd_xTe$ Thin Films by OMCVD for Infrared Detector Applications" was made for $60K to Dr. Solomon Zwerdling in December 1983. It was assigned JPL Account 730-00279-0-3410 (later changed to -3460). The actual obligations to 21 October 1984 are $38,958, and the actual costs are $38,951. The unobligated balance will be used toward the completion of the task.

An explanation of the circumstances and funding for these tasks is given in Section G.

E. PERSONNEL

The initial direction of the effort on the task "Investigation of Mixed Alloy Silicides for IR Devices" was provided by Andrew Morrison, supervisor of the Semiconductor Crystal Materials Group. The initial execution of the effort was performed by Dr. James K. Liu prior to his resignation from JPL early in FY'84. Subsequent execution of the effort was assigned to Dr. Solomon Zwerdling with assistance by Dr. John Lambe in May 1984.

The execution of the effort on "Growth of Epitaxial $Hg_{1-x}Cd_xTe$ Thin Films by OMCVD for Infrared Detector Applications" was assigned to Dr. Solomon Zwerdling. However in May 1984, approval was given for him to combine the two efforts in that both were concerned with materials for infrared devices.

Assistance for the combined effort was rendered by Dr. John Lambe and Dr. Paula Grunthaner of JPL, and the effort for producing and studying the silicide materials remained assigned to Prof. Nicolet and his group at Caltech under the JPL workorder granted.

F. PUBLICATIONS

1. C. D. Lien, F. C. T. So, and M-A. Nicolet, "An Improved Forward I-V Method for Non-Ideal Schottky Diodes with High Series Resistance," submitted for publication to IEEE Transactions on Electron Devices.

2. Wen Teh Chang, M-A. Nicolet and M. Van Rossum, "Electrical Properties of $MoSi_2$," prepared for publication.

G. REMARKS

The execution of the effort proposed under the DDF project "Growth of Epitaxial $Hg_{1-x}Cd_xTe$ Thin Films by OMCVD for Infrared Detector Applications" was based on the assumed availability of an existing OMCVD apparatus at JPL. When it became clear in May 1984 that this apparatus would not be available, it became necessary to alter the task and to continue to direct its thrust toward the study of infrared detector materials and applications. After review of the circumstances with the Section Management and the Chief Technologist, the decision was made to combine this effort with the DDF project entitled "Investigation of Mixed Alloy Silicides for IR Devices" and to conduct a study on selected metal silicide thin films on silicon wafer substrates. The objective of the combined study would be to analyze the features of the spectral reflectance and absorptance properties of this silicide structure and correlate the results with the electrical properties, as they both pertain to infrared detector devices. This combined effort began during the early part of June 1984. Assistance was provided by Dr. John Lambe and Dr. Paula Grunthaner of JPL.

FORMATION OF TERNARY SILICIDES FOR IR APPLICATIONS

Midterm Report

(JPL WORK ORDER 61542)

Marc-A. Nicolet, Caltech

We have undertaken the study of the electrical characteristics of thin films of hexagonal (C40) $MoSi_2$. Since hexagonal (C40) $MoSi_2$ has a structural similarity with $CrSi_2$, this similarity makes it a plausible candidate for semiconducting properties. The (C40) $MoSi_2$ phase was formed by electron-gun evaporation of 1200 Å of Si followed by 500 Å of Mo on SiO_2. The sample was then ion-mixed at a temperature of 415°C. The irradiation doses varied between 3×10^{15} cm^{-2} and 1×10^{16} cm^{-2} of 300 keV Xe^+. Structural characterization of the mixed samples, done by X-ray diffraction, confirmed the presence of a predominant (C40) $MoSi_2$ phase. Preliminary electrical characterization was performed by four-point probe and Hall-effect measurements using a van der Pauw configuration at room temperature. The resistivity of the Mo-Si bilayer samples reached an approximately constant level of ~450 μΩ-cm after irradiation with ~5×10^{15} Xe cm^{-2}. The Hall mobility μ_H determined on a sample irradiated with 5×10^{15} Xe cm^{-2} was 0.09 $cm^2\ V^{-1}s^{-1}$. We found a p-type conductivity with a carrier concentration of 1.5×10^{23} cm^{-3}. Therefore, it appears that the high resistivity of hexagonal $MoSi_2$ (compared to tetragonal $MoSi_2$, for which $\rho \simeq 50$ μΩ-cm) is due to a low carrier mobility rather than to a low carrier concentration in the material at room temperature. The origin of this low mobility still has to be understood. We intend to extend the electrical measurements to elevated temperatures.

RADAR DETECTION OF OCEAN CURRENTS

Interim Report

JPL 730-C0261-0-3300

Richard M. Goldstein, JPL

A. OBJECTIVES

The objective of this task is to devise and test a synthetic aperture system that can detect and measure the ocean current for each resolution element in the scene.

B. PROGRESS AND RESULTS

The data for our first attempt have proved inadequate. Most of the difficulty was the result of unfortunate timing; the data were collected over San Francisco Bay only 1/2 hour from slack water time. Another problem has been the placement of the second interferometer antenna (under the wing). The resulting baseline has a large component across-track, producing high sensitivity to the aircraft attitude. Although we could detect no ocean currents, the CV-990 roll was observable in the data.

C. FUTURE OUTLOOK

The summer (1984) flight series collected data with much better potential for ocean currents. For example, data were obtained over San Francisco Bay on September 26, 1984, only 1/2 hour from a current maximum of 5 knots. In addition, a new antenna was mounted near the forward baggage door, giving substantially more sensitivity to ocean currents and considerably less to aircraft attitude.

We expect to have processed images in mid-December, after the SIR-B rush slows.

D. FINANCIAL STATUS

The DDF award to this work was $32.0 K in FY'82. The cost of data collection and of the new antenna has been absorbed elsewhere, leaving sufficient DDF funds to finish the task.

E. PERSONNEL

T. W. Thompson supervised the data collection aircraft flights.

F. PUBLICATIONS

None.

A STUDY OF THE IMAGING POTENTIAL OF A SPACE VLBI OBSERVATORY

INTERIM REPORT

JPL 730-00270-0-3350

Robert A. Preston, JPL
Anthony C. S. Readhead, Caltech
Bernard F. Burke, MIT

A. OBJECTIVE

The rapid developments in Very Long Baseline Interferometry (VLBI) over the last few years have led to proposals for constructing dedicated VLBI instruments both on the ground and in space. The astronomy community has recognized the potential of this technique as is shown by the high priorities given by the Astronomy Survey Committee (Field Committee) of the National Academy of Sciences to the construction of both a ground-based VLB Array and a space VLBI observatory.

Despite this recommendation, the orbiting VLBI project had not yet received the strong backing that it deserved from the astronomy community when this task was begun, since neither the potential of the facility nor the need for an orbiting observatory had been adequately demonstrated. The objective of this present task was to show, by means of computer simulations, the enormous increase in imaging power that will be afforded by an orbiting telescope, and to show via observations at 1.3-cm and 7-mm wavelenghts, that there are compact structures in the nuclei of active galaxies, which will be mappable with the orbiting telescope when used in conjunction with ground-based facilities.

B. PROGRESS AND RESULTS

NASA and ESA are currently engaged in a joint mission study of an Explorer class orbiting VLBI observatory named Quasat. We have taken the preliminary design parameters for this mission as the basis for our study of the imaging capability of a space VLBI instrument. It was assumed that the space observatory would observe simultaneously with the planned 10-antenna dedicated ground array (VLBA) and with antennas of the European VLBI network. The ground arrays alone provide images with angular resolution up to 10^4 finer than other ground-based astronomical instruments, and over a hundred times greater than any planned astronomical instrument, including the Space Telescope. The addition of an orbiting telescope to a ground VLBI array will allow the synthesis of apertures larger than the Earth, and, hence, achieve image reconstruction of even finer detail.

The VLBI imaging software package at Caltech has been revised to allow the inclusion of an orbiting antenna. The first simulations tested the ability of Quasat to produce images of sources with simple structure. The results clearly demonstrated the increased resolving power of Quasat compared to the VLBA.

Simulations with much more complicated sources have also been performed to test the complexity of images which are possible with Quasat. The comparisons between the VLBA and Quasat were again dramatic, with the complex sources being reproduced by Quasat in startingly fine detail. Quantitative differences between the simulated map and the original source model have been calculated for different areas of the map and for different strength sources. The maps all approach the thermal noise level (about 0.2 mJy/beam) outside the source, and are a few times less reliable near the brightest source components.

Other simulations have investigated the field of view of the maps, the fineness of detail that can be reliably reproduced, map quality versus mapping time, southern hemisphere imaging, and orbit optimization.

A preliminary ground-based VLBI survey of the two dozen bright sources was performed at the extemely short wavelength of 1.3 cm. The results indicated that bright compact structure is a common feature of extragalactic radio sources at a smaller size scale than had been previously explored. Quasat will have a rich selection of objects to observe.

C. FUTURE OUTLOOK

Before the study ends, we will perform a few more simulations to further understand the benefits of a Quasat mission. In addition, we are preparing for additional ground-based VLBI surveys at short wavelength (1.34 cm and 7 mm) to investigate the existence of ultra-fine scale structure in celestial sources. A 43-GHz receiver should soon be installed at the Caltech Owens Valley Observatory.

The simulations have already produced strong justification for a space VLBI observatory. Preliminary results of the studies have elicited favorable reactions from not only the VLBI community, but also from both NASA and ESA headquarters.

D. FINANCIAL STATUS

Four thousand dollars have been spent out of a $13K grant in FY83. The DDF grant is supplementary to a larger concurrent President's Fund grant covering the same work. In addition, the Quasat mission assessment study is also supporting the simulation effort.

E. PERSONNEL

The following people have worked on this task, and all have been resident at JPL/Caltech during some portion of the study: JPL - R. A. Preston, D. L. Meier, R. P. Linfield, S. Bolton, J. F. Jordan, and A. E. Niell; Caltech - A. C. S. Readhead, K. F. Evans, C. Lawrence, T. J. Pearson, A. T. Moffet, and S. C. Unwin; MIT - B. F. Burke and V. Dhawan; Brandeis University - D. H. Roberts; NRAO - T. J. Cornwell; Naval Research Laboratory - K. Johnston, R. Simon, J. Spencer; Jodrell Bank - P. Wilkinson.

F. PUBLICATIONS

A preliminary report on the simulation results has been prepared and submitted to the U.S. and European Quasat working groups for review.

A NEW CONCEPT IN DAMPING TECHNOLOGY FOR LARGE FLEXIBLE SPACE STRUCTURES

Interim Report

JPL 730-00272-0-3540

Jay-Chung Chen, JPL

James L. Fanson, Caltech

A. OBJECTIVES

Recent trends in satellite technology have been towards significantly larger spacecraft. Space structures with large dimensions and minimal weight are necessarily flexible. Since the performance of these systems relies, in many cases, on precise pointing and/or a precise structural configuration, it is necessary to minimize their structural dynamic response to disturbances. The sources of these disturbances include meteoroid impact, docking, deployment, and maneuvers.

For large space structures, the increased flexibility and size requires the control system to recognize and compensate for multiple elastic mode behavior. The problems of devising a properly stable control scheme, modeling the structure, making inflight response measurements using sensors, and the interpretation of these measured data have become increasingly difficult. These problems have received a great deal of attention in recent years. One of the major objectives for the control of large space structures is to provide active damping for the transient responses. This is accomplished by making the control forces proportional to the velocities of the responding structures. These control forces are usually applied to the structures via actuators such as compressed gas jets and small rockets. For certain large structures whose material density per unit area is extremely small, these control actuators become too bulky and heavy. It would be impractical to utilize a distributed system of actuators for these types of structures. Alternative actuation schemes become desirable.

The objective is to develop a new approach using miniature piezoelectric strain transducers for system stiffness variation which in turn achieves the structural control.

B. PROGRESS AND RESULTS

The feasibility of the approach was first demonstrated by a vibrating string, whose system stiffness is exclusively derived from the tension. By modulating the tension, i.e., varying the stiffness, an effective damping was produced to suppress the vibration (Publication 1).

In order to gain an insight into the basic physical relationships of stiffness control for multi-degree-of-freedom systems, a low order system was considered. By varying the system stiffness according to the designed control law, selective modal damping is achieved (Publication 2).

An experiment for the purpose of verifying quantitatively the control capability, as well as demonstrating qualitatively the stiffness control characteristics, has been designed and is being calibrated at the present time.

C. FUTURE OUTLOOK

Work is continuing into the investigations of system stability, robustness, optimal sensor/actuator locations, and the experimental study. Based on the preliminary results, NASA/OAST has agreed to support further studies beginning in FY'86.

D. FINANCIAL STATUS

The total DDF funding for this task was $51,189.00, of which $28,915.00 is obligated to Caltech to support the graduate student and other expenses. The remaining funds will be sufficient for carrying out the task.

E. PERSONNEL

Overall direction of this effort is provided by Jay-Chung Chen of Section 354. Specific analytical and experimental work is being performed by James L. Fanson, graduate student at Caltech, under the supervision of Professor Thomas K. Caughey.

F. PUBLICATIONS

1. Chen, J. C., "Response of Large Space Structures with Stiffness Control," Journal of Spacecraft and Rockets, Vol. 21, No. 5, September-October 1984, pp. 463-467.

2. Fanson, J. L., and Chen, J. C., "Stiffness Control of Large Space Structures," Workshop on Identification and Control of Large Space Structures, June 4-6, 1984, San Diego, CA.

A NEW MEMORY MATRIX

Interim Report

JPL 730-00273-0-3460

John Lambe, JPL

A. OBJECTIVES

The central objective of this work has been to explore possible applications of memory-matrix concepts to dense information storage. The memory-matrix concept has been discussed most recently in the writings of Professor John Hopfield in terms of human memory. We are applying certain aspects of Prof. Hopfield's work to electronic circuits that could function as associative memories.

B. PROGRESS AND RESULTS

In addressing the question of storage capacity, we have identified the crucial need for a coding scheme. This necessitated some new approaches to storage algorithms which would permit special coding. The essential point is that one stores only the outer product of words in a positive feedback network and utilizes a lateral inhibition scheme for negative feedback.

A 16 x 16 hardware embodiment using discrete components based on these principles was designed, fabricated, and tested. The circuit consisted of Shift Register Strings used as inputs and the output was displayed on an arrays of LEDs. This circuit revealed different stable states (memories) as predicted by Hopfield's model.

C. FUTURE OUTLOOK

We will simulate our coding scheme (which we term "dilute" coding) in an actual example of a useful memory device. We will also examine the question of internal error correction to optimize storage capacity.

D. FINANCIAL STATUS

The DDF award to this task in FY'84 was $57,300. As of the end of October 1984, the amount obligated was $26,624. The remaining funds will used for further simulation studies on coding.

E. PERSONNEL

Overall direction of this effort at JPL is provided by John Lambe, Senior Research Scientist, Section 346. Mr. Dayalan Kasilingam, Caltech student, worked during the summer for four months on this project.

F. PUBLICATIONS

None.

A MODULAR IMAGING PHOTOMETER

Interim Report

JPL 730-00274-0-3250

John T. Trauger, JPL
Richard J. Terrile, JPL
Jay T. Bergstralh, JPL

A. OBJECTIVES

The objective of this task is the fabrication of a modular, general purpose imaging photometer appropriate for use with our newly developed CCD imaging camera (cryogenic CCD detector and image aquisition/processing computer). The photometer will be adapted for use by JPL astronomers primarily at JPL's Table Mountain facility. The modular concept was chosen to accomodate a wide variety of anticipated instrument configurations with a minimum of new hardware, and to provide for future modifications and component additions with a minimum of expense and new effort. This instrument is deemed fundamental for the development of first-rate scientific research programs at the Table Mountain Observatory.

B. PROGRESS AND RESULTS

The modular instrument design has been developed during the past year. The fundamental components are (1) a guider module, including provision for both central-field and off-axis guiding with either an eyepiece or an existing Quantex image intensified TV system, (2) a nine-position filter wheel with remote filter selection, filter tilting, and temperature stabilization, (3) a two-inch diameter shutter assembly, (4) a one-to-one pair of collimator and imaging elements to provide a two-inch diameter collimated beam for narrow-band interference filters, transmission gratings, and Fabry-Perot interferometers, and to provide an internal image of the telescope pupil for coronagraphic applications, (5) an selection of entrance apertures with mounting hardware, and (6) a mounting plate for the CCD detector dewar and telescope mounted electronics. All of these components reside on mounting plates of uniform size (12-inches square), and the instrument is assembled for a specific application by mounting the required modules in the appropriate sequence as "shelves" between a standard pair of side plates. Future needs will be accomodated by adding just the required module, avoiding the need to design and build each new instrument from scratch.

The fabrication of the instrument has begun in the machine shops of the Caltech Division of Geological and Planetary Sciences. This choice was made to take advantage of the prior experience of its personnel in the construction of similar astronomical instruments (including the PFUEI and Four-Shooter cameras now in use at Palomar). The guider box is an extensive modification of a basic design provided by the University of Texas Astronomy department. The filter module is a modification of J. Trauger's seven-position filter box, which has been in service for several years. Collimator and imaging optics are now being designed, and it is anticipated that they will be all-reflective systems, with off-axis parabolic primary and field-flattening secondary elements. These are superior to objective lenses, since they provide a uniform focal length at all wavelengths accessible to the CCD (0.3-1.0 microns), and the absence of a central obscuration allows use with a wide variety of telescope systems. The instrument will be operational at the 24- and 40-inch telescopes at Table Mountain Observatory by mid-FY 85.

C. FUTURE OUTLOOK

The photometer will play an important role in the development of new observing programs at Table Mountain Observatory. Photometric imaging of Comet Halley will begin in fall 1985 with the instrument in each of three configurations: (1) direct photometry with the standard Halley-watch filter set, (2) imaging at moderate spectral resolution with narrow-band interference filters, and (3) Doppler velocity-resolved imaging at high spectral resolution with Fabry-Perot interferometers. Spatially resolved spectroscopy of the Jovian disk will begin in summer 1985 with dual Fabry-Perot imaging in the molecular hydrogen quadrupole bands. The new instrument should prove valuable for coronagraphic studies of dust distributions around nearby stars, the study of neutral and ionized species in the Io/Jupiter torus, and ongoing asteroid photometry programs. The availability of this in-house instrument should catalyze new programs and collaborations among JPL astronomers.

D. FINANCIAL STATUS

The DDF funding for this task is $30,600. Of this total, $18,000 has been obligated by means of a work order to the Caltech (Division of Geological and Planetary Sciences) machine shop to carry out the aquisition, machining, and assembly of the basic components. The remaining funds are reserved for aquisition of optical components.

E. PERSONNEL

The detailed design and fabrication of the instrument is under the supervision of John T. Trauger, in his capacity as science manager of the Table Mountain optical facilities. The basic design requirements have been defined by the three investigators.

ARCHITECTURES AND ALGORITHMS FOR VERY HIGH SPEED DIGITAL FILTERING

Interim Report

JPL 730-00276-0-3310

Raymond F. Jurgens, JPL
Leslie J. Deutsch, JPL

A. OBJECTIVES

The objectives of this task are to evaluate the items of current technology relative to the implementation of certain algorithms that are known to be useful in data acquisition and signal processing and to demonstrate new digital filter architectures based on these items. The types of digital circuits that are to be analyzed include the conversion of IF signals to complex baseband signals (i.e., complex mixers), baseband digital filters, simple detectors, and format decoders. Both finite impulse response (FIR) and infinite impulse response (IIR) filters are being considered as well as hybrid combinations of these two types.

B. PROGRESS AND RESULTS

The major emphasis during the past six months has been devoted to finding solutions to several design problems that provide useful signal processing systems near the limit of clock rates that are possible with current technology. Toward this end, we have concentrated on the parts needed for digital baud integration, digital complex mixing, and low-pass filtering.

The digital baud integration problem was studied first, since it involved only the addition of signal samples. However, the number of samples summed is programmable over a wide range in order to accommodate several applications in radar and telemetry systems. Such integrators must also be able to compensate for Doppler effects caused by the motion of the signal source relative to the observer. This is accomplished by resampling the data according to a digital clock that holds the position of the baud boundaries fixed relative to the location of the samples.

The complex mixer was studied next to determine if various existing VLSI multipliers could be configured to meet the sampling specifications of a useful receiver system. A useful system is one having an IF of between 5 and 10 MHz with the full pass band being utilized (i.e., offset baseband). Sample rates from 25 to 100 MHz were considered since these are easily obtained from modern flash converters.

These two projects are described in more detail below.

Three baud integrator structures were studied resulting in slightly different implementations. Normally baud integrators can be downsampled, so one possible implementation is to use a double-buffered accumulator to reduce the sampling rate. Implementations that downsample and correct for Doppler by resampling either result in greater error or complicated control logic. A better design is based on a FIR preprocessor. In this case, a running mean of five samples is computed by a pipeline adder. Data are resampled to correct for Doppler at the output of the adder. The basic structure of this pipeline is a series of latches and adder circuits. Doppler shift is corrected by occasionally sampling the filter one clock count early or late. The pre-baud filter then brings the sample rate down to a level that can be handled by current signal processing circuits that contain real multipliers and adders. Such circuits can be used as an IIR adder that is reinitialized at the end of the sum (integrate and dump analogy). A pre-multiplier can be used to scale the data such that the data fill the most significant bits when the sum is complete. Two implemenations of this structure were studied - one using offset binary number representation and the other using two's complement arithmetic. The offset binary procedure was found to be easier to implement due to its scaling properties. Breadboard tests were conducted using 74F series logic parts for the FIR filter and TRW TDC1043 VLSI signal processing circuits for the IIR filter. A maximum clock rate of 48 MHz was obtained, which corresponds to the theoretical limit imposed by the FIR adder circuit.

The digital complex mixer is a receiver element that accepts a digitized IF signal and converts it to quadrature baseband signals. The output of such a device might be the input to the digital baud integrator described above in a standard telemetry or radar application. A digital implementation of such a mixer requires a digital local oscillator that produces phase quadrature sine waves, two productors (multipliers), and two filters to eliminate the signal band at twice the local oscillator frequency. The resulting output can be down-sampled to reflect the decreased bandwidth set by the filter if desired. The major advantage of the digital baseband mixer over analog implementations is that the IF channel can be more fully utilized through the design of a sharp cutoff filter at the band edge. Such filters are not easily designed with analog components due to the component tolerances and the large group delay distortion normally associated with such filters. FIR filters, on the other hand, are linear phase devices having a constant group delay, and, since they are digital, the coefficients may be specified to whatever accuracy is necessary for the application. Also, the shape of the pass and stop bands can be programmed to change with varying requirements. One limitation of digital mixers is the dynamic range. First, the signal itself is quantized (usually to 8 bits). This quantizing limits the dynamic range of the signal to about six times the number of bits in dBs (i.e., 48 dB for 8 bits). A good digital mixer should not degrade the dynamic range appreciably nor should it produce biased statistics when random signals are applied. A simulation of this mixer indicates that the dynamic range is at least 44 dB.

We have simulated a complete digital mixer design to study the effects of quantizing, aliasing, and filter rejection properties. The optimized design uses a ROM sine table to generate the local oscillator. The products are also handled by table look-up from a fast ROM. The filters were optimized to provide a rapid cutoff beginning at 6 MHz with 45 dB attenuation above 7.5 MHz. An 11-tap bisymmetric filter having 8-bit coefficients has been found that satisfies these design criteria. Several implementations have been studied. Currently, a 50-MHz sampling rate requires the use of Emitter-Coupled Logic (ECL) parts. Because of the low level integration of these parts, it would require over 600 ICs if the filter coefficients are to be made programmable. One feature of the bisymmetric design is that the length of the filter can be extended easily by adding more stages to it.

C. FUTURE OUTLOOK

A report that describes the complex mixer design research will be published so that all the details of the various implementations can be documented for other digital designers at JPL.

A new effort will be started with the purpose of identifying the VLSI building blocks that will be needed to implement such high speed digital systems easily and economically. Architectures for these parts will be studied relative to the technologies that will be needed to fabricate them. In particular, we will be considering the newly emerging digital GaAs IC technology. GaAs chips have been shown to be capable of clock rates in the GHz range with moderate (several thousand) transistor complexities.

D. FINANCIAL STATUS

The total funding for this DDF task from FY'84 resources is $62,100. As of October 1984, the amount obligated was $15,520. The remainder of the funds will be spent in FY'85. This will include both the workpower and necessary procurement of electronic parts to complete the task.

E. PERSONNEL

The overall direction and management of this task is provided by the principal investigators, Raymond F. Jurgens and Leslie J. Deutsch.

The research on baud integrators and the demonstration of this technology was performed by K. Farazian of Section 331.

The work on complex mixers, and that on programmable FIR filter architectures was performed by F. Chan. Mr. Chan is a cooperative student from the University of California at Berkeley who is working for Section 331. Maureen Quirk studied the optimum digital filter functions for the baseband mixer application.

F. PUBLICATIONS

A paper on the baud integrator designs has been written and will appear in the next issue of the TDA progress reports.

MICROMACHINING OF INTEGRATED FLUIDIC CIRCUITS
ON SILICON CHIPS

Interim Report

JPL 730-00277-0-3750

J. B. Angell, Stanford University
Philip W. Barth, Stanford University
Mark Zdeblick, Stanford University
C. Martin Berdahl, JPL
John V. Walsh, JPL

A. OBJECTIVES

The objective of this DDF task is to improve the state-of-the-art of manufacturing submillimeter wave and logic fluidic elements by decreasing size of at least an order of magnitude without scarificing performance. In order to do this successfully, it is necessary to form geometric shapes such as holes, trenches, and walls with micron size dimensions and tight tolerances. Of the few examples of such capability cited in the open literature, the laboratory capabilities at Stanford University, as described in the publication entitled "Silicon Micromechanical Devices" by J. B. Angell, S. C. Tery, and P. W. Barth, Scientific American, April 1983, pp. 44-53, most closely demonstrates the capability required for our task.

B. PROGRESS AND RESULTS

A contract was negotiated with Stanford University whereby JPL and Stanford personnel could work jointly, with JPL providing the design and Stanford providing the micromachining techniques to produce the desired fluidic and submillimeter wave devices. The design of three experimental elements was completed at JPL and forwarded to Stanford for further design changes necessary for proper orientation to etch on the surface of a silicon wafer. Stanford completed the computer aided design changes, produced the necessary photolithography work, and made a set of masks. The fluidic element designs were successfully reduced by a factor of ten during the above process and transferred to the surface of silicon wafers by a photo-resist process.

Experiments on the etching fabrication process, silicon wafer orientation, and process techniques for the fluidic amplifier were carried out. JPL representatives participated in the etching operations, which resulted in successfully producing a one-tenth scale amplifier of approximately forty micrometers (0.001 inch) depth in the silicon surface. Figure 1. The mechanics for installing and testing the fluidic elements were demonstrated. Further work in the etching techniques, which affect the critical geometry of the amplifier, was successful in bringing the gain above unity. This was a significant accomplishment in that the normal maximum gain of a fluidic amplifier seldom exceeds a factor of ten. It is known that several improvements in the geometry of the amplifier are required. It is expected that a significant increase in amplifier gain will result from such changes in geometry.

An attempt is also being made to fabricate a one-tenth scale fluidic oscillator. It has been found difficult to develop a technique to obtain the required input and output porting to opposite sides of the silicon wafer. A working oscillator has still not been developed at this time.

A submillimeter wave dichroic filter was designed in accordance with the specifications given by H. Pickett of Division 38. The problem one faces in micromachining such a device is to etch vertical wall holes in silicon wafers. If diamond-shape patterns are etched in the 110 plane of silicon, vertical walls are cut, but the holes bottom out with reverse pyramids due to angled 111 planes, which resist the etchant. A laser spoiling technique was developed to allow etchant to penetrate under these 111 planes and, thereby, cut vertical wall diamond-shaped holes through a silicon wafer. Test specimens prove the method works. Figures 2 & 3. It is now intended to use this technique to produce a filter with 120,000 holes in it.

Since this task as well as the contract with Standford is scheduled to run through March of 1985, it is expected that the oscillator and the dichroic filter as well as a fluidic amplifier of usable gain will have been produced by the end of this task.

C. FUTURE OUTLOOK

By March of 1985, the three micromachined elements should be completed and operable. An amplifier with a gain of five or greater appears feasible and will be useful in many applications where miniaturization and economy are prime requisites. Both Harry Diamond Laboratories and DARPA have an interest in the military applications of the fluidic elements, and a successful dichroic filter will have many applications in secure microwave communications. Proof of satisfactory operation and mating of micromachined elements and circuits with transducers and output devices should suffice to secure funding for further development.

An effort will be made to transfer this technology for micromachining to JPL. However, existing equipment at JPL may not be precise enough.

D. FINANCIAL STATUS

The total DDF funding for this task from FY'84 resources was $69,800. As of the end of October 1984, the amount obligated was $56,545 including $39,620 obligated with a purchase order to Standford University.

Funds remaining in the Standford contract will support Stanford through March 1985 and suffice to meet the objectives and complete the deliverables required by the contract.

E. PERSONNEL

Direction of this effort is provided by C. Martin Berdahl and John V. Walsh of the Instrumentation Section 375, with participation by Paul Shlichta of Section 354.

The silicon micromachining and etching provided by the contract with Stanford University is under the direction of Dr. Philip Barth and Dr. J. B. Angell with technical suport by graduate student Mark Zdeblick.

F. PUBLICATION

No publications have been made at this time. An oral presentation of silicon etching techniques associated with micromachining of fluidic amplifiers was made at the ASME meeting held in New Orleans, December 9-14, 1984.

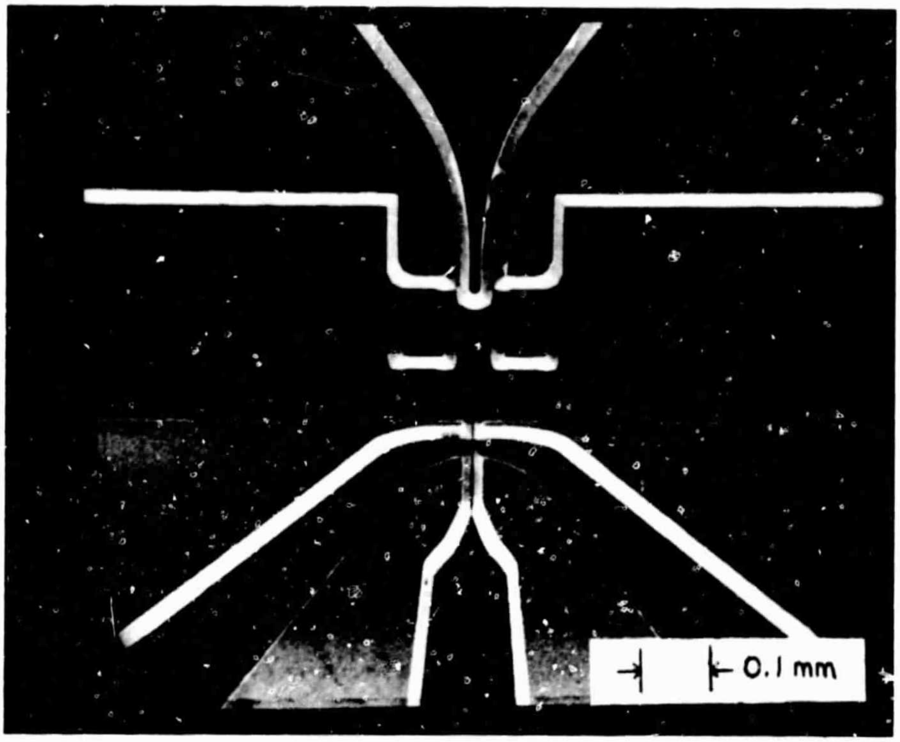

Figure 1. Fluidic Amplifier

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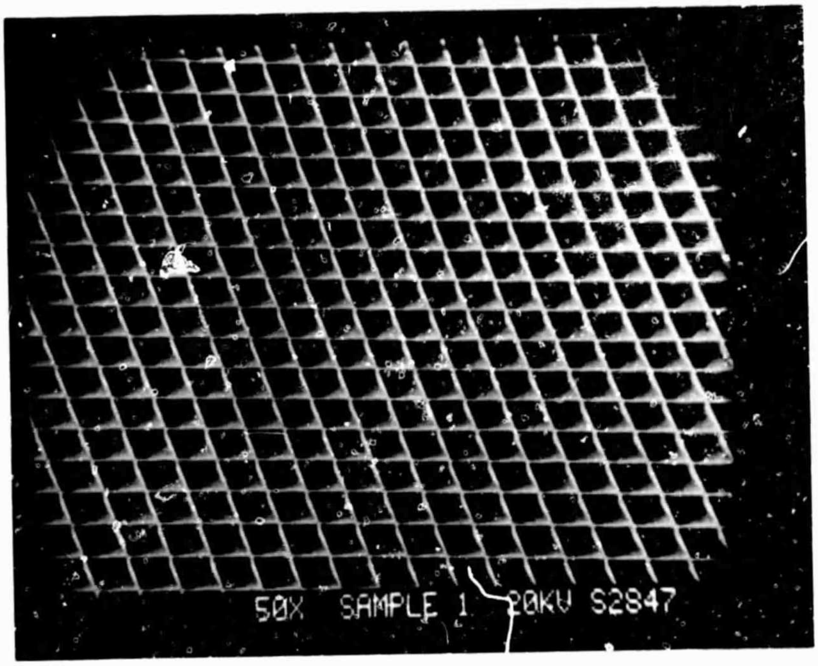

Figure 2. Dichoric Filter (50X)

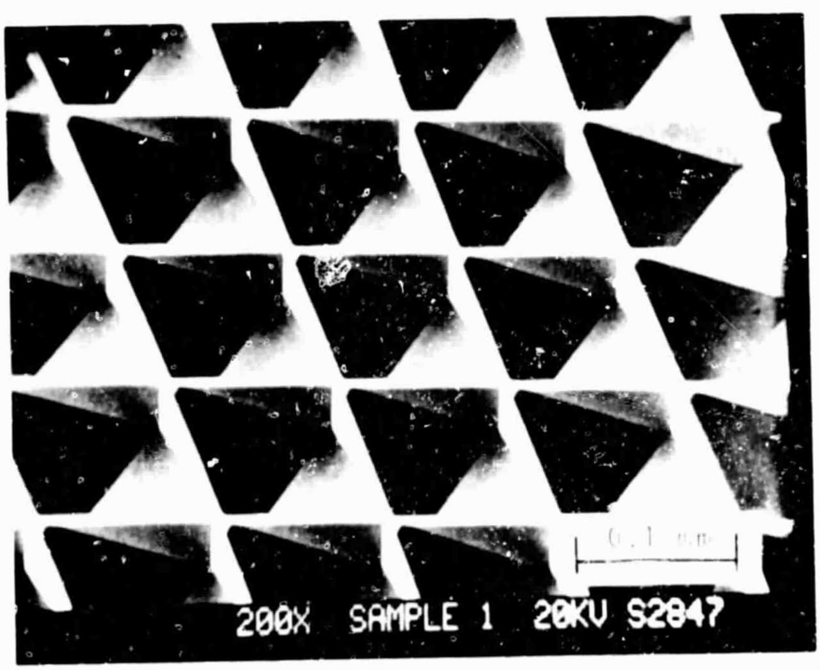

Figure 3. Dichoric Filter (200X)

SENSING AND CONTROL FOR MULTIFINGERED ROBOT HANDS

Interim Report

JPL 730-00278-0-3470

Carl F. Ruoff, JPL
Daniel Yang, UCLA

A. OBJECTIVES

The overall objective of this task is to improve robotic manipulation by investigating and implementing sensor-based control techniques for multifingered robot hands. Subobjectives include (1) instrumenting a dexterous robot hand with tactile sensors; (2) developing sensing and control algorithms with supporting computer codes for the robust execution of cooperative finger and part motion sequences; (3) developing high-level primitives for the specification of part and finger motions; and (4) conducting experiments involving single manipulative tasks.

B. PROGRESS AND RESULTS

In order to simplify the effort while retaining the essential features of the problem, we have decided to address quasistatic dexterous motion in the context of peg-hole insertion operations. To make the insertion task representative and to provide tactile features, the peg consists of a shank and a head. Our work to date, which has been mostly analytical, has dealt with the following:

(1) Tactile sensor feature identification and tracking.
(2) Hand-tactile sensor kinematics.
(3) Object motion description.
(4) Insertion algorithms.
(5) Computational architecture.
(6) Motion primitive definition.
(7) Force/compliance control algorithms.

This analysis has assumed that flexible tactile sensors, which are tessellations of the plane, would be available.

A parallel effort, conducted by two Caltech students, Gary Chew and Pang-Chieh Chen, attempted to construct tactile sensing arrays as a Caltech class project. Because of limitations in materials and time, this effort was not successful, though the vacuum deposition of silver electrodes on neoprene was demonstrated. It is currently anticipated that recently announced commercial tactile sensor and interface electronics will be used.

The software/demonstration phase of this project has been delayed by the unavailability of the JPL-Stanford hand, the lack of success in fabricating suitable tactile sensors, and the lack of documented arm control/support software in the JPL robotics lab. It is anticipated, however, that the overall objective of the task will be met with, perhaps, a somewhat reduced scope. Rather than using the JPL-Stanford hand and fabricating tactile sensors, we now plan to use commercially-available tactile sensors and to create a kinematic structure similar to the JPL-Stanford hand by using a fixture and the JPL PUMA 600 manipulator (the PUMA 600 is a commercial six-degree-of-freedom manipulator manufactured by the Westinghouse Corporation). Mounted on a common base, this arrangement will duplicate essential features of dexterous object motion. Arm control software will be based upon JARS (JPL Autonomous Robot System), which is PASCAL-based and runs on the PDP 11-34. This work should be completed by fall of 1985.

C. FUTURE OUTLOOK

This task is quite ambitious, breaking new ground in several areas. As mentioned above, the software/demonstration phase has been delayed by limitations in support infrastructure. We still believe, however, that the principal objectives can be realized if the task is somewhat reduced in scope and if commercial components are used where applicable.

We believe that this effort can form the basis for work on the OAST space station robotics initiative wherein modular, free-flying robots would be developed for various uses in and around the space station. Scheduling of such an effort is not appropriate at this time because headquarters planning is not yet complete.

D. FINANCIAL STATUS

The total funding awarded to this task for FY'84 is $54.4 K. As of the end of FY'84, 68% of funds had been obligated or costed. No equipment funds have been expended. As the UCLA portion will expire in February 1985, the award will not be adequate to cover work remaining. Professor Daniel Yang, however, has stated his intention to continue the work to a reasonable point even if additional funding cannot be identified.

E. PERSONNEL

JPL participants are Carl F. Ruoff and Samad Hayati of the Robotics and Teleoperator Research Group.

UCLA participants are Professor Daniel Yang of the Mechanical Engineering department, and graduate students Ker-Fong Kenneth Her and Dong-Liang Daniel Sheu.

F. PUBLICATIONS

No external publications have yet resulted from this task. It is intended, however, that results will be published in the open literature when our work is completed.

MOLECULAR ELECTRONIC SWITCHES

Interim Report

JPL 730-00280-0-3460

Vincent M. Miskowski, JPL
John Lambe, JPL

A. OBJECTIVES

Our primary objective is to assess the feasibility of bistable (non-volatile) electronic switching based on thin films of molecular electronic materials. Our particular interest in molecular electronic materials is that they can be switched between states of different conductivity by the reduction or oxidation of their molecular units.

B. PROGRESS AND RESULTS

Two specific approaches were undertaken to attain the objectives of this DDF. Firstly, multilayer assemblies of polymeric materials, which are redox active, were evaluated. In particular, Pt/poly-[Ru^{II}(4-vinyl)$_2$ (bipyridine)$_2$]-(ClO_4)$_2$/polypyrrole thin layer assemblies demonstrated electrochemically driven rectification action; thus, the assemblies can be maintained in conducting or non-conducting states, and are switched from one state to another by ± 1 V potential excursions. However, switching times were relatively slow (of the order of seconds) for 10-100 µm thick layers. Secondly, we evaluated the reported switching of CuTCNQ in strong electric fields; our results are in essential agreement with reported properties. Our interest in these relatively unstable and tractable materials lessened due to our discovery that switching properties appear to be more simply attained by layered oxide materials (CuO, V_xO_y...). Since these oxide materials have advantages, in terms of handling and stability, we are focusing the remainder of our effort on evaluating these materials.

C. FUTURE OUTLOOK

The remainder of this effort will consist of evaluating the switching properties of one or more oxides (CuO, V_xO_y...) for the reasons described in Paragraph B.

D. FINANCIAL STATUS

The total DDF funding for this task (FY'84) was $53,300. As of the end of October 1984, the amount obligated was $42,654. The remaining funds will be utilized during FY'85 to complete the work as described above.

E. PERSONNEL

Overall direction of this effort is provided by Drs. Vincent M. Miskowski and John Lambe, both of the Solid State Science Group, Section 346.

F. PUBLICATIONS

None yet.

AMORPHOUS MAGNETIC FILMS
FOR NON-VOLATILE MEMORY

Interim Report

JPL 730-00281-0-3460

A. P. Thakoor, JPL
S. K. Khanna, JPL
R. B. Somoano, JPL

A. OBJECTIVES

The primary objective of this task is to evaluate the suitability of sputter-deposited amorphous thin films of ferromagnetic alloys for high density non-volatile memory. The work involves the deposition of thin stoichiometric films by magnetron sputtering, a study of the growth kinetics, analysis of the structural and magnetic properties of the films deposited under various conditions leading to a better understanding of the "structure-property" relationship, and a performance assessment of the "tailor-made" films for magneto-optical recording.

B. PROGRESS AND RESULTS

Composite sputtering targets of ferromagnetic alloys with the nominal compositions of $Co_{73}Gd_{27}$ (CoGd) and $Fe_{70}Cr_{10}P_{13}C_7$ (FeCrPC) were fabricated by compressing (under the pressure of 300,000 psi) the thoroughly mixed, high purity (99.99%), fine grain (~ 325 mesh) powders of the alloy constituents at room temperature. In the case of FeCrPC target, an appropriate amount of Fe_2P powder was added as a source of phosphorous in order to avoid the handling of elemental phosphorous. Films of the two alloys were deposited onto glass and mica substrates by magnetron sputtering using argon as carrier gas under various deposition conditions. The systematically varied deposition parameters include the sputtering rate, substrate to target distance, substrate bias, and the carrier gas pressure during sputtering. Film thicknesses were routinely measured by a surface profilometer (Tencor, Alphastep-100). The deposited films of both the alloys, CoGd as well as FeCrPC, were amorphous as indicated by the diffuse halo patterns obtained from the X-ray diffracti n study. Differential scanning calorimetry (DSC) analysis indicated that FeC PC films crystallized at ~420°C. Surface profilometry, optical microscopy, and scanning electron microscopy examinations of the films revealed that the ilms deposited at low argon pressure (<10 mTorr) were extremely smooth. ensitive dependence of the film microstructure, internal stresses, and, thereby, film adhesion strength on the sputtering conditions, primarily the carrier gas pressure at constant temperature, indicated a possibility of deposition of the films with "tailored" microstructure.

As deposited films are indeed ferromagnetic, Dr. Timir Datta of USC, Columbia, SC, has initiated studies on the magnetic properties of our FeCrPC films in an attempt to establish correlations between the film microstructure and properties.

C. FUTURE OUTLOOK

In collaboration with Dr. Timir Datta, we will study the Curie temperature, saturation magnetization, magnetic anisotropy, and their dependence on film microstructure for both the alloys. This study will lead us to establish the optimum deposition conditions for the films before they can be tested for their recording performance.

To evaluate the effects of the target fabrication process (which controls the target density) on the film microstructure and growth kinetics, target fabrication by induction melting and/or arc melting will also be attempted. This will be carried out at the University of Pennyslvania in collaboration with Prof. T. Egami.

D. FINANCIAL STATUS

The total DDF funding for this task from FY'84 resources was $55,000. As of the end of October 1984, the amount obligated was $32,214.

E. PERSONNEL

The work at JPL was performed by Anil P. Thakoor, Satish K. Khanna, and Robert B. Somoano, all from Section 346. Prof. Timir Datta of University of South Carolina is involved in the magnetic properties of these films and Prof. T. Egami of University of Pennsylvania is involved in the detailed microstructure studies of these films.

F. PUBLICATIONS

1. A Magnetization Study of Amorphous $Fe_{70}Cr_{10}P_{13}C_7$ Thin Films, J. Magnetism and Magnetic Materials (1985) in press.

2. Magnetic Study of Amorphous $Fe_{70}Cr_{10}P_{13}C_7$ Thin Films, to be presented at the Am. Phys. Soc. Meeting, Baltimore, MD; March 1985.

PRELIMINARY STUDY OF SPACE BASED OPTICAL INTERFEROMETRY

Interim Report

JPL 730-00282-0-3140

S. P. Synnott and J. B. Breckinridge, Jet Propulsion Laboratory

N.Woolf, University of Arizona

A. OBJECTIVES

The primary objective of this task was to conduct a preliminary study into the design, development, and use of an optical interferometer to be flown in the space shuttle bay. The work involves identification of significant scientific objectives, which can be accomplished in a typical 7- to 9-day shuttle mission with an 18-m baseline instrument, and a study of the optical and control technology requirements imposed by the need to maintain baseline knowledge to a small fraction of the operating wavelength. In our minds, such a shuttle-based instrument is a necessary first step on the path, for example, to 50- to 100-m space-station-based interferometers (Fraucherre et al, 1984) or to the free-flying multiple spacecraft missions of the (distant?) future with baselines ranging up to kilometers (Kuiper et al, 1985).

A secondary goal, if resources allow, is to examine the feasibility of and benefits from flying a 1-or 2-m optical interferometer into, for example, a Saturn orbit. Such an instrument could provide extremely accurate measurements of ring and satellite morphology and dynamics.

B. PROGRESS AND RESULTS

A preliminary discussion of our proposed shuttle based optical interferometer was presented at the workshop on "High Angular Resolution Optical Interferometry from Space" held at the AAS meeting in June 1984 in Baltimore. N. Woolf presented the results in the paper "UV Spectro-Interferometry from the Shuttle Bay," (N. Woolf et al, 1984). In our concept of a Michelson stellar interferometer, 25-to 50-cm mirrors are placed at either end of the 18-m shuttle bay with a combiner package between them. The operating wavelength region extends from the visible down into the UV providing, at the shortest wavelengths, angular resolutions of the order of 1 milliarcsecond. This is of the order of the expected size of the broad emission line region of Seyfert galaxies and quasars. This resolution is also of the same order as that achievable with VLBI in the radio part of the spectrum. It appears the shuttle instrument will be able to provide a complementary measure of structure in the optical and UV regime for the nearest Seyfert galaxy NGC 4151 and the nearest quasar 3C273. An independent signal-to-noise calculation (Fraucherre et al, 1984) also, seems to indicate that these objects can be observed with 25- to 50- cm interferometer elements, although the integration time may be of the order of one hour.

Long integration times, or the desire to maintain phase information to allow the use of the interferometer as an imaging instrument, impose severe constraints on baseline length and orientation knowledge. In the shuttle bay, the mirror-to-mirror distance can be measured to sufficient accuracy with commercial multifrequency lasers. The orientation knowledge is much more difficult to achieve. An apparently feasible scheme, at least in the visible wavelength region, would be to use a second interferometer with smaller mirrors to effectively lock onto $\leq$ 11th mag Hipparcos stars (several per square degree and of accuracy 2 mas) and, with further internal laser metrology, maintain knowledge of the orientation of the "science" interferometer with respect to the "pointing" interferometer. Full phase recovery at the highest spatial frequencies would probably still have to rely upon using an unresolved fringe reference internal to the source itself.

C. FUTURE OUTLOOK

In addition to continuing our signal-to-noise calculations to identify other interesting science applications, we have to address the major technology question, that is, of the appropriate interface with the shuttle bay. We have begun to acquire information on the characteristics of the shuttle, for example, vibration modes, thermal expansion rates, and orientation sensing and control. The response times of the control mechanisms that are needed to measure and use baseline length and orientation knowledge must, of course, be short compared to shuttle flexing and orientation motions.

Our intent in the next six months is to put together a strawman proposal to NASA Headquarters to continue to study the details of this concept of an optical interferometer in the shuttle bay.

As a result of our discussions at NASA Headquarters, an OAST technology development shuttle flight is tentatively planned to measure the physical properties of the shuttle bay to determine suitability for interferometry. This planned flight will be the first of several directed toward technology development for a space-based Michelson stellar interferometer.

D. FINANCIAL STATUS

The total funding for this DDF was \$28K of which \$10K was obligated by means of a work order to N. Woolf of the University of Arizona. Of the \$18K left in house, approximately \$4K are left.

E. PERSONNEL

Dr. S. P. Synnott is the leader of the study, including primary responsibility for analyzing shuttle orbit and structural constraints. Dr. J. B. Breckinridge is directing the overall optical design, including signal-to-noise calculations and Dr. N. Woolf is studying astrophysical applications.

F. PUBLICATIONS

N. Woolf, S. P. Synnott, and J. B. Breckinridge, "UV Spectro-Interferometry from the Shuttle Bay," BAAS 16 No. 3 (II), 1984.

G. REFERENCES :

(1) M. Fraucherre, M. Lacasse, P. Nisenson, R. Reasenberg, M. Shao, R. Stachnick, and W. Traub, "A 50-meter Michelson Stellar Interferometer on a Space Platform," BAAS 16 No. 3 (II), 1984.

(2) T. B. H. Kuiper, S. P. Synnott, R. P. Linfield, G. M. Resch, and E. F. Tubbs, "Aperture Synthesis with Orbiting Telescopes." To be submitted to Radio Science, 1985.

SHUTTLE SAMPLE RETURN EXPERIMENT

Interim Report

JPL 730-00283-0-3130

Peter Tsou, JPL

A. OBJECTIVES

The sample collection concepts being developed for comet flyby sample return lack space environment validation. An opportunity was secured on the Shuttle Get Away Special program for a test bed for the collection concepts. The objective of this task is then to develop and to procure the hardware needed for the Shuttle sample return experiment.

B. PROGRESS AND RESULTS

Official agreement has been made with the Get Away Special program on the Shuttle sample return experiment. The hardware design is completed. Documents for the safety package including the structure, thermal, and test results have been completed. The hardware has been procured. The flight hardware is assembled by the University of Washington at Seattle, Washington with some of the parts supplied by the University of Kent, Canterbury, England.

Three of the five pieces of the flight hardware for the experiments have been delivered to Kennedy Space Center to await the next available flight opportunity.

C. FUTURE OUTLOOK

There will be the need for coordination for the first few flights and some diagnostic analyses of returned cells. Based upon the first few flights, there may be hardware changes to make.

D. FINANCIAL STATUS

The total DDF granted to this experiment task came to $30K. As of September 30, 1984, $22K was spent.

No additional funding for this instrument will be requested. Funding for continuing work on the Shuttle will be sought from instrument development sources.

E. PERSONNEL

The experiment opportunity is secured, coordinated, and engineered by Peter Tsou with assistance from the University of Washington and the University of Kent.

F. PUBLICATION

A paper will be written after the initial flights.

LARGE APERTURE INFRARED SPECTROMETERS

Interim Report

JPL 730-00284-0-3820

Michael P. Chrisp, JPL

A. OBJECTIVES

The main objective is to improve the signal-to-noise ratio for background limited detector arrays by reducing the background noise. This is being done by designing low f/# stigmatic spectrometers, which, as a consequence, have smaller detector areas. An effort is made to ensure that the exit pupil of the optical system lies at the detectors cold stop so that the detectors only see the low emissivity mirrors. The smaller detectors provide uncooled optical systems with improved signal-to-noise ratios for the longer infrared wavelengths. These spectrometer systems will be important on long range space missions where cryogenic cooling of the optical system is not feasible.

B. PROGRESS AND RESULTS

A conceptual design was studied radiometrically to find the improvement in performance made by reducing the detectors size and using an efficient cold stop. To do this, the telescope and spectrometer were modeled viewing Titan at a wavelength of 10 microns and with a spectral resolving power of 100. A conventional f/4 spectrometer design, with 200 micron pixels was compared with the new f/1.5 spectrometer design, which had 74 micron pixels. The temperature of the telescope and spectrometer was the same in both designs. The results showed that the spectrometer background flux was reduced by two orders of magnitude in the new design. This improved the noise equivalent temperature difference by a factor of six for an integration time of a tenth of a second. These radiometric calculations are reported in detail in a proposal to the Planetary Instrument Definition and Development program (Publication 1).

An extensive survey of holographic gratings and their mountings has been made to evaluate their suitability for use in the spectrometer design. This survey is to be published as a review article on aberration corrected spectrometers and monochromators (Publication 2). The ease of fabrication of large area holographic gratings, with their extra degrees of freedom for aberration correction, make them particularly suitable for the spectrometer design. There are two possibilities for obtaining high efficiency aberration corrected holographic gratings. The first is to choose the groove frequency and modulation so that the sinusoidal gratings operate in the high efficiency region. For the infrared wavelength region 8-12 microns, gratings with frequencies of 70-165 grooves/mm and groove depths greater than 3 microns will produce peak diffraction efficiencies of 8595%. The second possibility is to use blazed aberration corrected gratings. The fabrication method for these gratings has recently been developed by JobinYvon, and blaze angles can be produced from 4 to 39 degrees.

The next stage in the work is the production of optical designs for the spectrometers. This will be accomplished by producing initial designs based on a modified Offner mirror system. These will then be optimized using Code V and evaluated for spectral resolution. Designs with both ruled and holographic gratings will be compared with respect to resolution and diffraction efficiency. The design work is expected to be finished by September 1985.

C. FUTURE OUTLOOK

The initial radiometric study has demonstrated the advantages of large numerical aperture infrared spectrometers. The optical design of these will prove interesting and challenging. The potential of high efficiency aberration corrected gratings in the infrared region has been overlooked. This is because the research effort on holographic gratings has been concerned with their operation in the vacuum ultraviolet region. Optical designs produced using high efficiency infrared holographic gratings should be of great interest.

D. FINANCIAL STATUS

The total funding for this task was $47,000. As of the end of October 1984, $9,000 has been spent. During the 1985 financial year $15,000 is obligated by means of a work order to University of Arizona. The remaining funds will be sufficient for the optical design work.

E. PERSONNEL

Execution of this effort at JPL is by Michael P. Chrisp, Optical Sciences Group, Section 382. The radiometric work at University of Arizona is under the direction of William L. Wolfe.

F. PUBLICATIONS

1. "Infrared Imaging Spectrometer for Solar System Applications," proposal to the NASA Planetary Instrument and Development Program, 1984.

2. Chrisp, M. P., "Aberration Corrected Holographic Gratings and their Mountings," to be published in Applied Optics and Optical Engineering (eds., R. R. Shannon and J. A. Wyant), Academic Press, New York.

600-GHz COOLED SCHOTTKY DIODE RADIOMETER

Interim Report

JPL 730-00285-0-3830

P. Zimmermann, JPL
H. M. Pickett, JPL
M. Frerking, JPL
W. J. Wilson, JPL

A. OBJECTIVE

The objective of the task is to develop a 600-GHz Cooled Schottky mixer and various waveguide and quasioptical devices, which will be incorporated in a radiometer operated aboard the NASA C-141 Kuiper Airborne Observatory. The main difficulties are in fabrication of very fine structures to tight tolerances.

B. PROGRESS AND RESULTS

A mixer-block for 600-GHz was designed following the design of existing waveguide mixers at around 200-GHz. The dimensions of the 600-GHz mount are a factor of three smaller than for the 200-GHz design. The waveguide channel became as small as 0.016 in. wide and 0.002 in. high and the filter channel for the IF output as small as 0.007 in. x 0.005 in. x 0.030 in. Several techniques were tried before a unit with acceptable dimensions and surface finish was received.

The fabrication of filter structures on a quartz substrate of dimensions 0.002 x 0.007 x .030 in. by photolithographic techniques has been completed successfully. The gold structure tended to peel off when soldering a gold ribbon to it. The adhesion of the gold was improved by sputtering on the final structure using a mask, rather than etching it off from the overall gold plated quartz.

Reliable backshorts of size 0.016 x 0.002 x 0.150 in. have been manufactured from beryllium copper material. They are more wear-resistant than those formerly made from brass shim stock material.

As the power generated from the existing quasioptical doubler is marginal for mixer operation, a higher efficiency waveguide doubler was designed and fabricated. Again due to the tight tolerances, a few mounts had to be built before an acceptable one was received. The quartz filter structures for the doubler are even smaller than those for the mixer, but have been successfully fabricated.

Feedhorns for mixer and multiplier have been designed and manufactured by electro-forming, where again the problem of maunufacturing components with very small dimensions had to be solved.

Various quasioptical components, such as offset paraboloids, curved mirrors, and a Fabry-Perot diplexer for coupling signal- and LO-power with high efficiency into mixer and multiplier, were designed and manufactured. All components have been mounted and aligned on their fixtures. Mixer and multiplier are mounted on the 20K and 77K stage of a cryogenic refrigerator and covered by a dewar.

C. FUTURE OUTLOOK

The next step is to mount Schottky diodes into mixer- and multiplier-blocks. They will be tested for their noise performance and efficiency. Diodes from different batches will have to be tried, as no conclusive statement about its RF performance can be made from a diode's DC behavior. Tests will be made at room temperature first. Cooling down the devices will lower the noise temperature, and improve the efficiency. The final steps will be the integration of the front-end with the IF back-end and filter bank, and the airplane demonstration program.

D. FINANCIAL STATUS

The DDF award to this task from FY'84 resources is \$44.1K. As of the end of the fiscal year '84, \$19.6K had been obligated.

E. PERSONNEL

Direction of this effort is provided by P. Zimmermann, with advice on the quasi-optics given by H. M. Pickett and M. Frerking. W. Wilson will provide support with supply of a filter bank.

F. PUBLICATIONS

No publications have been made at this time. It is expected that a paper about the results will be given at the Infrared and Millimeterwave Conference in Miami, December 1985.

FAULT-TOLERANT CUSTOM LSI/VLSI COST/RISK ASSESSMENT AND FEASIBILITY DEMONSTRATION

Interim Report

JPL 730-00287-0-3610

Martin G. Buehler, JPL
Daniel E. Erickson, JPL
William C. Frasher, JPL
Dwight A. Geer, JPL
David F. Hendry, JPL
Albert Y. Lam, JPL
David A. Rennels, UCLA
Norman F. Stahlberg, JPL

A. OBJECTIVES

The objective of this task is to assess and demonstrate the capability of designing and fabricating a custom LSI/VLSI device for fault-tolerant spacecraft computers. The task, in conjunction with a companion DDF task entitled "Qualification Research for Reliable Custom LSI/VLSI Electronics," will address issues of design to specification, design for verification, and flight qualification. It will assess development costs and schedules, the effectiveness of design tools and techniques, and the difficulties of and proposed techniques for flight qualification.

This task will develop a custom CMOS LSI device, implementing a portion of a Memory Interface Building Block (MIBB), which is similar to a prototype gate-array device developed by the Autonomous Redundancy and Maintenance Management Subsystem (ARMMS) demonstration project. During the development, the participants will record time spent, resources used, and problems encountered. The data will be evaluated to assess custom LSI/VLSI viability.

B. PROGRESS AND RESULTS

The transistor level design of a portion of the MIBB has been completed. This was performed on a Mentor computer aided engineering (CAE) workstation. The Mentor CAE workstation was then integrated with the VLSI design facility computer aided design (CAD) tools now running on the JPL VLSI VAX computer. This entailed the transfer of ULYSSES from the VLSI VAX computer to the Mentor CAE workstation. ULYSSES is a computer program that provides for mixed-mode (functional/logical/transistor) circuit design description and simulation, including timing analysis. ULYSSES was then checked-out on the Mentor CAE workstation. Other computer programs were developed and tested. These programs take a design developed and described on the Mentor CAE workstation (in Computer Vision Netlist format) and translate it to the ULYSSES netlist format and the JPL Topological Format (JTF), which are compatible with the VLSI design facility CAD tools. Also, information on time spent, resources used, and problems encountered was collected and consolidated. This information will be used in assessing the cost/risk of developing flight usable LSI/VLSI devices. No significant technical difficulties have been encountered to date. The next major near-term task activity will be to complete transition of the MIBB design to the VLSI VAX CAD facility and to commence chip layout, cell design, and fault simulation in preparation for design review and chip fabrication activities.

C. FUTURE OUTLOOK

This proposal has been discussed with the NASA Information Systems Program Office. However, the uncertainties in the cost/risk/schedule have inhibited JPL's sponsors from funding development leading to the production of flight usable devices. This task will give us experience with developing custom devices in a manner similar to that which will be used for flight projects. This task will reduce the uncertainties associated with custom LSI development. By doing so, it is very likely that NASA will fund further development. With this continued development we will be able to develop and qualify custom devices, such as the Self-Checking Computer Module building blocks, for flight projects.

D. FINANCIAL STATUS

The DDF funding for this task was $65,000 in FY'84. As of the end of October 1984, the amount costed and obligated was $18,993. Additional funding of $95,000 for FY'85 has been requested. The remaining funds, not spent in FY'84, will not be sufficient for the remaining circuit design, fabrication, test, and evaluation activities. It is projected that the remaining funds will allow for completion of the remaining circuit design, fabrication, and some evaluation activities.

E. PERSONNEL

Overall direction of this effort was provided by Daniel E. Erickson and Dwight A. Geer. Martin G. Buehler greatly contributed to the coordination of all the investigators participating on this task. The execution of the effort was carried out by William C. Frasher and David F. Hendry.

F. PUBLICATIONS

No external publications or papers have been presented.

Task activities have been published in JPL Significant Events reports and the DDF Annual Report. Results from this task were noted during a presentation, entitled "Demonstration of the VLSI Design Tools," held at JPL on November 6, 1984.

Also, as a result of the activity on the companion qualification research DDF task, four private industrial companies, which specialize in fabrication of high reliability class S components, have expressed interest in working with JPL to develop LSI/VLSI components like those being developed by this and other tasks.

QUALIFICATION RESEARCH FOR RELIABLE CUSTOM LSI/VLSI ELECTRONICS

Interim Report

JPL 730-00288-0-5140

Martin G. Buehler, JPL
Thomas W. Griswold, JPL
Lawrence M. Hess, JPL
Cesar A. Pina, JPL
Norman F. Stahlberg, JPL
John L. Prince, University of Arizona
Barry Matsumori, University of Arizona

A. OBJECTIVES

The objective of this research task is to formulate a comprehensive approach to LSI/VLSI qualification that will support the design commitment to highly reliable, radiation-hard microcircuit components for use in space systems. This effort includes the evaluation of various qualification procedures, the identification of vendor portability and interface issues, and the preparation of prototype procedures designed to meet the stated objective. All qualification approaches are being evaluated with respect to both component and system reliability, producibility, and cost-effectiveness. Particular attention is being given to the non-traditional "silicon foundry" approach to custom fabrication, popularized by Professor Carver A. Mead of Caltech. Demonstration of the capabilities of this approach when applied to high-performance, high-reliability microelectric devices is intended to be an adjunct to this research task.

B. PROGRESS AND RESULTS

Milestones reached during FY'84 include the completion of a comprehensive Implementation Plan for the program and the initial phase of the Technology Review. The review and evaluation of the current military qualification process is well under way, with a detailed report due from the University of Arizona investigators by the end of the calendar year. Some preliminary results of this latter subtask have already been established and were presented to the sponsors of the Product Assurance Technology program (NASA, DARPA, and NSA) at a meeting held at NASA Headquarters on August 28, 1984. Among these preliminary conclusions are the following:

> Although the current MIL qualification process has proven effective when applied to devices of moderate scale produced by traditional means, many of the concepts incorporated into this process are ineffective; and many technical requirements are either inadequate or inapplicable, from the standpoint of custom, foundry-fabricated VLSI device qualification. For example, the Foreword to MIL-STD-976A states: "Definite criteria will assure that microcircuits are manufactured under conditions which have been demonstrated to be capable of continuously producing highly

reliable products." The problems with this premise are (at least) threefold:

(1) The criteria for capability assessment are unknown at present, and are the subject for current research.

(2) No such conditions have been demonstrated for devices having the small feature sizes typical of "VLSI."

(3) Capability does not imply accomplishment. A great deal of attention is currently paid to the examination of the process, the associated quality control apparatus, and the quality of the raw materials. Emphasis should be shifted to an examination of the results of the process by improved testing of the end product.

The current Class S qualification requirements also do not address several major VLSI-level failure mechanisms, and should be modified and strengthened in this regard. Among these failure mechanisms are the following:

(1) Time-dependent dielectric breakdown (TDDB).

(2) Electrostatic discharge (ESD).

(3) Hot carrier effects.

The effects of Items 1 and 2, which are specific to CMOS devices, are exacerbated by high density and small feature size. Item 3 is specific to small geometries (less than 3 μm).

Furthermore, the current procedures do not reflect the separation of developmental functions (design, wafer fabrication, packaging, etc.) that exists in a "silicon foundry" scenario. In particular, the qualification process must be extended to include design evaluation through advanced but proven analytical techniques. Coverage should include validation and verification of the design at all levels of description, fault simulation, and performance and testability analyses.

Finally, the screening procedures (stressing, testing) to be applied to the final package devices need to be strengthened and updated to reflect the wealth of experimental and empirical data that has been gathered over the last several years, and to address the failure mechanisms described previously.

This preliminary assessment indicates that a major effort in reexamining and redefining the qualification process is both necessary and justifiable to accommodate custom, large-scale, high-reliability integrated circuits and subsystems. The present DDF task is providing an appropriate beginning toward that effort by providing this assessment.

The listed investigators are interfacing on a continuous basis with several developmental programs regarding VLSI implementatins of advanced subsystem circuitry for upcoming flight programs, a well as with the companion

DDF task on Fault-Tolerant Custom LSI/VLSI and the Product Assurance Technology (PAT) program. This constant contact provides valuable insight into the requirements associated with contemporary programs and allows immediate assistance to those programs, concerning both technical and procedural problems, on an interactive basis. Because of this interaction, this DDF task is constantly responding and adapting to the scheduling requirements of the various projects, as well as to their specific problem areas. Taken together, these interlinked projects are expected to provide an understanding of the capabilities of the "silicon foundry" concept as applied to high-performance, high-reliability microelectronics, as was referred to earlier.

C. FUTURE OUTLOOK

This DDF task was originally proposed as a two-year project, and tasking was projected on that basis. Since DDF sponsorship will be unavailable for the second year, other methods of underwriting the effort now must be identified. The primary subtasks to be continued into FY'85 were the reviews of Design Verification and Functional Testing requirements, and the generation of a prototype Qualification Procedure. It is currently hoped that these subtasks can be underwritten by the PAT program, perhaps with assistance from flight programs such as Mariner Mark II. The Technology, Foundry, and Design Capability reviews should be brought to completion and reported on in the near term, probably on carryover funds from FY'84.

D. FINANCIAL STATUS

The total funding for this task (FY'84) was $84.9K. As of the end of September 1984, the amount obligated was $54.9K, including $29.9K obligated by means of a contract with the Engineering Experiment Station of the University of Arizona. The remaining funds should be sufficient for completion of subtasks now in progress, as explained in Paragraph C.

E. PERSONNEL

The primary participant in this effort has been Norman F. Stahlberg, VLSI technology specialist in Section 514. Coordination has been provided by Dr. Martin G. Buehler, Senior Staff Scientist in Division 360, and by Lawrence M. Hess, LSI Components Group leader in Section 514.

The detailed review of documentation related to the military qualification process was carried out by the University of Arizona investigator, Professor John L. Prince, and his assistant, Barry Matsumori.

F. PUBLICATIONS

None.

INTERFACIAL CHEMISTRY AND SCHOTTKY BARRIER FORMATION AT TRANSITION METAL-SILICON INTERFACES

Interim Report
JPL 730-00289-0-3640

Paula J. Grunthaner, JPL
Frank J. Grunthaner, JPL
A. Madhukar, USC

A. OBJECTIVES

The objective of this task is to use high resolution X-ray photoemission (XPS) to investigate the role of the microscopic chemistry occurring at transition metal-silicon interfaces in determining the Schottky barrier height of the contact. In previous investigations of the Ni-Si, Pd-Si, and Pt-Si systems, we observed that the barrier height correlated with (1) the charge density around the Si atoms at the interface and (2) the strength of the metal-silicon bond. Both observations suggest that the intrinsic metal-silicon bond is playing a fundamental role in establishing the barrier, but an extension of the previous study to silicides outside the near-noble metal family is necessary to verify and understand the correlation between the electronic and chemical properties of the contact.

B. PROGRESS AND RESULTS

Our task approach involves the systematic XPS investigation of selected transition metal silicides on silicon, with the specific metal being chosen so as to cover the range of possible barrier heights. Because impurity atoms (oxygen and carbon) are known to affect the electronic properties of the metal-silicon interface, proper implementation of the task requires an in situ ultra high vacuum (UHV) multisource metal evaporation system. This evaporation system has been designed, implemented, and successfully tested. The design involves back-side electron beam heating of the metal crucible to evaporate the metal while shielding the silicon substrate from the possible deleterious effect of exposure to the electron beam (i.e., electron beam induced chemical reactions at the metal-silicon interface). The metal can be deposited while maintaining a background of $\sim 10^{-10}$ torr, the result of which is that a negligible number of impurity atoms are detected by XPS in the metal film. Annealing of the metal film to form the silicide is also being performed in situ under UHV conditions.

The task also proposes the use of in situ spectroscopic ellipsometry to simulataneously examine the optical properties of the metal-silicon interface. Implementation of in situ ellipsometry capabilities in the 0.2 to 2.6 micron range is nearing completion. A Cary 14i monochromator has been modified for microprocessor control and automatic wavelength scanning. The hardware system items, including the internal UHV optical bench, analyzer, polarizer, and detection system, have all been fabricated and are undergoing tests.

C. FUTURE OUTLOOK

The key effort remaining for completion of the spectroscopic ellipsometer is software implementation and system testing. We anticipate approximately two months will be required for this. At that point, the final deposition experiments will be completed.

We anticipate being able to submit a follow-on funding proposal to DARPA and/or ONR by the end of March 1985.

D. FINANCIAL STATUS

The total DDF funding for this task was \$40K. As of the end of September 1984, the amount obligated was \$27K. The remaining funds are sufficient for completion of the task as planned. Additional support for the design and implementation of the situ UHV metal evaporator and spectroscopic ellipsometer was provided by NASA.

E. PERSONNEL

Execution of the XPS studies for this effort is being carried out by Paula J. Grunthaner and Frank J. Grunthaner, Section 364. F. Lombardi (364) and D. Lawson (364) were responsible for the implementation and testing of the UHV metal evaporation system. D. Varney (364) and R. Vasquez (364) are responsible for the spectroscopic ellipsometry effort. A. Madhukar contributes to the interpretation of the photoemission data.

F. PUBLICATIONS

Results will be submitted for publication following completion of the effort. Two publications are anticipated.

SCIENTIFIC FINITE ELEMENT RESEARCH AND APPLICATIONS TO CONCURRENT PROCESSING

Interim Report

JPL 730-00291-0-3350

Arthur Raefsky, JPL
Gregory A. Lyzenga, JPL
David L. Meier, JPL

A. OBJECTIVES

The primary objectives of this task consist of researching and implementing finite element modeling techniques for concurrent processing. The implementation aspect of this work is directed towards the Caltech/JPL developed Hypercube Concurrent Processor.

The need to solve boundary value problems involving elliptic partial differential equations on geometrically complex domains, arises in many engineering contexts, and increasingly in a wide variety of scientific fields. The finite element method, which has been treated in a large number of excellent texts, provides a flexible and powerful numerical technique for the solution of such problems. The physical problems, which have been solved by finite element methods, come from diverse fields as structural and continuum mechanics, fluid dynamics, hydrology, heat flow analysis, and many others.

Traditionally, derivatives of Gaussian elimination have been used to solve these systems, giving robust performance under a wide range of matrix ill-conditioning circumstances. In these cases, the solution task nearly always represents the dominant computational cost. This cost, however, increases rapidly with problem size, being proportional to $N_{eq}b^2$, where N_{eq} is the global number of solved for degrees of freedom, and b is the mean diagonal bandwidth of nonzero elements in the matrix. This means that the work necessary to solve the system, especially for grids in higher dimensions, will increase much faster than the number of nodes increases for larger problems.

For these reasons, we have considered in this work, an implementation of an increasingly popular iterative technique, which, assuming it converges, offers the potential for much improved performance on large three-dimensional grids. This, combined with a rather straightforward concurrent generalization, made this an attractive area to explore.

B. PROGRESS AND RESULTS

During the past year, we have succeeded in formulating and testing a concurrent finite element program, which applies the method of conjugate gradients to problems of two-dimensional elastic strain analysis. The prototype discussed here was written in the C language, and cross-compiled on a VAX 11/750 system for execution on the 8086-based 32-node hypercube (Mark II) machine. Listings and further information on this code may be obtained by contacting one of the investigators.

The above described finite element/conjugate gradient program was tested on a series of two-dimensional plane strain elastostatics problems, intended to (1) verify the proper execution of the program and (2) provide benchmark measurements of the program's concurrent efficiency as a function of problem size and number of processors.

The Mark II hypercube was used in these tests in configurations from one node (0-dimensional cube) through the full 32 nodes (5-dimensional cube). In addition, a variety of problem sizes were explored to determine the characteristics of efficiency scaling with problem size. The results were that when the processor nodes were fully utilized (in terms of maximum problem size) concurrent speed-up efficiency in the range of 94-98% was achieved. In addition, the efficiency scaling laws were found to agree with the theoretically predicted relation.

C. FUTURE OUTLOOK

We find that the concurrent conjugate gradient algorithm outlined here meets our expectations in providing large speedup in finite element system solutions. Results from actual runs on the 32-node Mark II hypercube system yield net efficiencies upwards of 90%. From this we can conclude that future major use of this and related algorithms on large finite element application will hinge upon the applicability of iterative techniques, and not upon any issue of of concurrency or efficiency.

Several areas are now indicated for future research in this area. Among the most immediate needs are: (1) effective preconditioners, such as the element-by-element (EBE) scheme, (2) extension to three dimensions, (3) investigation of assembled stiffness versus element storage techniques, and, perhaps most importantly, (4) automated procedures for breaking up and balancing an arbitrary finite element problem among processors. We anticipate addressing these problems in the near future.

D. FINANCIAL STATUS

The DDF funding for this task in FY'84 was $49.2K. As of the end of October 1984, $17.5K had been expended, representing expenditures over approximately the last half of FY'84. The remaining $31.7K, in addition to the second year funding of $20K will permit the completion of our projected task goals in the following one or one and one half fiscal years.

E. PERSONNEL

Principal scientific responsibility for this work rests with Arthur Raefsky working in collaboration with JPL, Caltech, and Stanford University groups. Gregory A. Lyzenga and David L. Meier had managerial responsibility over the task, as well as participatory scientific involvement.

F. PUBLICATIONS

Publications, which are now in preparation, include a journal paper describing the concurrent finite element results, and a chapter for a book on applications of concurrent processing.

SUPPORT FOR SOLAR SAIL DEVELOPMENT ACTIVITIES

Final Report

JPL 730-00193-0-3140

Mark J. Bergam, JPL

A. OBJECTIVE

The objective of this task has been to support the World Space Foundation's Solar Sail Project. Throughout its history, support has been utilized in the following areas:

(1) Development and construction of a low-cost, easily manufactured deployment mechanism to be used on the Solar Sail Deployment Experiment (SSDE) now being negotiated to fly aboard the Shuttle.

(2) Define the sail pointing history within an orbit necessary to circularize an eccentric orbit.

(3) Develop the control algorithms for the attitude control system necessary to bring the sail from a perturbed state to a predefined desired sail attitude.

(4) Size the control vanes and choose the sensors and actuators necessary for input to the control system.

(5) Produce a second set of 20-meter length, collapsable spars to be used on the SSDE.

B. PROGRESS AND RESULTS

Support for the Solar Sail Development Activities has occurred over the past four years, initially under the direction of H. Price. Although the objectives have changed somewhat over the course of time, this DDF support has produced the following results.

A deployment structure and four 20-m spars have been produced in the Sheet Metal Fabrication Shop. The spars, wound up on the deployment mechanisms, allows for compact storage of these long beams. A half-scale prototype sail (15 x 15 m) was deployed at the Planetfest in August 1981.

A vacuum chamber test was performed to test the integrity of the seams of the sail fabricated of Mylar. Using a hands on fabrication progress introduced into the seam very small bubbles, which would later be expanded from the vacuum of space, possibly rupturing the seam. The test verified that small bubbles in the seams were not big enough to cause rupturing of the seams.

The navigation system received much attention with the development activities. Assuming a flat sail, the pointing history within an elliptic orbit has been defined. This history maximizes the orbit energy gained from the resultant thrust vector provided by the refected sunlight. This and other algorithms guarantee that orbit parameters can be changed using only reflected sunlight, thus verifying the concept of propulsion by sunlight.

Discrete axis Euler rotations have also been developed in order to perform body axis rotations to reach desired attitudes (and therefore desired thrust). This information, coupled with sensor inputs, guides the strategy of commanding the solar sail. All this information then gets processed on the ground to determine the commands necessary to keep the sail on its desired course. The involvement of the author on the flight of the SIR-B radar this past year has delayed the publication of the paper discussing the navigation system as currently envisioned and developed.

Larger vanes produce faster rotation capabilities and more control force. However, oscillations due to moving parts at the extreme ends of large flexible structures has not been investigated. Larger vane sizes could also mean more instability, thus cancelling their benefit of more control force.

Outside of DDF support, the Foundation has progressed on many fronts. A Memorandum of Understanding has been signed between the Foundation and the Radio Amateur Satelite Corporation (AMSAT) to provide communications equipment and ground tracking support. A presentation was given to the AMSAT Board of Directors November 10, 1984, outlining the relationship that is to exist between the Foundation and AMSAT. Provisions are also included to accept small-scale, low impact to Foundation resources experiments to fly with the Engineering Development Mission (EDM).

This author was also invited to and represented the solar sail propulsion technique at the 10-week NASA Summer Study sponsored by UC San Diego and Cal Space.

Alan Mole, a professional engineer in structures from Boulder, CO, has also been solicited to provide a stress analysis on the SSDE structure to be used aboard the Shuttle. (Gratis professional expertise is not an easy commodity to come by.)

UC San Diego has also supported, with a grant from Cal Space, a study to determine the electrostatic potential that will build up on the sail in the near Earth radiation environment. Flying edge on to the velocity vector in the shadow of the Earth was found to be the worst conditions for the greatest electrostatic potential buildup on the sail. The study was finalized with a paper outlining the results.

C. FUTURE OUTLOOK

The Solar Sail Project has a bright outlook ahead outside DDF circles. A Joint Endeavor Agreement (JEA) is currently being negotiated with NASA to provide the mutual benefit of a free launch for the Foundation's solar sail and shared technology for NASA. Although this is a relatively new and, therefore, slow process, the Foundation feels that it is well worth the effort. Initially, the JEA was intended to be exclusively for the EDM, but NASA felt that commitment was too big a risk on its part. NASA has since suggested and included the SSDE in the JEA negotiations as a stepping stone to the full scale Engineering Development Mission.

The Space Association of Australia, Inc., has also been in contact with Foundation staff to determine possible areas of cooperation that utilize the expertise available in that country to help in the solar sailing efforts. Possible areas of involvement includes software development, computer simulations, optical as well as radiometric tracking, and the station and equipment needed for the task. Negotiations have been through Ian R. Bryce, Councillor.

A study has also been performed by Societe d'Astronomie Populaire (SAP) for the Foundation. SAP is an astronomy group based in Toulouse, France. They are interested in optical tracking of the solar sail and determined that under optimal viewing conditions, the sail would be as bright as Venus at twilight. Optical tracking provides plane-of-sky type orbital information, which compliments the range and range-rate information provided by radiometric tracking.

Dr. Harry Ruppe of Technische Universitat Munchen (Technical University of Munich) is still interested in providing a pre-deployment attitude control system. However, since this effort (as are most outside efforts) is provided on a no transfer of funds basis, Dr Ruppe needs to show a commitment from NASA to the Foundation to his management in order secure funding for his own support of the Solar Sail Project (SSP).

Negotiations with possible funding sources continues.

D. FINANCIAL STATUS

Total DDF awards to this task have been $47.5K. The remaining $28.6K carried into FY 84 has been spent on developing the navigation system and the final set of spars. Expenditures occuring under both cognizant individuals for the entire task are outlined below.

Work Area	Expenditures, $		Remaining, $		
Spar development, container, 2 spars	14,500				
Instrument package	4,400				
Navigation system	17,500				
Final 2 spars	8,800				
			about 2,300		
Total	45,200	+	2,300	=	$47.5K

E. PERSONNEL

Navigation systems work proceeded under the direction of David Sonnabend and was carried out by Vijay Araghavan Alwar of Section 314. Spar fabrication has been directed by Richard Evans of the Section 357 machine shop.

F. PUBLICATIONS

(1) "Navigation of a Solar Sail," M. J. Bergam, D. Sonnabend, and V. A. Alwar, to appear.

(2) Foundation News, published quarterly by the Foundation.

(3) "Vacuum Chamber Test of the Solar Sail Seams," M. J. Bergam, JPL IOM 314.3-439, 14 February 1983.

(4) "The Solar Sail Engineering Development Mission and the AMSAT Community," M. J. Bergam, presented at the 1984 AMSAT Annual Meeting, Amfac Hotel, Marina del Ray, CA, 10 November 1984.

G. CONCLUSIONS

The spars, their container, and navigation systems work were the most significant aspects of the Solar Sail Project supported by the Director's Discretionary Fund. It is possible that the spars could fly aboard the Shuttle for the Solar Sail Deployment Experiment. Continuous, high quality spars will be needed for the Engineering Development Mission. The navigation system of the solar sail, though not complete, will be one of a kind. No spacecraft yet has demonstrated both attitude control and thrusting capability with only sunlight.

THE SOLAR SAIL ENGINEERING DEVELOPMENT MISSION AND THE AMSAT COMMUNITY

Mark J. Bergam, Executive Director
Solar Sail Project, World Space Foundation

ABSTRACT

The Solar Sail Project Engineering Development Mission being planned by the World Space Foundation will be the first attempt to demonstrate solar sailing as a means of spacecraft propulsion and control. The spacecraft for this pioneering venture will require substantial guidance and control capability in order to carry out its mission, which involves significant Earth orbit operation out to lunar flyby, possibly leading either to permanent Earth orbit or Earth escape. Implementation of this mission profile will require development of guidance algorithms and software. Tracking and navigation will be most important because of the constantly changing orbit of the sail. This will involve extensive use of existing capabilities such as the AMSAT network. While the prime purpose of the mission is the demonstration of the solar sail, there is excellent potential for various other investigations such as charge buildup on the sail. The spacecraft may also function as a communications relay.

BACKGROUND

Communication to the solar sail will be of vital importance to its navigation; the sail will only be able to carry out instructions received from the ground. The heart of the solar sail, the navigation system, is responsible for planned orbital perturbations with properly reflected sunlight. The hardware of the solar sail's navigation system consists of the sail or reflective surface, control surfaces or vanes (also reflective), a moveable tip mass, sensors, and a computer to monitor and coordinate their movements (see Figure 1). Foundation staff have fabricated and deployed a 15 x 15 meter sail, and fabricated a 30 x 30 meter sail.

The triangular shaped vanes act as control surfaces to impart translations, rotations, and dampening to the sail. The moveable tip mass changes the center of mass, and therefore, center of pressure of the sail, acting as a sort of rudder. The onboard computer then processes the stored commands that have been uplinked from the ground to instruct the positions of these attitude control devices.

To eventually roam the inner solar system, future solar sail navigation systems will have to be self-contained, onboard the spacecraft. However, for the Engineering Development Mission, demonstrating substantial changes in orbital parameters via control from the ground will constitute mission success. Using commercial microcomputers to determine the sail's orbit and

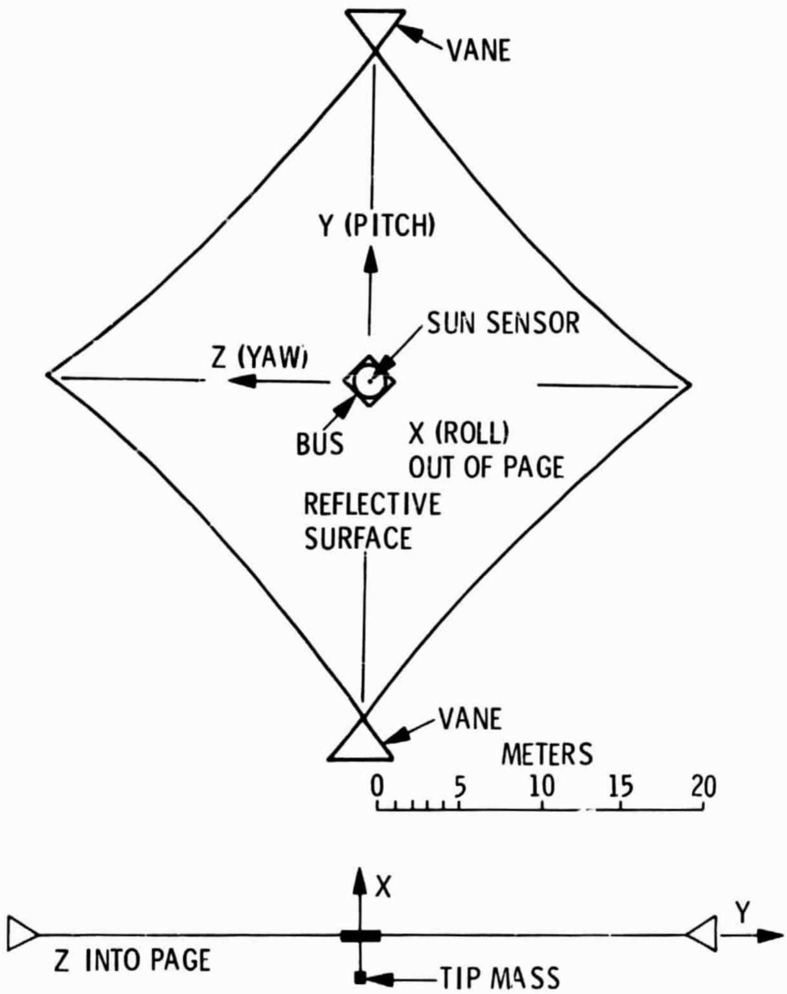

Figure 1. Solar Sail

attitude history, desired orbital progression acheived by proper attitude control positions will be determined and then commanded to the sail. Figure 2 shows a navigation system block diagram.

The philosopy of ground intensive operations was adopted for two basically distinct purposes, least expense and the capability of the navigation system to evolve. In terms of both development time and dollars spent, the cost to develop an onboard "smart" navigation system would be prohibitively expensive. Also, by leaving the heart of the navigation system on the ground, we allow for reaction to unforseen events and phenomenon, which manifests itself in new control algorithms to be determined, evaluated, and then used for the attitude control strategy.

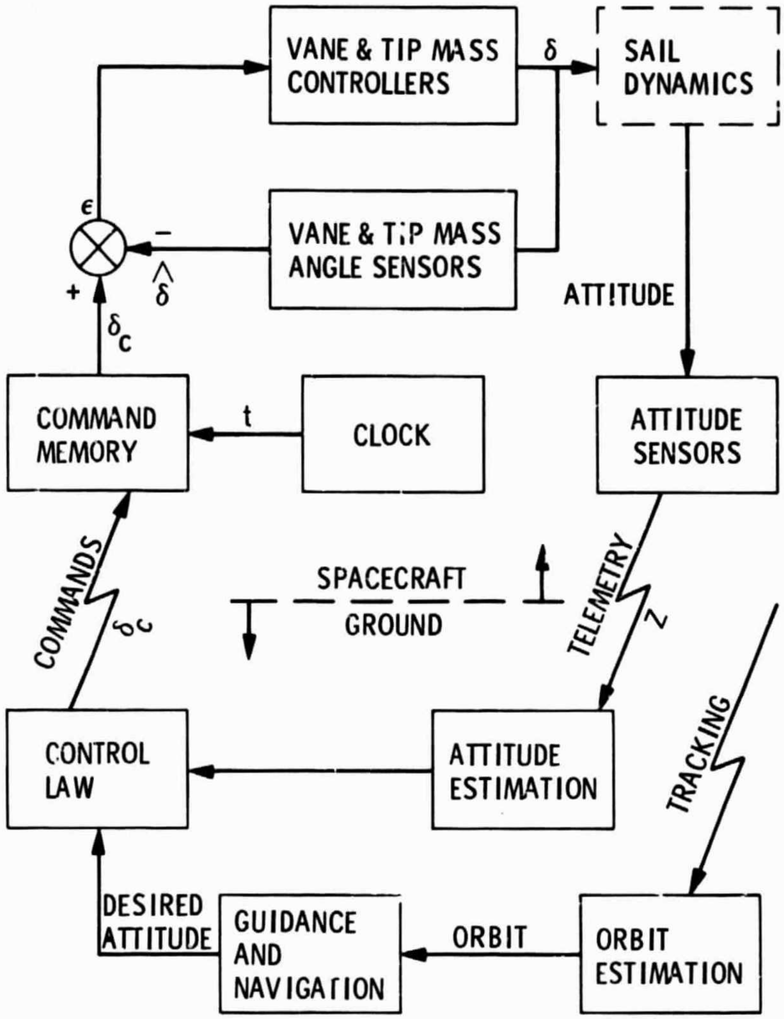

Figure 2. Navigation System

OPERATIONS

Through a Memorandum of Understanding, AMSAT has decided to cooperate in the Engineering Development Mission by providing the design and hardware of the communications system to fly aboard the solar sail. This includes spacecraft quality transmitters, receivers, transponders, antenna, and other communications related components. This communication subsystem will be a key link in solar sail operations.

Unlike planetary probes on ballistic trajectories requiring infrequent tracking, the constantly expanding orbit of the sail will require frequent orbit updates. Employing the existing AMSAT tracking capabilities is a perfect mating of the Foundation's need and AMSAT's capability. Collectively, the AMSAT community can provide a great service to the World Space Foundation by being responsible for monitoring the evolution of a new space propulsion technology proving itself!

In addition, this responsibility could also lead to a new type of challenge to the AMSAT community. As the solar sail's orbit increases in size it will slowly venture from near Earth to geosynchronous, and finally, to lunar distances. Tracking stations available will diminish throughout the course of the mission as power required increases.

Optical tracking has also been offered by the Societe d'Astronomie Populaire of Toulouse, France, to supplement plane-of-sky location information to the range, range-rate capabilities of AMSAT's radiometric tracking. The French group have also done a visibility study of the sail in anticipation of their participation. As one can see, coordinating and correlating all this orbital information will be no small task.

Backup ground stations capable of uplinking commands will also be needed to supplement the Foundations's abilities in case of bad weather or emergency situations requiring commanding from other parts of the world. Levels of cooperation and exchange of expertise should be of the upmost benefit to both parties, in terms of technology exchange and public visibility.

OTHER POSSIBILITIES

Although the major purpose of the Engineering Development Mission is to demonstrate attitude control and orbit changing capability, with small impact to spacecraft and Foundation resources, other simple experiments can be accomodated. The radial distance to which the previously mentioned French group can optically track the receeding solar sail will be an experiment in itself.

A study of the electrostatic potential on the sail surface that would occur in the near Earth environment has been studied by Jay Hill and Elden Whipple of UC San Diego. The large reflective surface of the sail provides an opportunity to study sudden changes in the spacecraft electrical potential which has been known to have an undesirable effect on space components. The plasma environment around the sail could easily be monitored during the sail's slow altitude climb.

Signals bounced off the sail surface might even provide a communications relay experiment to interested AMSAT individuals.

Also, the Foundation is considering using a slow-scan CCD type camera as the tip mass if communications capability allows. This camera could be used for monitoring sail response, trouble-shooting purposes, or viewing other nearby objects.

SUMMARY

The benefits of AMSAT's participation in the Solar Sail Engineering Development Mission exists in many areas. A "spot onboard" the solar sail will be pubically visible to many people from various countries. It will also expand AMSAT's and the Foundation's continued cooperation with similar organizations to share the experience gained through efforts such as this. And most important to some, it will provide a challenge not only to the worldwide AMSAT communications community, but also to the general endeavor of putting useful, private spacecraft into space.

INTEGRATED OPTICS ELECTRONICALLY SCANNED IMAGING FOURIER TRANSFORM SPECTROMETER

Final Report

JPL 730-00224-0-3820

J. B. Breckinridge, JPL
F. G. O'Callaghan, JPL
R. A. Schindler, JPL
J. C. Wyant, University of Arizona

A. OBJECTIVES

The purpose of this DDF task is the analysis and preliminary development of a rugged monolithic Fourier transform spectrometer (FTS) for remote spectroscopic measurements across a two-dimensional scene. Detailed analysis of the throughput of the instrument, computer modeling of the system, identification of the driving technologies, and limited breadboard construction were planned.

B. PROGRESS AND RESULTS

(1) Analytical Work. Analysis was completed. A derivative of this optical configuration, which has performance significantly above that given by the design in the original paper, was discovered.

A spectrometer comparison factor based on system throughput, spectral resolution, system transmittance, spectral bandwidth, and detector noise equivalent power was calculated for a grating spectrometer, the electronically scanned Fourier interference transform spectrometer (ESFITS) originally proposed, the revised ESFITS discussed below, the classical Fourier Transform Spectrometer, and each of two hybrid-ESFITS[1,2] suggested in the literature by the Japanese. Other authors[3,4,5] discuss the principles of two-dimensional Fourier transform spectrometer. Table I, below, gives the ratio between the spectrometer comparison factor (SCF) for the analyzed system and the SCF for the grating. All cases are done for a spectral resolution of 1200.

(2) Experimental Work. The discovery of the new, more efficient optical configuration was so exciting that further analysis of the new system was pursued. No comprehensive experimental verification was performed for any system.

C. FUTURE OUTLOOK

The analysis is now of sufficient detail that a proposal for a laboratory demonstration can be pursued. As soon as a NASA program in generic optical systems research is established, funds will be sought to develop this instrument.

Table I. SCF/SCF (Grating) Comparison

SPECTROMETER	SCF
Grating	1.00
Original ESFITS	0.22
Revised ESFITS	10.12
Classical FTS	4.23
Yoshihara, Nakashima and Higuchi	0.40
Kamiya, Yoshihara and Okada	0.13

D. FINANCIAL STATUS

The original amount was awarded in 1982 for $37K. A $10K contract was given to the University of Arizona, Optical Sciences Center for Dr. Wyant's participation. All funds are exhausted.

E. PERSONNEL

Rudy A. Schindler of JPL has been the primary investigator this past year. J. B. Breckinridge and F. G. O'Callaghan provided creative contributions.

F. PUBLICATIONS

A rough draft proposal for follow-on work was outlined, but not finished since there is no appropriate office for submittance. Generic optical systems research, although needed by NASA, is not directly funded by NASA.

G. CONCLUSIONS

A new spectrometer configuration, based on the original electronically scanned imaging, Fourier transform spectrometer, was discovered during this analysis task. The configuration was found to have 10 times the throughput of a classical grating spectrometer and to have more than twice the throughput of a classical Fourier transform spectrometer.

H. REFERENCES

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EVALUATION OF INSTRUMENTAL CONCEPTS FOR A SPACE-BASED SOLAR OSCILLATION TACHOMETER

Final Report

JPL 730-00229-0-3280

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Alessandro Cacciani, University of Rome
Fred E. Vescelus, JPL
Edward J. Smith, JPL
Roger K. Ulrich, UCLA
Robert F. Howard, National Solar Observatory

A. OBJECTIVE

The objective of this task was a study of the feasibility of employing either a magneto-optical resonance cell filter, a Fabry-Perot interferometer, or a Fizeau interferometer as the Doppler analyzer element in a compact solar oscillation tachometer. Specifically, this task was designed to demonstrate whether any of these three instruments would have sufficient radial velocity precision and stability, as well as sufficient simplicity, to be suitable for the acquisition of long-duration, uninterrupted time series of solar velocity-field measurements from above the Earth's atmosphere. In turn, such extensive data sets, by virtue of their continuity over months and even years and their lack of terrestrial-induced image distortion, would allow us to extend greatly recent ground-based advancements in the rapidly-emerging field of solar seismology. In particular, we would be able to search for those modes of solar oscillation which are currently unobservable from the ground and we would also be able to study dynamical changes as they are occurring throughout the solar convection zone.

This specific project was designed to allow us to carry out our comparison of the three different types of instruments by actually testing experimental versions of each of them. We did so by installing each of the instruments in a specially-designed oscillation observing system, which we had previously developed at the Mount Wilson Observatory for this purpose. Our initial experimental tests of the Fizeau interferometer showed that it would be quite difficult to use for our needs; and, hence, we spent most of the past two years in a comparison of only the magneto-optical filter (MOF), and the Fabry-Perot interferometer (FPI).

B. PROGRESS AND RESULTS

During the past two years, we have indeed succeeded in demonstrating that the MOF appears to be a feasible candidate for a space-based oscillation tachometer. We have done so first by studying the spectral transmission properties of the MOF with the spectrograph of the Mount Wilson 150-ft solar tower, then by obtaining several one-day sequences of solar Dopplergrams with our existing CID-camera acquisition system at the Mount Wilson 60-ft solar tower during 1983, next by employing the MOF and the CID to obtain measurements on 90 different days during 1984, and lastly by combining the MOF with the JPL "traveling" CCD camera in order to obtain the first full-disk solar Dopplergrams having a spatial resolution of only three arcseconds per pixel.

The 150-ft tower measurements showed that the MOF could indeed produce extremely narrow transmission peaks whose wavelengths could be suitably adjusted by changing the amount of electrical power input to the MOF. These tests also showed that the spectral transmission properties of the MOF were similar to those predicted from a theoretical model of the filter. This agreement gave us confidence that we were truly learning how the MOF operated.

The 1983 observations at the 60-ft tower were subsequently converted into two-dimensional (k_h-ω) power spectra of the solar p-mode oscillations. These (k_h-ω) spectra served to illustrate the relatively low noise present in the MOF while operating for many hours at a time. An example of these (k_h-ω) power spectra is shown here as Figure 1. These measurements showed that a relatively simple mechanical installation of the MOF was sufficient to allow us to observe solar oscillations in as little as five hours of data gathering.

The 1984 CID observing season has served to demonstrate the durability of the MOF over a several-month period. The operation of the MOF and our existing 244 x 248 pixel CID camera system from June through September 1984, has resulted in the most extensive set of full-disk solar Dopplergrams yet obtained at any solar observatory. These data are currently being analyzed at Mount Wilson and at JPL and we are confident that they will confirm and extend our 1983 experiences with the MOF. For example, we will be able to see how repeatable the instrumental conversion from intensity to radial velocity is on a daily basis over 90 different days.

As mentioned above, we not only employed our own CID camera with the MOF, we also employed the JPL "traveling" CCD camera on several occasions. A sample full-disk Dopplergram obtained with the MOF and the JPL CCD camera is shown here in Figure 2. This particular image covers an area of 500 x 500 pixels on the CCD chip while other images were obtained that covered up to 700 x 700 pixels. The rotation of the Sun is visible in Figure 2 as the smooth variation in mean gray level across the solar disk.

In addition to the above results with the MOF, we were also successful at obtaining a few magnetograms with it at the Big Bear Solar Observatory during August 1983. We currently hope to obtain additional magnetograms with the MOF, but we have not yet done so. We also fabricated permanent magnet assemblies of 2000- and 6000-gauss longitudinal field strength. These magnets were designed to determine whether or not the MOF's performance can be improved at higher levels of magnetic field strength. We have not yet been able to complete these tests.

In order to evaluate the FPI, we decided to try out a method of wavelength tuning, which employed changes in the pressure of the gas-filled enclosure surrounding the interferometer. In order to test such a pressure-scanning technique, we had to first modify our Mount Wilson observing system in order to accommodate the pressurized vessel itself. We designed,

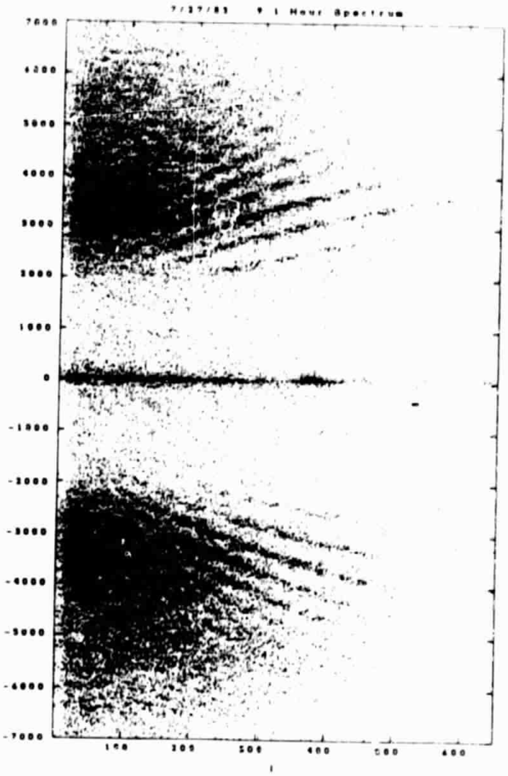

Figure 1.

Figure 2.

fabricated, and installed an entirely new optical path at the 60-ft tower, which had an optical bench large enough to accommodate the pressure-scanning oven. This was completed by mid-1984 and we were able to demonstrate that a pressure servo system would be required in order to even approach the level of pressure stability which this method would require. Consequently, we tried out a second-generation presure vessel, which did contain an integral pressure servo subsystem. Our initial tests of this new pressure oven at Mount Wilson showed that the extremely high levels of radio-frequency interference present there were overwhelming the servo circuits. Subsequent tests of the second generation oven at the Mount Wilson offices in Pasadena, where the rf environment is quite benign, showed that the pressure servo system is now performing to within a factor of roughly four of that required. Unfortunately, the only solar observations we were able to obtain with the FPI and the new oven were obtained in the harsh rf environment and only had a duration of three hours. More extensive observations with the FPI will have to await an rf-hardening of the servo circuit and better observing weather. Thus, while we have not yet encountered any fatal flaws with the use of the FPI, the extra complexity required of this approach has not yet allowed us to obtain a clean (k_h-ω) diagram such as those we have already been able to obtain with the MOF.

C. FUTURE OUTLOOK

The encouraging results of the last two summer's MOF tests suggest that this device may indeed be suitable for our needs. Hence, we are actively participating in the joint ESA/NASA Science Working Group (SWG), which is now studying the proposed Solar and Heliospheric Observatory (SOHO) mission in order to have an opportunity to fly a solar oscillations imager (SOI) experiment. Since one of the principal scientific objectives of the SOHO mission is the study of the solar interior with solar oscillations, the mission will be a prime candidate for the flight of an SOI. Consequently, E. J. Rhodes and R. K. Ulrich have attended several meetings of the SOHO SWG during the past year at ESTEC. These meetings have resulted in a recommendation that an instrument having the characteristics we desire be included in the SOHO strawman payload. This strawman payload is currently being studied by two different European industrial consortia as part of ESA's Phase A study of SOHO. The inclusion of an SOI is being studied by both industrial teams and the large data rate of this instrument has meant that additional NASA collaboration in the form of DSN tracking support of SOHO would be essential.

The continuation of the hardware tasks begun with these DDF awards has already been funded by the Astrophysics Division Office at NASA Headquarters. An RTOP outlining the follow-on tasks to those described in this report has already been submitted for FY'85. Briefly, this RTOP includes additional experimental tests of the MOF at Mount Wilson with the new magnets and physical arrangements and the completion of a 1024 x 1024 pixel CCD camera and acquisition system. The new camera will be coupled with the MOF at Mount Wilson to obtain full-disk Dopplergrams having two-arcsecond spatial resolution. Additional testing of the FPI will also take place during the coming year but most of our emphasis will be on the MOF.

One potential problem for this project is the transfer of operations and funding of the Mount Wilson Observatory to an as yet undetermined organization. This impending change will likely have an impact on our continued access to the 60-ft and 150-ft tower telescopes. For this reason we may have to request additional DDF funding in FY'86.

D. FINANCIAL STATUS

The combined FY'82 and FY'83 DDF awards for this project totaled $98,300. As of April 1984, all funds had been exhausted and the account was closed.

In addition to the DDF support provided for this research, the JPL Equipment and Instrumentation Committee provided $26,000 to purchase additional computing hardware, NASA headquarters provided $220,000 to JPL during FY'84 for the Mount Wilson tasks, and NASA Grant NAGW-13 to the University of Southern California provided $104,000 during 1983 and $90,000 during 1984 for helioseismology research at Mount Wilson. Furthermore, Prof. A. Cacciani of the University of Rome also received financial assistance from the Italian National Research Council, CNR, while J. Blamont received financial support from CNRS and CNES in France.

E. PERSONNEL

The overall direction of this project at JPL was provided by Edward J. Rhodes, Jr., of Section 328. Dr. Rhodes was assisted at JPL by Jacques E. Blamont, Fred E. Vescelus, and Edward J. Smith. Dr. Cacciani, who originally invented the MOF in Italy, supplied several of the cells for the work at Mount Wilson. Dr. Blamont directed the fabrication of the FPI and its ovens in France and Roger K. Ulrich of UCLA, and Dr. Robert F. Howard (formerly assistant director of the Mount Wilson and Los Campanas Observatories) also collaborated on this research. Along with the above investigators, this project also benefitted from significant contributions from the following individuals: Tom Andrews, Section 351; Tom Bursch, Bob Wilson, Steve Geller, Harry Marsh, and Peter Kobzeff, Section 381; Doug Clay and Tom Thorpe, Section 328; Maynard Clark, Harvey Crist, and John Boyden, Mt. Wilson staff members; Dr. Wendee M. Brunish, USC, Dr. Philip J. Dumont, USC; Stephen Tomczyk, Bradley Wood, and Daniel McKenna, UCLA personnel; and Jeff Mannan, Orbis Corporation.

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G. CONCLUSIONS

The successful acquisition of solar (k_h-ω) power spectra, the subsequent acquisition of 90 days of data during the summer of 1984, and the successful use of a large-area CCD camera all represent very significant milestones in the development of a space-borne solar oscillations experiment. The work carried out on this project has helped JPL to establish its role as the de facto lead center in the development of such an experiment for the SOHO mission. The work carried out with DDF support has recently been followed by additional observational tests of the instruments and also by a conceptual design exercise for such an SOI experiment-all with NASA Headquarters support. The current experimental data clearly favors the magneto-optical filter over the Fabry-Perot interferometer; however, both approaches still appear to be feasible and further testing will be necessary before a final selection can be made. At all stages, JPL personnel will continue to be involved in the SOHO mission planning.

CHEMICALLY RECHARGEABLE IRON-AIR BATTERY

FINAL REPORT

JPL 730-00232-0-3420

Stephen F. Dawson, JPL

James E. Graf, JPL
John J. Rowlette, JPL
Roger M. Williams, JPL

A. OBJECTIVE

The objective of this task was to demonstrate the feasibility of recharging an iron-air battery via chemical methods as opposed to traditional electrical means. The iron-air battery is capable of relatively high specific energy (~100 Wh/Kg) and moderate specific power (~90W/Kg), and has achieved 300 cycles at 80% Depth of Discharge (DOD). The specific objectives of this effort were:

(1) Evaluate the reduction of $Fe(OH)_2$ to Fe^o in basic aqueous and basic methanol solutions at temperatures 20-100°C.

(2) Investigate feasibility of chemically assisted recharge of discharged iron electrodes.

B. PROGRESS AND RESULTS

Two test activities were undertaken: one to evaluate reducing solutions and the other to obtain a quantitative recharge capacity for the system. The following results have been obtained from laboratory cell charge/discharge experiments:

(1) Two aqueous reducing solutions (sodium dithionite and sodium hypophosphite) have been tested at various temperatures and under different techniques. Under temperatures of 100°C and pure chemical environment (zero applied voltage across the electrodes), no significant recharge was observed. At moderate temperatures (~80°C) and under "electrochemical" recharge conditions (a small applied voltage across the electrode in conjunction with the reducing agent), a

significant, but incomplete, recharge was achieved. It is believed that hydrogen evolution was limiting the effectiveness of the charging in aqueous solution.

(2) Six nonaqueous reducing solutions have been tested at different temperatures under both pure chemical and "electrochemical" techniques. The results have been favorable with 10 to 100% recharge being observed for the "electrochemical" and up to 25% for the pure chemical recharge. Temperatures varied from room temperature (~25°C) to 85°C. Results are summarized in Table 1.

(3) Quantitative chemical recharge experiments were carried out using pressed (Fe) electrodes of 1 cm^2 gross surface area. Electrical or chemically charged electrodes were discharged in 8M KOH/H_2O. Chemical recharge was accomplished using 4 M KOH/CH_3OH. All electrochemical experiments were carried out at a constant current of 10 milliamperes under an inert gas (N_2) blanket at 20 and 40°C. Recharge periods were 16 hours in duration with the working (Fe) electrode shorted to the counter (Pt or Ni) electrode. Chemical recharge was observed at 20 and 40°C. However, recharge levels were not reproduceable for the electrodes tested. Loss of electrode material was observed in all electrodes (see Table 2). Loss occurred for both chemical and electrical recharge cycles.

C. FUTURE OUTLOOK

Chemical recharge of an iron electrode has been demonstrated. These elements need addressing:

(1) Elimination of chemical etching of the iron electrode during recharge of electrode.

(2) Reduction of recharge temperature requirements.

(3) Enhance the rate of recharge for chemical and chemically assisted over traditional electrical recharge.

(4) Follow-on or new funding has not yet been identified.

D. FINANCIAL STATUS

The DDF award for this activity was $45,000 in FY'82. All monies were expended by the end of the first quarter of FY'84.

E. PERSONAL

The investigators for this task were James E. Graf, John J. Rowlette, Roger M. Williams, and Stephen F. Dawson.

F. PUBLICATIONS

A New Technology Report "Chemical Recharge of Iron electrodes in Iron-Air Batteries using Basic Alcohol Solutions" by Roger Williams, John Rowlette, and James Graf, was submitted in June 1982. A patent disclosure "Chemically Rechargeable Battery" with the same coinventors was prepared in February - March 1983. A NASA tech brief will be published based on the processes covered in the patent disclosure.

G. CONCLUSIONS

Reduction of $Fe(OH)_2$ to Fe^o via chemically and chemically assisted electrical recharge has been demonstrated. Chemical reduction of $Fe(OH)_2$ in aqueous system shows only limited promise for recharging air iron-air battery.

The "chemical" corrosion of the iron electrode remains a major problem for this system.

Table 1. Recharge Experiment Results Small Iron Electrodes (Hg/HgO Reference)

Electrode	Solution	Voltage Bias	Maximum Temperature	% Recharge
#1 (4.5^2)	4M KOH/MeOH	0.3V	~80°C	32%
	4M KOH/MeOH 10% PF*	0.5V	~80°C	~100%
	4M KOH/MeOH 10% PF	0.0V	~50°C	~25%
	4M KOH/MeOH	0.0V	~36°C	~12%
#2 $(\sim 2.3^2)$	40% PF 4M KOH/MeOH	0.0V	R.T.#	~20%
#3 $(\sim 4.6^2)$	40% PF 4M KOH/MeOH	0.0V	~30°C	~12%
	40% PF 4M KOH/MeOH	0.2V	R.T.	~20%
	2M NaOH/MeOH 5% H_2O	0.3V	R.T.	~22%
	15% PF 8M NaOH/H_2O	0.0V	R.T. (~4 HR)	~14%
	4M NaOH/ MeOH/10% H_2O	0.0V	285°C (3 HR)	~13%

*PF = Paraformaldehyde. #R.T. = Room temperature.

Table 2. Physical Iron Electrode History

Electrode	Weight Change (%)	Cycles	Final Cycle
A	17.8	4	~30% loss
B	31.5	10	~60% loss
C	15.4	8	----------
D	22.6	10	~45% loss

* Electrode fail completely on final cycle

REAL-TIME OPTICAL ACQUISITION OF DEPTH INFORMATION

Final Report

JPL 730-00237-0-3820

R. Keith Jenkins, USC
James B. Breckinridge, JPL

A. OBJECTIVE

The objective of the task, using interferometry and a diffraction-based optical technique, which relies on the self-imaging properties of gratings, will be to devise a method for the measurement of depth that is suitable for use in robotics system.

B. PROGRESS

An experimental Talbot range finding system has been implemented at USC. It has performed optical depth acquisition at TV frame rates, which gives it a substantial advantage over other range finding systems in many applications. These preliminary results have been very encouraging. There are some problems, however, that are being investigated to ascertain the utility of this technique.

The light efficiency of the system is worth investigating. In order to obtain a high resolution in z, a 5% duty cycle absorption grating was used in the experiment, absorbing 95% of the illumination. (Lower resolution in z permits larger grating duty cycles. A linear contract profile in z permits the use of a 35% duty cycle grating, but even this blocks over half of the incident illumination.) Use of a phase grating may alleviate this problem. A phase grating is known to self image, but its images are of no use here since they are not visible. However, planes in which the grating is visible also exist, and may provide a means of measuring depth with the phase grating. We have just begun investigating this possibility and have no results to report as yet.

C. FUTURE OUTLOOK

Increased light efficiency would be a substantial improvement; it would provide more freedom in choosing the contrast profile in z, making it more adaptable to different applications, in addition to permitting the illumination of larger volumes. We are pursuing the following approach in investigating the use of phase grating:

1. Determine, theoretically, the contrast and locations of the planes of visible contrast.

2. If the contrast is sufficiently high, proceed with an analysis to determine the z-axis profile of the visible contrast.

3. Demonstrate the visible images experimentally and measure the z-axis contrast profile.

If contrast at these planes is not sufficiently high, there are other possible approaches. Foremost among these is the use of partially coherent illumination, which has the advantage of reducing speckle and, thereby, improving the signal-to-noise ratio.

Another question worthy of study is the removal of the redundancy in the depth measurement or, equivalently, the extension of the depth measurement range. This is the other main area where improvement could make a substantial impact. The use of different illumination wavelengths can be cumbersome and impractical. A possibility here is the use of novel grating profiles that provide images at two different frequencies and at two different Talbot distances. Two electronic filters could then be used in parallel to convert the contrast at each grating frequency to depth information. This will also be investigated, as time and funding permit.

D. FINANCIAL STATUS

The DDF award for this task in FY'83 as requested by Professor T. C. Strand (USC), J. B. Breckinridge (JPL), and Dr. Atul Jain (JPL) was $47,400.00. Funds were exhausted in a contract to the University of Southern California.

E. PERSONNEL

This work was done by Dr. R. Keith Jenkins, Research Assistant Professor, Electrical Engineering Department, University of Southern California. T. C. Strand, now at IBM, San Jose, left USC at the start of this reporting period.

F. PUBLICATIONS

T. C. Strand published the following paper partially funded by this DDF.

P. Chavel and T. C. Strand, Range Measurement Using Talbot Diffraction Imaging of Gratings, Applied Optics, 1984.

G. CONCLUSIONS

Optical systems will have a major role in sensor systems for robotic sensors and depth determination.

FLUIDIZED BED COAL DESULFURIZATION

Final Report

JPL 730-00239-0-3450

M. Ravindram, JPL

EDITORIAL NOTE

Dr. M. Ravindram was a NASA-NRC Resident Research Associate at the time the work corresponding to this DDF task was performed. By the time material for this report was called for, Dr. Ravindram had left JPL and returned to his parent organization in India. Thus a specific contribution by him was not very practical. However, Dr. Ravindram had prepared a quite complete internal report (60 pages, dated January 1984) on his investigations before leaving, and a copy of it has been placed in the DDF task files for reference. For present purposes, the "Summary and Conclusions" section of Dr. Ravindram's report will suffice; it is as follows:

SUMMARY AND CONCLUSIONS

This is the final report for the Coal Desulfurization Studies conducted at the Jet Propulsion Laboratory of the California Institute of Technology at Pasadena, California, under a JPL Director's Discretionary Fund (DDF) grant, for the period December 14, 1982 through December 13, 1983.

The scope of the work consisted of: (1) laboratory scale coal desulfurization tests consisting of sequential chlorination and dechlorination of coal in a fluidized bed reactor system; (2) comparative evaluation of coal desulfurization based on chlorination in the aqueous and solid phases; (3) assessment of alternative approaches to dechlorination such as dechlorination by aqueous alkaline solutions, and gaseous ammonia in the solid phase; (4) studying the effect of catalysts during dechlorination by hydrogen; (5) development of innovative methods for coal desulfurization based on displacement by alkalies; and (6) identification of sulfur-chlorine gaseous species during coal chlorination.

Laboratory scale screening tests were conducted with two high volatile bituminous coals, PSOC 276 and PSOC 282, employing the batch fluidized bed reactor system designed and fabricated in the laboratory (first year effort) and a commercial Parr pressure reactor system acquired in an earlier program. Experiments were conducted to investigate: (1) slurry phase dechlorination employing aqueous solutions of sodium hydroxide and ammonium hydroxide; (2) dechlorination in the fluidized bed reactor employing anhydrous ammonia; (3) dechlorination by hydrogen over commercial cobalt-molybdate catalyst supported on alumina in the fluidized bed reactor; (4) dechlorination by hydrogen of coal impregnated with cobalt acetate and zinc acetate in the fluidized bed reactor; (5) desulfurization by steam treatment of alkali impregnated coal in the fluidized bed reactor; and (6) coal desulfurization by leaching with cupric chloride and sulfate. Product gas species collected during chlorination of coal in the fluidized bed reactor were analyzed employing gas chromatography and mass spectra techniques.

Results of these studies indicate that (1) none of the alternative methods investigated for dechlorination offer any significant advantage over dechlorination by hydrogen in the fluidized bed reactor; (2) contrary to results reported by other investigators, cupric salts were not overly effective in leaching sulfur from coal; (3) steam treatment of alkali impregnated coal in the fluidized bed reactor appears to be a viable alternative to employing molten alkali for coal desulfurization; and (4) the presence of sulfur monochloride (S_2Cl_2) and sulfur dichloride (SCl_2) was qualitatively identified in the product gas species collected during coal chlorination in the fluidized bed reactor by Gas Chromatography and Mass Spectra. This lends support to the mechanism proposed earlier for coal desulfurization in the fluidized bed reactor, viz., that the coal sulfur is removed as sulfur chlorides in the gas phase.

Investigations carried out in the last 2 years have resulted in the development of two potential methods for coal desulfurization. Though differing in the chemistry of desulfurization, one involving oxidation by chlorine and the other displacement by alkali, both of these processes based on fluidized bed reactor processing gave sulfur removals comparable to those achieved in the aqueous phase chlorinolysis process.

In conclusion, some of the characteristic features of the proposed fluidized processes could be summarized as:

1) Shorter reaction times and hence lower operating costs.

2) Reduced reactant requirement. This will also reduce the load of regeneration. Since both the above costs make up a substantial portion of the overall process cost, significant improvement in the economics of the processes is possible.

3) Fluidized bed reactors are known to promote good mixing between the phases and hence provide better process control and uniform product quality.

4) The proposed processes comprise fewer processing steps, thereby contributing to lower costs, and

5) Fluidized bed reactor processing is amenable to batch or continuous operation.

The proposed processes based on the application of fluidized bed reactors for chemical coal cleaning represent novel and advanced technology. While the feasibility of these is demonstrated in laboratory scale experiments, extensive development work would be needed to scale up the results of the bench scale experiments. In addition, engineering design data pertaining to downstream auxiliary process steps is also needed. Future effort could include:

1) Basic studies on reaction mechanisms and characterization of product and waste streams to enhance the understanding of the process chemistry.

2) Development of methods for the direct determination of organic sulfur in coal to provide more realistic estimates of its removal, and

3) Collection of design data and economic evaluation of the processes based on more precise cost factors.

ASTEROID OCCULTATION WITH A PORTABLE PHOTOMETER

Final Report

JPL 730-00241-0-3250

Alan W. Harris, JPL
Dennis L. Matson, JPL
Douglas M. Varney, JPL

A. OBJECTIVE

The objective of this task is to design, fabricate, and operate a portable photometric system for remote observations of asteroid occultations. In previous systems, expense, size, and power requirements hampered the formation of an organized network of observers. The availability of CMOS (complementary metal oxide semiconductor) processors and other low-power components has helped make this project possible.

B. PROGRESS AND RESULTS

Artwork and circuit boards for the control electronics have been produced and testing will commence before Christmas. Part of the photometer head has also been fabricated. However, due to a disk drive malfunction, software development has been delayed.

C. FUTURE OUTLOOK

Due to recent correspondence and problems with other portable systems, it is expected that this photometer will be able to provide useable occultation data, especially via the amateur community.

D. FINANCIAL STATUS

The DDF award for the project was $10,000 in FY'83. The original funds have been exhusted but additional funds have been provided through Douglas M. Varney for any needed electronics.

E. PERSONNEL

Douglas M. Varney is continuing to work on the project on a "donated-time" basis.

F. PUBLICATIONS

Correspondence is continuing with Carter Observatory in Wellington, New Zealand. Mr. Graham Blow, Science Officer at the Observatory, has continued to express interest.

ULTRAVIOLET ASTRONOMY
CCD DEVELOPMENT
Final Report
JPL 730-00252-0-381
James R. Janesick, JPL

A. OBJECTIVES

The objective of this task is to obtain understanding and experience to support the conceptual design of a CCD-based faint object spectrograph (FOS) for the Hubble space telescope (HST). Specific goals include the use of a CCD in a ground-based telescopic spectrograph and the characterization of CCD sensitivity at a wide range of ultraviolet wavelengths, where CCDs have not been tested heretofore. Finally, a theoretical model has been sought to explain observed CCD characteristics of sensitivity and charge spreading. This task has been done in collaboration with Dr. Beverly Oke at the Caltech campus.

B. PROGRESS AND RESULTS

Significant advances in CCD sensitivity have been demonstrated by this task. Specifically, interacting quantum efficiency of >50% throughout the spectral range of 600-10,000 Å with comparable sensitivity expected to continue to wavelengths as short as a few angstroms.

It has been determined that corona discharge or exposure to UV light charges the backside of the CCD through the process of ionosorption of O_2^-. The charging process, which amounts to only 10^{-4} monolayers of O_2^-, causes the backside energy bands of the CCD to bend in the upward direction promoting accumulation. The technique provides an ideal surface for the incoming photon by providing minimum absorbing layers (10^{-4} monolayer of O^-_2 and a <20 Å native oxide) and creating a backside electric field in directing a signal charge towards the front-side potential wells where the charge is collected and transfered.

It has been shown that the structure generated by backside charging is far superior to past backside structures fabricated since the invention of the CCD 15 years ago. Also it has been shown that organic fluorescent compounds, which are sometimes used (e.g., Space Telescope CCDs) to extend the UV response, are inferior to the direct response of the CCD and therefore are not required.

Additionally, a CCD camera has been fabricated and delivered to Dr. Oke, who is actively using it with a spectrograph at the Palomar 5-meter telescope.

Finally, software models have been developed that accurately predict the absorption of ultraviolet energy in thin surface layers of a CCD and the subsequent spreading of photo-generated charge. Specifically, for current depletion depths (~ 10 μm) more than 90% of the charge is confined to a single pixel, but the models indicate that such performance cannot be maintained for the greater depletion depths that may be desired for certain applications.

C. FUTURE OUTLOOK

The task has been very successful in meeting the objectives stated and has demonstrated that the CCD offers tremendous potential as a detector for spectrographic applications. We feel that the technique of backside charging will become an integral part of the future CCD in providing optimum sensitivity and charge collection efficiency. An Announcement of Opportunity has recently been released by NASA for follow-on HST instrumentation. JPL is at present engaged in preparing a proposal, with A. Davidson, B. Oke, and others, to develop a CCD-based FOS.

D. FINANCIAL STATUS

The DDF award for this task was $45,000 in FY83. To date, $36,685 has been expended. The balance is expected to be used within the next several months as publications are completed.

E. PERSONNEL

Overall direction of this effort at JPL is provided by James R. Janesick, technical group leader of the advanced CCD development group, Section 381. Laboratory testing was accomplished through the effort of Thomas Elliott and Harry H. Marsh IV of JPL. Significant modeling software was developed by James McCarthy, a graduate student of Dr. Oke, during Mr. McCarthy's summer employment at JPL. Mr. McCarthy continues to support this program under a JPL-funded graduate research assistantship. Some absolute quantum efficiency measurements were provided by Chet Opal of NRL and Larry Majorana of JPL.

F. PUBLICATIONS

Over 150 internal memos have been distributed that were promoted by this task. The following is a list of recent formal publications related to the task.

1) Janesick, J., T. Elliott, S. Collins, H. Marsh, M. Blouke, and J. Freeman, Proceedings of SPIE, Vol. 501, San Diego, California, August 21, 1984.

2) Janesick, J., T. Elliott, S. Collins, H. Marsh, M. Blouke, and J. McCarthy, 5th Topical Conference on High Temperature Plasma Diagnostics, Lake Tahoe, California, September 16, 1984.

3) Janesick, J., T. Elliott, J. McCarthy, H. Marsh, and S. Collins, IEEE Nuclear Proceedings, October 1984.

4) Janesick, J., K. Klaasen, and T. Elliott, American Astronomical Society Conference, Tucson, Arizona, January 15, 1985.

5) Janesick, J., T. Elliott, Materials Research Society, San Francisco, California, April 1985.

G. CONCLUSIONS

A CCD-based astronomical spectrograph can be developed whose sensitivity, especially throughout the UV, is significantly superior to that of previous spectrographs.

IMPROVED MAPPING OF RADIO SOURCES FROM VLBI DATA BY LEAST-SQUARES FIT

Final Report

JPL 730-00255-0-3310

Eugene R. Rodemich, JPL
Edward C. Posner, JPL and Campus

A. OBJECTIVE

The objective of this task was to develop a method for producing improved mapping of radio sources from VLBI data. The input data are values of the visibility function, which is the Fourier transform of the brightness distribution. The problem of finding the unknown brightness distribution was accordingly expressed as the problem of finding an inverse Fourier transform. The methods previously used, however, depended on approximate inversion methods for a Fourier transform, which is known on an irregularly spaced set of points.

An additional complication was that the signal received at each antenna can have an unknown gain and phase offset, depending on conditions at the antenna as well as on atmospheric conditions. This introduces unknown multiplicative factors into the visibilities, which must be eliminated before inverting the Fourier transform. Iterative methods have been previously developed for this estimation. These methods use an assumed map to recalibrate the data and then get a new map by Fourier inversion. The procedure is then repeated starting from the new map. These iterative methods require considerable user interaction as well as computer time. They are also biased in favor of certain types of brightness distributions in the resulting map. The task then is to overcome these deficiencies.

B. PROGRESS AND RESULTS

The new method is more direct, often more accurate, and runs at least as fast. The visibility data is modeled as a functional of the unknown brightness distribution and the unknown antenna gains and phases. (This modeling is inherent also in the methods referred to above.) What we really did is to choose these unknowns so that the resulting function values are as near as possible to the observed values. Since we use the RMS deviation to measure the closeness of this fit to the observed values, we are led to the problem of minimizing a certain function of all the unknown parameters. This minimization problem cannot be solved directly, but it can be attacked by iterative methods, which converge automatically to the minimum with no user intervention.

The resulting brightness distribution furnishes the best fit to the data among all brightness distributions of given resolution. This was demonstrated with both real and synthetic data. The maps were compared one-on-one with those produced by existing methods, a comparison in resolution, accuracy, and running time. For diffuse sources, clear improvements in accuracy were noted. In any case, no greater complexity, and possibly less, is required. Certainly, the need for human intervention to inspect intermediate products disappears.

We have worked closely with Dr. Timothy I. Pearson of Caltech Astronomy on this. In addition, a seminar on the method was presented to a Campus Astronomy working group attended by both junior and senior investigators. In addition to the method itself generating interest, some of the intermediate techniques for solving large systems of equations were felt to be worth incorporating into even existing mapping techniques.

C. FUTURE OUTLOOK

We are tying off this work with direct funds by transferring a Program Sustaining document and Users Guide to the Campus. We will follow its use to the production of the first scientific paper based on the new mapping technique; we will also remain available to Caltech astronomers as consultants during the process. This technique may, indeed should, also be of use in orbiting VLBI; we have informed that preproject (QUASAT) of this new algorithm. Finally, the VLA will be interested. Contacts with them will be via the JPL TDA/Division 33 interfaces already established for arraying the VLA with the Goldstone local array for enhanced support of Voyager at its Neptune encounter.

D. FINANCIAL STATUS

The DDF award to this task was $40.0K in FY'83. These funds have been exhausted. Tie-off funding is via TDA Direct ("Voyager at Neptune - VLA Array" and "TDA Technologist") and via E. C. Posner's Campus part-time appointment.

E. Personnel

Principal:	Eugene R. Rodemich, JPL
Advisor:	Edward C. Posner, JPL/Campus
Consultant:	Timothy J. Pearson, Campus

Only Dr. Rodemich's time was charged to this task. The Caltech Astronomy department funded the needed computing time on their facility for development of the operational software.

F. PUBLICATIONS

(1) Rodemich, E. R. "Improved Mapping of Radio Sources from VLBI Data by Least-Squares Fit," to be submitted to JPL TDA Progress Report 42-81 (January-March 1985).

(2) Rodemich, E. R., "Computer Programs for Mapping of Radio Sources from

VLBI Data by Least-Squares Fit," Software Sustaining Document and Users Guide, in preparation for sending to Campus Radio Astronomy.

G. CONCLUSIONS

This new technique may well become the basis for a new standard technique in radio astronomy for interferometric mapping of diffuse sources using arrays.

TEST CIRCUITS FOR OBTAINING THE HIGH SPEED PARAMETERS OF LSI/VLSI CIRCUITS

Final Report

JPL 730-00256-0-3600

Stephen I. Long, Jayant Krishna,
University of California Santa Barbara
Brent R. Blaes, Martin G. Buehler, JPL

A. OBJECTIVE

The objective of this task was to design and evaluate a prototype set of high-frequency test structures that could be used for accurate measurement of propagation delay and power consumption. The measurements were to be made possible at wafer level using existing data acquisition systems even though the parameters of interest require high speed circuits. This was to be accomplished through the use of circuits that can interface at reduced test frequencies or the use of on-chip clock generation.

B. PROGRESS AND RESULTS

1. Summary

a. Circuits were designed and layouts generated using 4-micron NMOS (n-channel metal oxide semiconductor) design rules (see Figure 1). These designs were fabricated through the DARPA sponsored NMOS runs. The fabricated parts were then tested with parametric test systems at UCSB and JPL. The measured results from the circuit types tested were found to yield timing data with reasonably good correlation.

b. Circuits were designed and layouts generated using 3-micron CMOS/bulk (complementary metal oxide semiconductor) design rules. These designs were fabricated through the DARPA sponsored CMOS/bulk runs. The fabricated parts were tested and the results analyzed. Final CMOS versions of the synchronous counter will be tested when chips are available.

Figure 1 legend: GND - ground, IN - input, OUT - output, RO - ring oscillator, TS - timing sampler, VDD - circuit power, B0 - bit zero of timing sampler output.

JPL/UCSB TIMING CIRCUITS (4-μm NMOS)

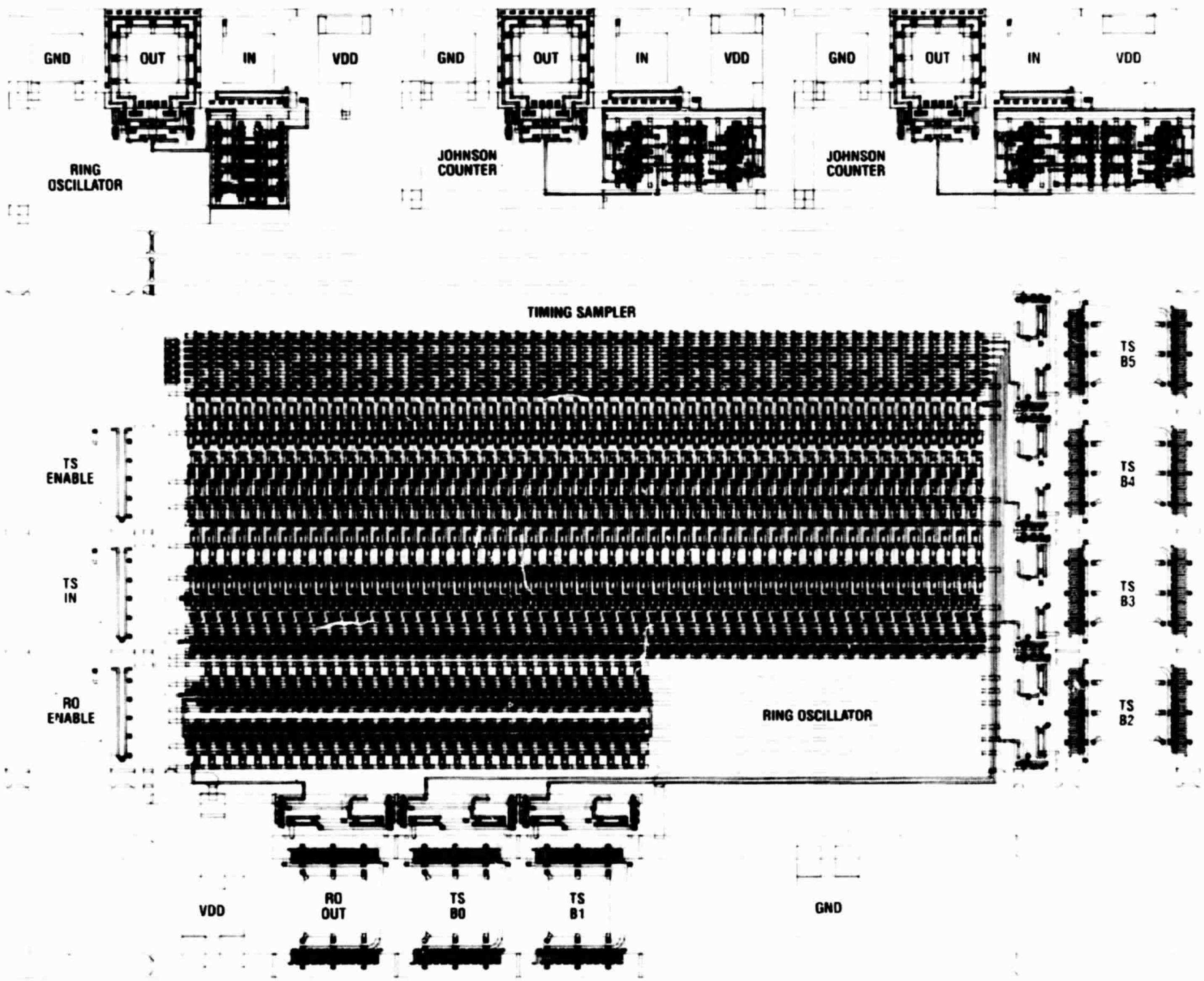


FIGURE 1

2. Synchronous Test Circuits

Several circuit approaches for extracting propagation delay information from high-speed digital integrated circuits (ICs) have been proposed. Ring oscillators (ROs) and ripple frequency dividers have been the most common test circuits. Loaded ROs have been shown to provide more realistic values of propagation delay. The main problem with simple frequency divider circuits is that the relationship between the maximum frequency of operation (for proper division) and the gate delay (Td) is not easily determined. Due to the varying amounts of loading on the different gates in the circuit, the maximum operating frequency corresponds to a non-integral multiple of Td; the exact multiplying factor can only be determined by transient simulation for a particular implementation. In order to measure Td with better accuracy, and for realistic fan-outs, a synchronous test structure is proposed. The proposed circuit obviates the need for careful transient simulation for a particular circuit realization and also permits Td measurements under various fan-outs and loading conditions.

A timing analysis of a synchronous divide-by-2 counter (implemented using cross-coupled NOR# latches) shows that the maximum clocking frequency for proper divider action is given by,

$$fmax = \frac{1}{5Td} \tag{1}$$

where Td is the propagation delay per gate. This analysis assumes identical rise and fall delays for all the gates in the counter. In practice, the gate delay is a function of fanout loading. The rise and fall delays may also be different as in the case of NMOS technology. Hence, fmax can only be expressed as,

$$fmax = \frac{1}{nTd}, \text{ where } n = N \pm 1\ dn \tag{2}$$

N is an integer representing the number of unit gate delays based on a certain fanout assumption, say 2 or 3, and dn is the deviation due to non-uniform loading between the gates. Since dn is usually unknown, and depends on the circuit structure, the value of n is not accurately known. This in turn leads to an inaccurate measurement of Td. The variance of Td due to the random nature of n can be expressed as a function of the variance of n as,

$$\sigma^2_{Td} = \left[\frac{1}{f_n^2}\right]^2 \sigma^2_n \tag{3}$$

#NOR is defined as a function of logical elements that is true if all elements are false.

Since σ_n could be as large as 1, it is desirable to minimize σ_{Td}. A circuit which achieves this is described below. The timing analysis of the synchronous counter also shows that Equation 2 holds only for a specific clock symmetry.

Consider the test circuit shown in Figure 2. It consists of two Johnson counters differing only in the number of delay gates. The reference and delayed counters have 2·m1 and 2·m2 delay gates, respectively, in their frequency is given by the following equations for the two counters:

$$\text{Reference counter:} \qquad Tpd = \frac{1}{n1 \cdot f1}, \text{ where } n1 = dn1 + m1 \tag{4}$$

$$\text{Delayed counter:} \qquad Tpd = \frac{1}{n2 \cdot f2}, \text{ where } n2 = dn2 + m2 \tag{5}$$

n1 and n2 are the total number of pair delays in the reference and delayed counter data paths, respectively, based on a certain fanout (in this case, fanout = 2). The addition of extra delay gates reduces the error indicated in Equation 3. Due to varying fan-outs for the gates within the flip-flops, the intrinsic number of pair delays in the flip-flop, dn1 is not accurately known. Since dn1 and dn2 are the same due to the identical flip-flops, we can solve for dn1 in Equation 4 and substitute the result into Equation 5 to get the following expression for Tpd,

$$Tpd = \frac{1}{m1 - m2} \left[\frac{1}{f1} - \frac{1}{f2} \right] \tag{6}$$

which is only a function of the maximum clocking frequency of each counter at its optimum duty cycle and the difference in the number of delay gates between the two counters. This technique eliminates the dependence of Tpd on n1 and n2. Effectively, this computed value of Tpd corresponds to the loading on the delay gates. By varying the loading on these gates, it is possible to obtain Tpd values for various loading conditions. Tpd is the pair delay, and can be expressed in terms of the fall time tau and the pull-up/pull-down ratio k, as,

$$Tpd = (1 + k)tau \tag{7}$$

The test structures were implemented in 4-micron NMOS technology using the Mead and Conway design rules. A NOR gate is used as the basic building block. It is designed for minimum area and delay and maximum nestability. Cross-coupled NOR gates are interconnected to form the D fli[illegible]-flops for the Johnson counters. The reference counter is designed with [illegible] delay gates in its forward data path, whereas the delayed counter has [illegible] delay gates in its data path. Each delay gate is loaded to simulate a fa[illegible] of 2. A 7-stage ring oscillator has also been implemented using loaded NOR gates identical with those used in the Johnson counters. The test chips were fabricated through USC's Information Sciences Institute multiproject chip

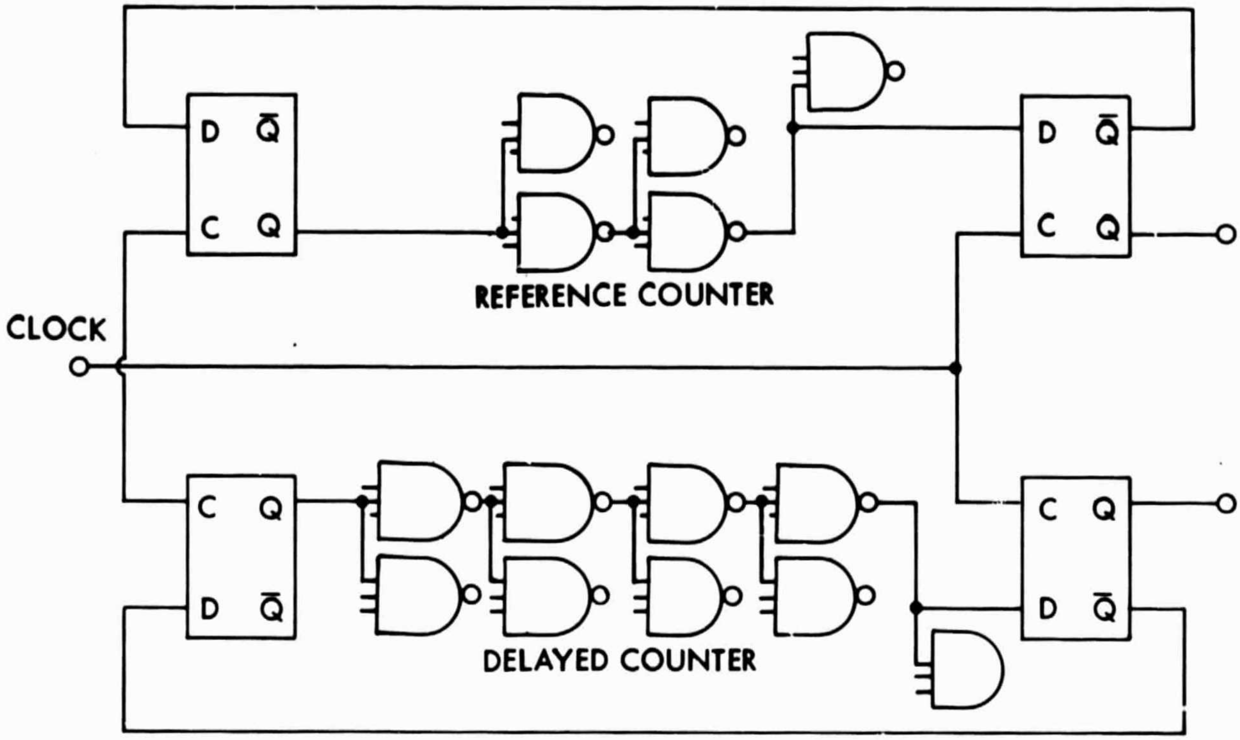


Figure 2

NMOS DELAYED COUNTER DATA

Chip	Delayed Counter				Ring Oscillator		
	frmax (MHz)	fdmax (MHz)	Tpd (nsec)	tau (nsec)	RO freq (MHz)	Tpd (nsec)	tau (nsec)
1	79.0	60.20	3.96	0.79	32.42	4.41	0.89
2	68.53	50.80	5.10	1.02	28.29	5.05	1.01
3	64.55	45.75	6.36	1.27	29.13	4.90	0.98
4	111.40	86.41	2.60	0.52	47.44	3.01	0.60
5	111.90	90.45	2.12	0.42	47.91	2.98	0.60
6	111.20	86.14	2.62	0.52	46.85	3.05	[illegible]

Table 1

foundry interface.

The measurement technique consists of determining the maximum clocking frequencies for the reference and delayed counters at their respective optimum duty cycles. These measured frequencies are then used to calculate Tpd using Equation 6. Data on six chips is shown in Table 1. Chip sets (1, 2, and 3) and (4, 5, and 6) were fabricated by two different foundries. Propagation delays are usually uniform for chips made from the same wafer. Considerable variation in the Tpd values is observed for Chips 1, 2, and 3 (Wafer #1). Measurement of the supply current in these chips showed considerable variation. This implies a lack of uniformity in the saturation drain currents for the transistors in these chips. Such variations in Ids, which are not considered in the theoretical analysis, lead to erroneous values of Tpd. Chips 4, 5, and 6 (Wafer #2) have nearly equal supply currents; the Tpd values for these chips are also fairly constant. Correlation between RO and counter delays is also better on these chips, with the counter extracted delay smaller than the RO delay.

In order to minimize the error due to Ids variations over a single wafer, a single test circuit with a switchable number of delay gates has been designed. This has been implemented in CMOS using CMOS transmission gates as switches. The design uses CMOS NOR gates for the D flip-flops. The reference counter has 8 loaded delay gates in its data path and the delayed counter has 12. The desired delay is switched in using a control line. Increasing the number of delay gates increases the accuracy of the calculated propagation delay but poses the problem of a highly asymmetric clock requirement. Hence, additional delays had to be introduced within the D flip-flops to permit a more symmetric clock to be used. This CMOS version has been laid out and is awaiting fabrication. Use of on-chip clock generation was considered in order to eliminate a high-frequency probe interface, but was found to be impractical because both the clock duty cycle and frequency must be varied to determine delay.

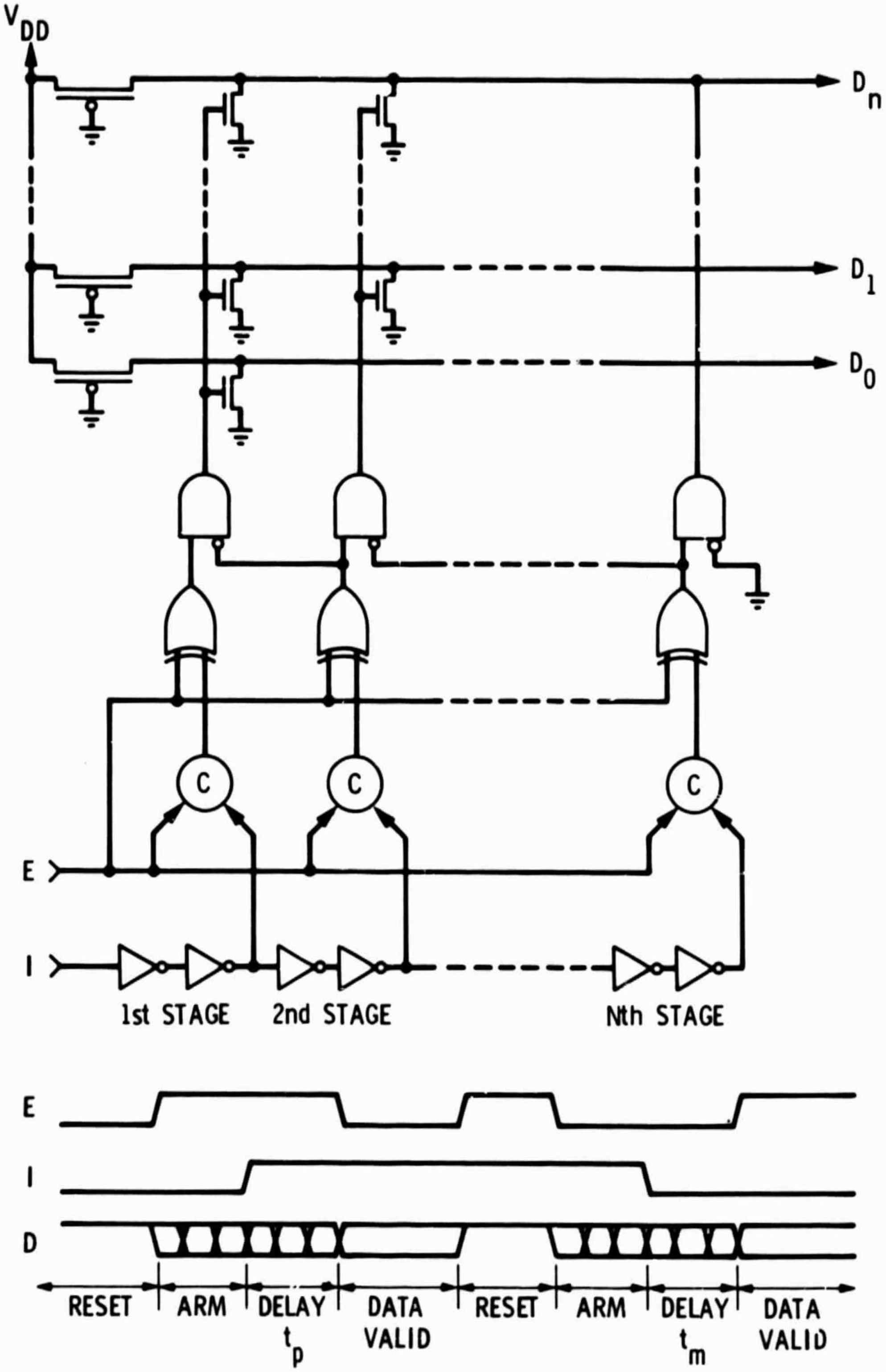
3. Asynchronous Test Circuits

Two types of asynchronous circuits were designed and tested for determining the delays of logic transitions through inverters. These circuits are the ring oscillator and the timing sampler. The ring oscillator is the most commonly used circuit for determining propagation delays of logic gates. The ring oscillator, however, has been shown to sometimes give erroneous results. In particular, there is the possibility of higher harmonic oscillation modes of ring oscillators that, if incorrectly interpreted, can lead to the false calculation of gate delay time [1], [2]. The timing sampler, on the other hand, is free of this problem because delays are directly measured by means of externally generated timing events (transitions) as opposed to internally generated timing events (oscillation) in the ring oscillator. The ring oscillator consists of a ring connection of an odd number of inverters. It has no stable condition and will oscillate with a period that is some odd submultiple of the delay time twice around the ring. The ring oscillator is tested by initializing it into its fundamental mode of oscillation and then, while assuming that it stays in this mode, measuring the frequency with a frequency counter. The timing sampler is tested by applying a start transition input, waiting a known delay, applying a stop transition input, and then sampling a binary output. It provides for a fast, repeatable, and all digital measurement of gate delay. The timing sampler consists of a tapped delay line in which the tapped outputs are sampled, held, and resolved to digital levels (see Figure 3). The circuits that accomplish this at each tap consists of a latch circuit followed by a mutual exclusion circuit(the circle elements labeled with "C" in Figure 3). Each latch has two inputs, one connected to a tap on the delay line and the other to a common enable input. The latches, which are initially reset to the same state, are successively tripped as a signal transition (originating from the start transition) traveling down the delay line reaches each tap. All latches, however, can be disabled from tripping at any time after the start transition by means of a stop transition on the enable input. As a result, the first latch through the Nth latch will be set while the other latches remain reset. The latch outputs are decoded to the binary value N, which is sampled at the circuit probe pads. The delay per stage (Tpd) is then calculated by dividing the total delay (the time elapsed from the start transition to the stop transition) by N. Since some of the tap nodes may be in the process of switching when the latches are disabled, the resulting non-digital voltages being sampled at this time will show up at the latch outputs. One of these latches could possibly be in a metastable state, so that the latch output would remain non-digital forever. To prevent such a non-digital level from getting into the decoder and showing up in the circuit output, the latch outputs go through mutual exclusion circuits. The mutual exclusion circuit output will not begin to change state until the latch is off balanced from its metastable point by at least one transistor threshold (approximately 1 volt). These circuits also sharpen the edges of the latch outputs that are switching, thus reducing the probability of sampling the binary output while a bit is changing. Since the timing sampler is essentially a delay-to-digital converter, there is a possible quantization error in the measured output N. This error is minus one least significant bit and results in a worst case stage delay error of [(N+1)/N-1] x 100 percent.

Inverter-pairs were used as delay elements (stages) in the timing sampler as well as the ring oscillator. This allowed the measured delays obtained from the ring oscillator to be directly compared with those obtained from the timing sampler. The first inverter in the pair drives an identical inverter, and, thus has a fanout of one, whereas the second inverter drives two inverters and has a fanout of two. In addition to the inverter pair delay, an effective transistor circuit tau (transit time) was independently calculated using the ring oscillator data and the timing sampler data. The summarized data obtained from the NMOS designs is shown in Table 2. The taus obtained from these timing samplers are on the average 11% less than the taus obtained from the ring oscillators.

Delays were measured on the CMOS/bulk circuits for both positive and negative transitions. The difference between these delays is a function of the p-channel and n-channel transistor channel mobility difference, the ratio of the p-channel to n-channel width to length ratio (r), and the

TIMING SAMPLER



BTM-16

NMOS TIMING SAMPLER DATA

Chip	Timing Sampler				Ring Oscillator		
	delay (nsec)	N	Tpd (nsec)	tau (nsec)	fosc (MHz)	Tpd (nsec)	tau (nsec)
1	120	42	2.86	0.500	2.70	3.70	0.566
2	150	45	3.33	0.556	2.43	4.12	0.629
3	150	43	3.49	0.581	2.34	4.27	0.653
4	100	48	2.08	0.347	3.94	2.54	0.389
5	100	51	1.96	0.327	4.06	2.46	0.377
6	100	50	2.00	0.333	3.92	2.55	0.390

Table 2

CMOS TIMING SAMPLER DATA

Chip	Lot	Timing Sampler			Ring Oscillator		
		Tpd (nsec)	taun (nsec)	taup (nsec)	Tpd (nsec)	taun (nsec)	taup (nsec)
1	A	2.50	0.313	0.521	2.47	0.307	0.512
2	A	3.14	0.392	0.654	3.07	0.382	0.637
3	A	2.55	0.318	0.530	2.41	0.300	0.500
4	A	2.66	0.332	0.553	3.15	0.393	0.654
5	B	3.40	0.426	0.709	3.35	0.418	0.696
6	B	3.15	0.394	0.656	3.07	0.382	0.637
7	B	3.48	0.435	0.725	3.32	0.414	0.690
8	B	3.54	0.442	0.737	3.27	0.408	0.679
9	B	3.37	0.422	0.703	3.28	0.411	0.685

Table 3

fanout of the inverter pairs (f). These delays turned out to be equal for this CMOS/bulk design (r = 5/3, f = 2). Values for the n-channel transistor tau (taun) and the p-channel transistor tau (taup) were calculated from these delays. The summarized data obtained from the CMOS/bulk design is shown in Table 3. The taus obtained from these timing samplers are on the average 3% larger than the taus obtained from the ring oscillators.

C. FUTURE OUTLOOK

These tasks, supported by the DDF, are being continued by funds provided by other programs. In particular, a version of the timing sampler is being used in the CRRES-MEP (Combined Release and Radiation Effects Satellite - Micro Electronics Package). This is a DARPA/NASA/NSA funded program in which part of its objective is to evaluate the effects of long term total dose ionizing radiation in a low Earth polar elliptical orbit on the performance of VLSI CMOS/bulk circuits. In addition, both the synchronous counters and the timing sampler are being considered for application as high-speed test chips in gallium arsenide ICs being designed at UCSB.

D. FINANCIAL STATUS

The DDF award for this task was $40,000 in FY 83. All funds have been expended.

E. PERSONNEL

The work in the UCSB Electrical and Computer Engineering Department was conducted by graduate student research assistants Gopal Krishna and Jayant Krishna and by Professor Stephen I. Long. Professor Steven E. Butner provided valuable consultations on the use of integrated circuit design software tools and design rules. The work at JPL was conducted by Brent R. Blaes and Dr. Martin G. Buehler.

F. PUBLICATIONS

A paper, entitled "Test Structures for Propagation Delay Measurements on High-Speed Integrated Circuits," by Stephen I. Long, was published in the IEEE (Institute of Electrical and Electronics Engineers) Transactions on Electronic Devices, vol. ED-31, no. 8, pp. 1072-1076, Aug. 1984.

G. CONCLUSIONS

The circuits and test techniques developed in this task hold promise as useful tools for obtaining meaningful timing data for the logic designer. Techniques were identified for design of synchronous test chips that will provide a measurement of delay with minimum error. These test cells will give much better correlation with VLSI circuit delays than will either minimum delay or loaded ring oscillators.

REFERENCES

[1] N. Sasaki, "Higher Harmonic Generation in CMOS/SOS Ring Oscillators," IEEE Trans. Electron Devices, vol. ED-29, pp. 280-283, 1982.

[2] T. W. Houston, "Comments on Higher Harmonic Generation in CMOS/SOS Ring Oscillators," IEEE Trans. Electron Devices, vol. ED-30, pp. 958-959, 1983.

A NEW CONCEPT FOR FAR-INFRARED BROAD-BAND AND HETERODYNE DETECTORS

Final Report

JPL 730-00257-0-3280

Charles Beichman, Victor Hadek, Larry Varnell, JPL
Thomas G. Phillips, Daniel M. Watson, Caltech

A. OBJECTIVE

The objective of this task was to develop infrared detectors for the 50-200 μm spectral region based on a new principle called depleted impurity detection. These detectors can operate in either the broadband or heterodyne mode, in a spectral region where very few detector options are otherwise available.

The new approach offers the advantages of increased quantum efficiency, extended spectral response, faster response and improved radiation tolerance compared to conventional detectors. It also leads in a natural way to the fabrication of monolithic detector arrays for far-infrared imaging applications.

B. PROGRESS AND RESULTS

To verify the basic concepts, a batch of experimental detector structures was fabricated using Ge with p-type (boron) doping (Figure 1). An essential feature of the fabrication of these detectors is the incorporation of modulation-doped epitaxial layers. Several combinations of doping concentrations and layer thicknesses were made to explore their effect on detector characteristics. Technical details of detector design and fabrication are available in the papers listed in Paragraph F of this report.

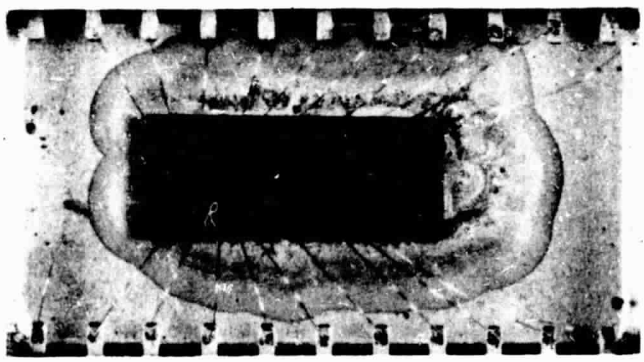


Figure 1. Photograph of an experimental detector structure mounted for electrical and optical evaluation. A number of individual detector elements of different sizes can be seen on the germaniun die.

Measurements of electrical characteristics at temperatures between 1.4 and 4.2K, the operating range for which these detectors were designed, showed the desired high impedance ($\gtrsim 10^{12}$ ohms) and demonstrated the validity of the basic detector principle of modulation-doped layers enabling depletion of impurity carriers to prevent the flow of dark current.

These detectors had a doping concentration of 3×10^{16} cm^{-3} in the photoconductive layer compared to typically $3 \times 10^{15} cm^{-3}$ in a conventional detector. In a detector of conventional design, this increased doping would be accompanied by an unacceptable increase in dark current. This is avoided in the depleted impurity detector by the inclusion of an undoped layer, adjacent to the photoconductive layer, which prevents the flow of dark current while permitting the flow of photogenerated carriers (Figure 2). In the absence of depletion, the impedance would have been orders of magnitude lower.

Unfortunately, these devices exhibited an undesirable avalanche breakdown above ~ 25mV which limited their maximum operating bias.

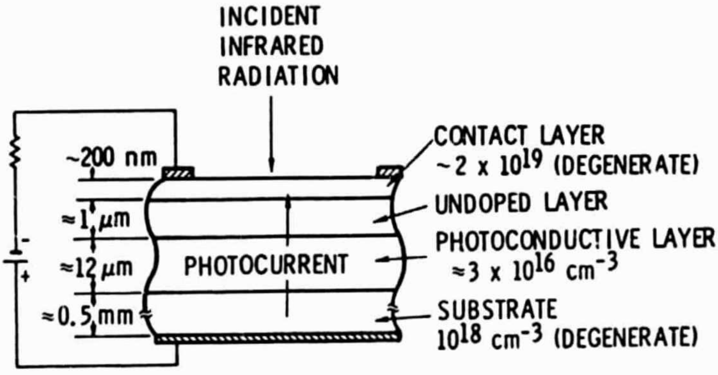


Figure 2. Structure of depleted impurity detector, showing the photoconductive layer, in which the doping can be adjusted for improved detector characteristics, and the undoped layer, which impedes undesirable impurity-related currents.

Based on the results of the electrical evaluation, infrared optical characteristics were measured for selected detectors. Measurements made by several methods confirmed that the detectors exhibited extended spectral response, to 200 μm, as shown in Figure 3.

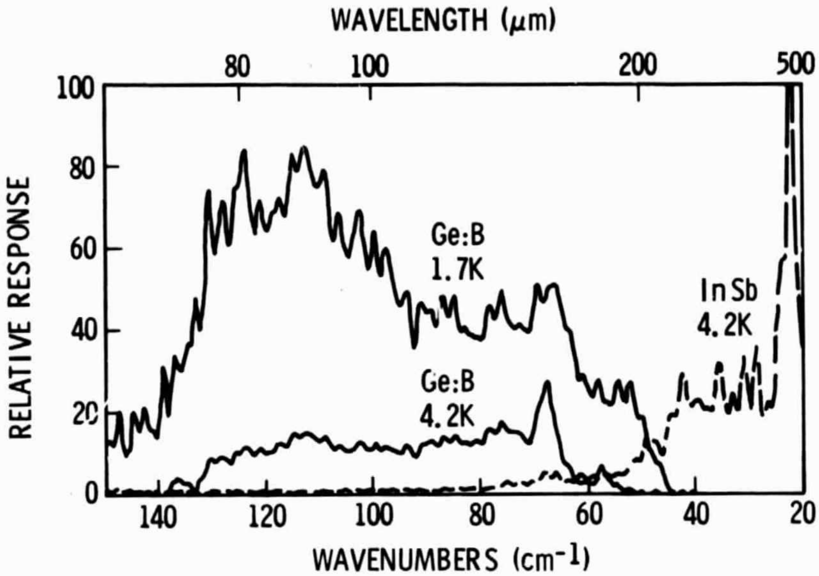


Figure 3. Results of measurements on an experimental detector (solid curves labeled Ge:B), showing that its spectral response can be extended to wavelengths as long as 200 μm. As can be seen, the detector covers the spectral region beyond the short-wavelength limit of InSb, and has comparable sensitivity.

Germanium photo-detectors using existing materials have a long-wavelength cutoff in the infrared of 120 μm. As an example, this detector cutoff imposed the observational limit for the Infrared Astronomy Satellite. Response of conventional materials can be extended only with difficulty beyond 120 μm by applying thousands of kg/cm^2 of stress in the cryogenic electro-optical systems which is very inconvenient for space applications, and also hinders the development of arrays.

Thus, this achievement of extended response could be the basis for a significant advance of astronomical observation in the long-wavelength infrared spectral region.

C. FUTURE OUTLOOK

This task has established the validity of the depleted impurity detector concept and demonstrated extended spectral response. However, this initial batch of experimental detectors made under this task were not configured for astronomical use. The batch also exhibited some undesirable characteristics, namely a low breakdown voltage and a quantum efficiency significantly lower than theoretical.

We believe that these shortcomings could be eliminated by improved materials' and fabrication processes to achieve a lower minority impurity concentration in the photoconductive layer and lower impurity of all types in the undoped layer. Better control of the epitaxial growth of these critical layers and interfaces is needed; we feel that this could be achieved through high-quality chemical vapor deposition (CVD) or preferably by molecular beam epitaxy (MBE).

Successful development and further evaluation along these lines should provide a technical basis for producing detectors for actual ground-based and spacecraft astronomy. It would also enable the fabrication of imaging arrays for these same applications.

Another avenue worth investigating is the possibility of further extending spectral response beyond 200 μm, possibly as far as 1000 μm, through further increases in doping concentration in the photoconductive layer.

NASA OAST has provided support through the Sensor Research and Technology task for further development of these detectors along the above lines.

D. FINANCIAL STATUS

Funding for this task was $44.9K for the first year (FY'83) and $50.7K for the second year (FY'84). All funds have been expended. Follow-on funding is being provided by NASA CAST.

E. PERSONNEL

Fabrication of the experimental detectors was done by Dr. Michael Jack at Hughes Aircraft Company (Carlsbad).

Measurements of the optical characteristics were made by Dr. D. Watson of Caltech and Jam Farhoomand of JPL, section 383.

Electrical measurements and theoretical analysis was performed by Dr. Victor Hadek of JPL, Section 359.

F. PUBLICATIONS

Hadek, V., Watson, D. M., Beichman, C. A., and Jack, M. D., "Far-Infrared Transmittance of Boron-Implanted Germanium at Liquid-Helium Temperatures," Physical Review B., March 15, 1985.

Hadek, V., Farhoomand, J., Watson, D. M., Beichman, C. A., and Jack, M. D., "Extension of Long Wavelength Response by Modulation Doping in Extrinsic Germanium Infrared Detectors," Applied Physics Letters, February 15, 1985.

Hadek, V., "Electric Potentials in a Modulation-Doped Extrinsic Infrared Detector," submitted to Physical Review B.

Hadek, V., "Response Time of a Modulation-Doped Extrinsic Infrared Detector," in preparation.

G. CONCLUSIONS

We have made initial demonstrations of the advantages of a new concept for infrared detectors based on epitaxial layers. This new concept offers advances in the state-of-the-art of far-infrared detectors for both broadband and heterodyne applications, including increased efficiency, sensitivity and radiation tolerance, and extended spectral response. The design of these detectors also leads in a natural way to the fabrication of monolithic arrays for imaging applications. Our most important achievement has been to demonstrate extension of the response of experimental detectors to a wavelength of 200 μm, covering the gap between conventional Ge and InSb detectors.

EVALUATION OF THE ELECTRONIC STEERABILITY OF A LASER DIODE PHASED ARRAY

Final Report

JPL 730-00260-0-3310

Amnon Yariv, Caltech

Joseph Katz, JPL

William K. Marshall, JPL

A. OBJECTIVE

The objective of the task is to investigate the feasibility of integrated electronic beam steering of linear (one dimensional) semiconductor injection laser arrays. The proposed application of these devices is to serve as light emitters in space-to-space optical communications systems. Other possible applications include any systems where optical beams are scanned, e.g., optical printers.

B. PROGRESS AND RESULTS

An electro-optical (E-O) testing station for semiconductor laser and electro-optic modulators has been set up at JPL. The system includes a micropositioned stage for placing the devices on an optical table, infrared and other electronic equipment (i.e., oscilloscope, curve tracer, power supply, pulse generator, etc).

Detailed calculations were performed on the modulaton characteristics of electro-optic modulators fabricated epitaxially on GaAs substrates as compared to bulk modulators. It was found that, in properly optimized modulators, linear modulation characteristics and phase delays of 2 radians can be achieved in 1-mm long single-mode devices [1].

Calculations on the coupling efficiency between semiconductor lasers and electro-optic modulators showed that for the practical device parameters, when taking into account limitations and tolerances of available technology, the amount of light coupled from the laser into the external E-O modulator in monolithic configurations is very small (less than 10%) [2]. The small efficiency thus renders this particular implementation impractical at this stage.

One alternative method that has been tried is based on performing the beam scanning function within the monolithic phase-locked semiconductor laser arrays. Using the recently developed phase-locked semiconductor laser array with separate contacts [3], beam scanning operations can be performed since each laser in the array can be addressed separately. Initial experiments were done where two lasers were operated, and the gain in the region between them was changed. It was found that the lasers can lock with any phase between them, not only 0° or 180° as has been typically assumed [4]. This phase change can correspond to motion of the far-field pattern of the array (i.e., beam scanning) within the far-field pattern established by the individual laser elements. An example of beam steering in arrays with separate contact is shown in Figure 1. The amount of beam steering corresponds to a phase-shift of $\pi/2$ radians.

C. FUTURE OUTLOOK

The problem of implementing electronic beam steering in laser arrays is now being analyzed. Initial results indicate that the amount of beam steering achievable in this method is also quite limited. Therefore, this method may be suitable for fine beam manipulations.

Another method involves nonmonolithic implementations, where the laser source and modulator-array are on separate substrates. In this case the alignment of the two units is more critical. Another possible variation is a coupled-cleaned cavity implementation, which may solve the alignment problem. However, in this method the epitaxial growth and fabrication of the device are more complicated.

D. FINANCIAL STATUS

The FY'83 DDF award for this task was $44,300. A work order for approximately $10,000 (unburdened) was issued to Caltech to support a graduate student. All funds will be exhausted by December, 1984. The DDF program was augmented by an FY'84 OAST work unit. No FY'85 funds are available beyond December, 1984 to continue this work.

E. PERSONNEL

The work at Caltech was conducted, under the direction of Professor Amnon Yariv, by Christopher Lindsey, a graduate student, and by Dr. Eli Kapon, a postdoctoral research fellow. The work at JPL was conducted by Dr. Joseph Katz and by William K. Marshall.

F. PUBLICATIONS

1. Marshall, W. K. and J. Katz, "Waveguide p-i-n Junction Electro-Optic Phase Modulators: Theoretical Analysis and Design Criteria," to be submitted to Applied Optics.

2. Katz, J, J. R. Lesh, W. K. Marshall, and D. L. Robinson, "Electro-Optic Phase Modulator Array: Final Report," (Section 2.5), JPL report D-1885.

3. Katz, J., E. Kapon, C. Lindsey, S. Margalit, U. Shreter, and A. Yariv, "Phase-Locked Semiconductor Laser Array with Separate Contracts," Appl. Phys. Lett. 43, pp. 521-523 (1983).

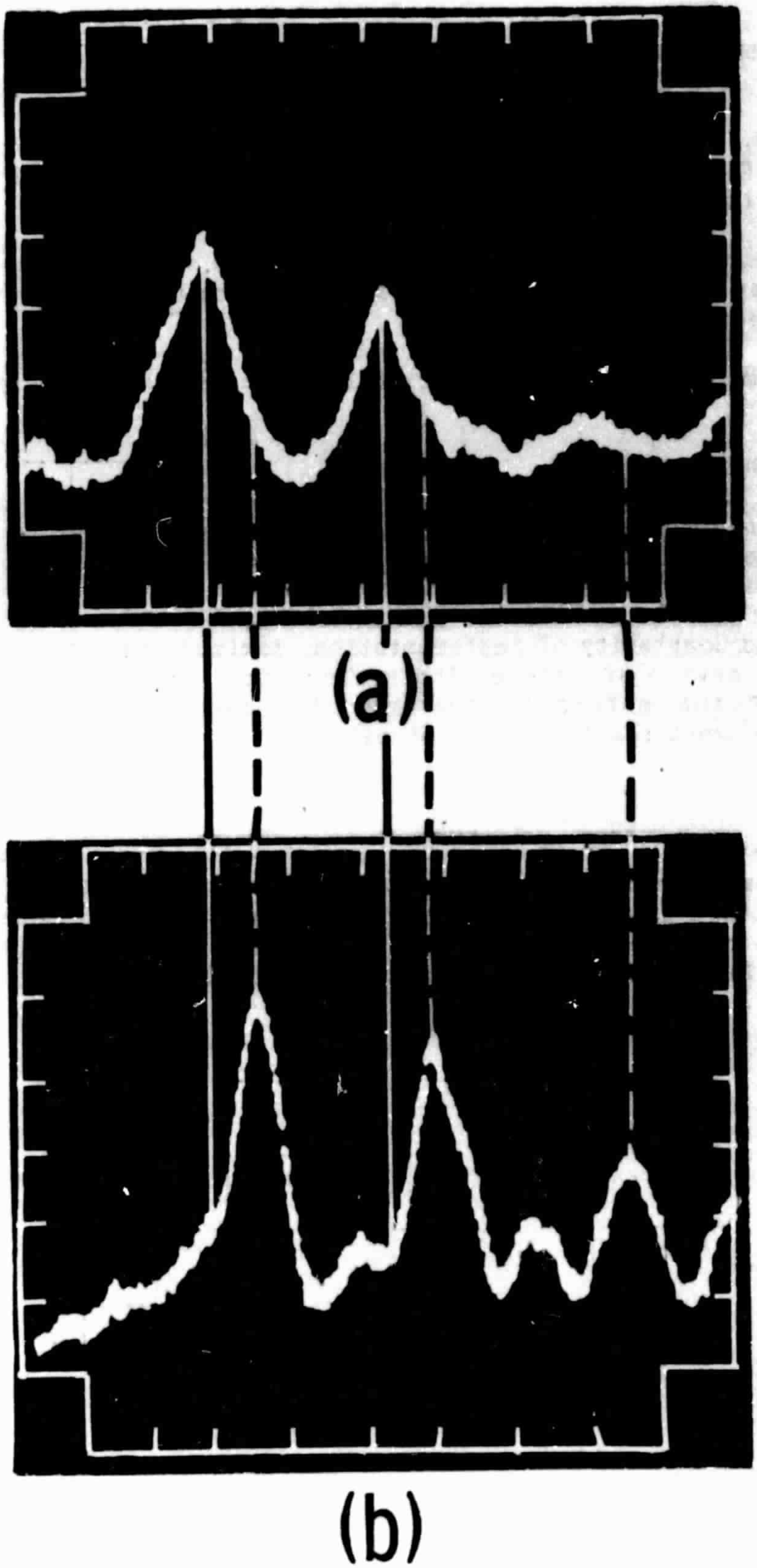
4. Kapon, E. C., Lindsey, J. Katz, S. Margalit, and A. Yariv, "Coupling Mechanism of Gain-Guided Integrated Semiconductor Laser Arrays," Appl. Phys. Lett. 44.

Additional report on beam steering in laser arrays will be prepared.

G. CONCLUSIONS

Electronic beam steering is an attractive alternative to mechanical beam steering. However, due to the difficulties in the various electronic methods known today, a careful trade-off analysis must be performed before a particular method is chosen. Among the trade-off criteria are the difficulty and complexity of implementation, maximum beam steering that can be achieved, device efficiency (both electrical and optical), possible extention of the method to systems with many elements, and other operational characteristics (e.g., stability).

Figure 1. Far field radiation pattern of semiconductor laser array with separate contacts under two different pumping conditions. The pattern in (b) represents a $\pi/2$ radians phase shifted version of the pattern in (a) (angular shift is 1.4 degrees). (Horizontal scale: approximately 2.2 degree/division)



BIOMOLECULAR DEVICES BASED ON GENETIC TECHNOLOGY

Final Report

JPL 730-00264-0-3460

Giuseppe Bertani, JPL

A. OBJECTIVE

The objective of this task was to initiate experimental work with the aim of eventually producing a class of chimeric proteins of the enzyme/metalloprotein type. A necessary first step towards this aim was the construction of plasmids carrying the genes for the proteins to be fused. It is to this purpose that the efforts under this task were addressed.

B. PROGRESS AND RESULTS

The work to-date has consisted of preparations for the cloning of azurine, a small blue-copper protein present in bacteria of the genus Pseudomonas, into a plasmid of the standard laboratory bacteria Escherichia coli. The material (bacterial strains and bacteriophages) necessary for this work were obtained. Preparations of Pseudomonas DNA [deoxyribonucleic acid] were made and characterized. They were partially digested with the restriction endonuclease PstI, and a fraction containing DNA fragments of size 10 to 20 kilobases was isolated. DNA of the E. coli plasmid pBR322 was cut with the same enzyme and treated with alkaline phosphatase. The next step (now in progress) will be ligation of the two DNA preparations and selection of cloned fragments.

Preparations of pure azurine were made. This followed a previously described procedure (Toscano, 1978), except that by using an extra-long column, it was possible to reduce the chromatographic steps from three to two, without sacrificing too much of the purity of the final product.

A rabbit antiserum against azurine was obtained and was tested for activity against the protein. It was determined that a microliter of antiserum could precipitate 0.5 micrograms of azurine. This ought to be a satisfactory level of activity for the purpose of using the antiserum to detect azurine in transformed E. coli clones.

C. FUTURE OUTLOOK

Work along the lines first proposed for this task is continuing with support from outside sources. A proposal submitted to the Army Research Office earlier this year was approved and funded. It will cover work on cloning and gene fusion for the metalloprotein azurine over a period of three years, beginning with fiscal year 1985.

D. FINANCIAL STATUS

The total DDF award for this task in FY'83 was $50,000. The funds are now exhausted.

E. PERSONNEL

Antiserum was obtained, thanks to the facilities at Caltech's Braun Laboratories of Cell Biology and Chemistry, under the supervision of Prof. J. Richards and Dr. J. Tomich. Dr. G. Smith (Fred Hutchinson Cancer Research Center, Seattle, WA) kindly supplied a bacteriophage strain. Drs. S. Sligar (Department of Biochemistry, University of Illinois, Urbana, IL) and W. A. Toscano (Department of Pharmacology, Harvard Medical School, Cambridge, MA) kindly supplied a reference sample of pure azurine.

F. PUBLICATIONS

None.

G. CONCLUSIONS

Since the original proposal was written, the interest for the possibility of applications of molecular biology to the development of new types of sensors or other macromolecular devices has continuously increased world-wide. A vast amount of research remains to be done, however, before such aplications can be realized. Our original proposal concerned, in particular, the possibility of demonstrating an allosteric effect in artifically constructed proteins. It now seems that given the preparatory work done under this task, the forthcoming support from the Army Research Office, and the collaboration of Prof. Richard's group at Caltech - our project has a very good chance of being brought to a conclusion.

DEVELOPMENT OF AN AUTOMATED DIGITAL PROCESSING SYSTEM FOR PHOTOGRAPHIC ASTEROID SURVEY PLATES

Final Report

JPL 730-00265-0-3260

Eleanor F. Helin and R. Scott Dunbar, JPL

A. OBJECTIVE

The objective of this task is to develop an automated data processing system for the scanning, measurement, and reduction of photographic plates and films obtained in our ongoing asteroid survey program. This system is based on a PDS microdensitometer and PDP-11/34 computer system as the major hardware components. Adaptation of this system to our research will proceed in a progression of tasks, leading ultimately to automation of nearly all aspects of our post-observing data gathering and reduction. This will result in a sigificant increase in scientific productivity while decreasing the amount of tedious human labor presently involved in these tasks.

B. PROGRESS AND RESULTS

All preliminary facilities-related tasks, including installation of the necessary electrical power outlets, a curtain enclosure for the microdensitometer, and a new corridor door for the laboratory room, were finally completed in March 1984. Verification of the computer system's operational status began in June 1984 and is still proceeding. The first major difficulty with the system was that the computer would not communicate with its peripheral devices, in particular the 200-megbyte disk drives, the magnetic tape drive, the line printer, and the microdensitometer. Several defective hardware components were isolated, requiring repair and/or replacement of the components. These problems are not unexpected, considering that the system has been idle since 1981. At present, the tape drive and the disk drives are working satisfactorily, and it is felt that the line printer and microdensitometer will present no major problems.

As planned, the microdensitometer and its precise X-Y readout system have been operated independently from the computer as a manual measuring machine, enabling us to obtain our astrometric data without the necessity of using off-lab facilities. The stage of the microdensitometer can be set to any position within 1 micron (0.001 millimeter), with manual repeatability of measurements to less than 10 microns. At the scale of the Schmidt plates and films which are used in our asteroid research, this linear precision corresponds to an angular precision on the sky of less than 1 arc second. Such precision is required for the determination of the asteroids' orbits.

C. FUTURE OUTLOOK

Current work to make the computer system fully operational is expected to be completed within the next two to three months, at which time we will integrate the microdensitometer with it and begin to write new software and/or adapt existing programs for our asteroid astrometry applications. An on-line data reduction system will be the first task, whereby the X-Y encoder registers of the PDS will be read directly into a measurement-reduction program in real time. This will enhance the current manual measurement capability. Experience gained in this task will lead naturally to automated scanning and measurement of a pre-determined set of asteroid images, using image processing techniques to reduce the data. Photographic density data obtained simultaneously with the X-Y positional information can also be used to make precise estimates of the asteroids' brightnesses.

The computer system itself will be used to perform certain demanding computational tasks such as orbit determination and correction, ephemeris computation, and asteroid dynamical and population studies. In addition, the large amount of mass storage afforded by the system will allow for the con-struction and maintenance of large data bases such as reference star catalogs, plate and film data archives, and asteroid position and orbits.

In addition to these practical applications of this system, there are two major studies which are of interest. The first study is to determine the proper method of calibration required for the precise photometry of tailed asteroid images from photograhic plates. We envision an "ideal" system in which the entire plate is digitized and a catalog of all asteroids found on the plate is produced containing measured positions and brightnesses, with little or no human intervention. Such a capability would speed up the post-observing plate reduction process by an order of magnitude. Using the present system, we hope to develop techniques which will help to define the characteristics and names of implementing such an ideal system.

D. FINANCIAL STATUS

The total DDF funding awarded for this task (FY83) was $26,500, primarily for the acquisition of the computer and microdensitometer system from the Radar Science and Engineering Section. A part of these funds was intended to cover the process of verifying that the system could be made operational. As of the end of 1984 fiscal year (September 1984), the funds were exhausted. Further work on this system will continue under current and anticipated NASA funding.

E. PERSONNEL

This work is being performed under the overall direction of Eleanor F. Helin. R. Scott Dunbar is conducting the technical planning and implementation of the project, with assistance from Steven Swanson, a Caltech under-graduate working part-time for the Asteroid Search Program.

One of the original investigators, Schelte J. Bus, has left JPL and is no longer ssociated with this project.

F. PUBLICATIONS

None.

G. CONCLUSIONS

None.

A TRHEE-DIMENSIONAL DYNAMIC AND LIBRATION ANALYSIS OF A TETHERED SATELLITES SYSTEM

Final Report

JPL 730-00266-0-3120

Charles C. H. Tang, JPL
Barry C. Barish, Caltech

A. OBJECTIVE

The objective of this task is to perform a comprehensive three-dimensional dynamic and librational analysis of a tethered satellites system (composed of two instruments, platforms, or stations attached together by an extensible tether of a length of a few kilometers) under the dominant influence of the gravity-gradient effect of a central body as well as other perturbing influences of the tether mass, small orbital eccentricity, central-body oblateness, aerodynamic drag force, and solar radiation pressure. Because of the virtually insurmountable complexity in deriving the exact set of ten coupled nonlinear second-order differential equations and the associated linearized equations, the characteristic equation and the associated librational stability criteria, it is necessary to use the recently (1982) implemented (but not certified) Symbolic Manipulation Program (SMP) from High Energy Physics Department of California Institute of Technology to obtain the differential equations, linearization, characteristic polynomial, and stability criteria.

B. PROGRESS AND RESULTS

The Lagrangian formulation with ten generalized coordinates is used in the dynamic analysis and the system potential energy is expressed in terms of distributed masses of the tethered end-bodies in motion in three dimensions. Other authors have performed similar studies in two dimensions only. By linearizing the exact set of ten coupled nonlinear second-order homogeneous differential equations derived from the Lagrangian formulation by SMP, it is shown that the in-plane (orbital plane) differential equations are decoupled from the out-of-plane differential equations. With the aid of SMP again, an eighth degree characteristic equation for the in-plane differential equations is obtained, and the stability constraints are established by using the Routh-Hurwitz necessary and sufficient criteria. It is shown conclusively that the coefficients of the characteristic polynomial will be positive non-zero if the following constraints are satisfied:

(A) $k_\ell \geqslant 3w^2 m_r$

(B) $I_{A1} \geqslant I_{A3}$

(C) $I_{B1} \geqslant I_{B3}$

$$(D)\quad h_\ell > 0 \ \text{or} \ h_{A1} + h_{B1} + h_{C1} > 0$$

The restoring "spring constant" k_ℓ representing the force per unit tether length must be larger than or equal to the tension ($3w^2m_r$) generated in the tether by the orbital motion. The moment of inertia of each end body about the principal axis normal to the tether must be larger than or equal to that about the principal axis along the tether. At least one of the damping constants (h_ℓ for along the tether, h_{A1}, h_{B1}, and h_{C1} for in-plane rotations of bodies A, B, and tether, respectively) must be present and positive. The necessary and sufficient conditions for the complex roots of the characteristic polynomial to have real negative parts turn out to be the criteria (A), (B), (C) above and $h_\ell > 0$ and $h_{A1} = h_{B1} = h_{C1} = 0$, instead of the constraint (D) above. In other words, the tether damping must be present (and the in-plane rotational dampings absent) in order to insure stability for the in-plane motion. It is important to bear in mind that in some cases the presence of h_{A1} and/or h_{B1} and/or h_{C1} might not destroy stability, but, instead, might reduce the amplitude of stable libration. The validity of the above statement can only be tested by future parametric studies of both the characteristic equation and the numerical integration of the linearized differential equations with perturbing forcing functions. Additional constraints might be placed on the rotational damping and/or restoring constants when the last two determinants (5 x 5 and 7 x 7) in the Routh-Hurwitz criteria are to be evaluated.

Results similar to those mentioned in the preceding paragraph for the in-plane motion can be obtained for the out-of-plane motion when the coefficients of the out-of-plane characteristic equation are to be analyzed by the Routh-Hurwitz criteria. The evaluation of the out-of-plane stability constraints, together with the evaluation of the two determinants mentioned in the last paragraph, probably will require an additional time period of at least one personnel-month, and will not be completed in this task due to lack of time.

C. FUTURE OUTLOOK

The comprehensive results of this task study on the three-dimensional dynamic and librational analysis of a tethered satellites system do not appear to be available in the current literatures. These comprehensive analytic results will put JPL into a significant lead position for any future project proposals on tethered satellites systems such as:

(1) Tethered long-base antennas as an interferometer for passive radio astronomy.

(2) Tethered Earth contour mapper or stereo SAR mapper.

(3) Tethered space platforms or space stations.

The constraints of the librational stability of the out-of-plane differential equations, however, have not been evaluated yet due to lack of time and funding. In order to acquire a broader understanding of the librational properties of the system, both a parametric study of stability constraints from the characteristic equations and a parametric study by numerical integration of the ten linearized differential equations with all real-world perturbing forcing functions will be absolutely necessary. A future DDF funding to complete the to-be-done items described in this paragraph will not only enhance our understanding of the problem but also make any future tethered system proposal "impressive."

D. FINANCIAL STATUS

The FY'83 DDF award to this task was $40,000 of which 95% has been spent. A temporary partial support at 0.2 workforce level was obtained through an RTOP (Research and Technology Objectives and Plans) on tether applications for the period from July through September 1983.

E. PERSONNEL

At JPL, the study was conducted by Charles C. H. Tang. A consultant and a student at Caltech used the SMP under the direction of Professor Barry C. Barish of High Energy Physics Department of Caltech.

F. PUBLICATION

The result of the task study will be submitted to a conference for oral presentation and then to a journal for publication.

G. CONCLUSIONS

The comprehensive three-dimensional dynamic and librational analysis of a tethered satellites system has been carried out in the Lagrangian formulation and an exact set of ten coupled nonlinear second-order differential equations has been derived by using SMP with considerations on perturbing effects of the tether mass, central-body oblateness, small orbital eccentricity, aerodynamic drag force, and solar radiation pressure. It is shown that the effects of central-body oblateness, small orbital eccentricity, and tether mass contribute not only to the forcing function part (i.e., inhomogeneous part) of the differential equations but also to the "natural frequency" or "normal mode" part (i.e., homogeneous part) of the differential equations, whereas the aerodynamic drag force and the solar radiation pressure contribute to the forcing function only.

By linearizing the ten homogeneous differential equations, the in-plane (orbital plane) set of differential equations becomes decoupled from the out-of-plane set of differential equations and the two sets, therefore, can be analyzed independently of each other. The coefficients of the eighth degree characteristic polynomial obtained from the in-plane set of differential equations prescribe the stability constraints according to the Routh-Hurwitz necessary and sufficient conditions as follows:

(A) The restoring "spring constant" of the tether must be larger or equal to the tension generated in the tether by the orbital motion.

(B) The moment of inertia of each end body about the in-plane principal axis normal to the tether must be larger than or equal to that about the principal axis along the tether.

(C) The positive damping constant along the tether must be present and the in-plane rotational damping for the tether and the end bodies absent.

(D) Additional constraints might be placed on the rotational damping and/or restoring constants when the last two determinants in the Routh-Hurwitz criteria are to be evaluated.

Similar out-of-plane stability constraints can be obtained when the corresponding characteristic equation and its associated determinants are evaluated from the out-of-plane differential equations.

The comprehensive results of this task study do not appear to be available in the current literatures and will put JPL into a significant lead position for any future project proposals on tethered satellites systems. A final documentation of the results of the task study has been issued as JPL D-1868 (September 1984).

VLSI IMPLEMENTATION OF A COUNTING DIGITAL FILTER (PHASE I)

Final Report

JPL 730-00267-0-3310

Shalhav Zohar, JPL

A. OBJECTIVE

The basic idea of a Counting Digital Filter was conceived by Zohar in 1968, published internally (JPL) in 1972 [1], and published in the open literature [2] as well as patented [3] in 1973. Though this idea was developed, at the time, without any particular regard to VLSI implementation, as the revolutionary developments in VLSI technology were unfolding, it became clear that the structure of a counting digital filter is eminently suitable for VLSI implementation.

The goal of the present task was to fabricate in NMOS the basic building block of such a fiter. While this is a necessary first step in the fabrication of the filter itself, the importance of this limited task is that it establishes quite clearly the capabilities of a counting digital filter that can be realized with current NMOS technology.

B. PROGRESS AND RESULTS

1. The FIR Counting Digital Filter

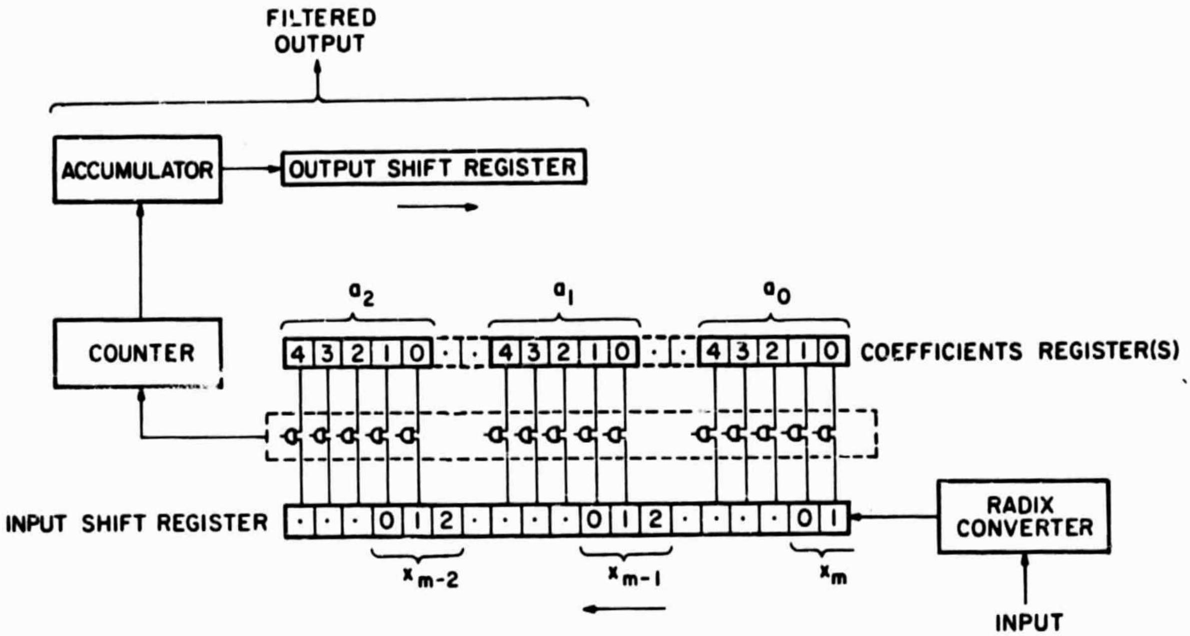
We are concerned here with a digital filter of the Finite-Impulse-Response (FIR) nonrecursive type, which is realized using the algorithm of the counting digital filter [2]. In an FIR filter, the output sample y_m is related to the x_i input samples by:

$$y_m = \sum_{k=0}^{K-1} a_k \, x_{m-k} \tag{1}$$

where the a_k coefficients determine the transfer function being realized.

The basic idea underlying the counting digital filter is the concept which, later on, came to be known as "distributed arithmetic" [4]. Loosely stated, it means that in expressions involving sums of products such as Equation (1), we evaluate the sum directly without ever evaluating any of the products comprising it. In the specific case of Equation (1), this is achieved by replacing a_k, x_{m-k} by their binary representation sums and then changing the order of summations (see [2] for details).

The resulting digital filter structure is shown in Figure 1. To simplify its description, let us assume initially that a_i, x_j are non-negative integers. In this case, the input radix converter of Figure 1 may be skipped,



$$y_m = \sum_{k=0}^{K-1} a_k x_{m-k}$$

COUNTING FIR DIGITAL FILTER

Fig. 1

and we see that the input signal samples are fed serially into a shift-register, which is cross-linked by AND gates to registers holding the filter coefficients. The conventions of Figure 1 are as follows: A dotted register cell represents an "empty" cell (zero). A number in a cell represents the cell's weight, that is, the radix power that multiplies its bit value. Thus, if a cell shows the number 3, it represents the number 2^3 when it holds the logic value 1.

As each new bit is fed in, the outputs of the AND gates change and the counter simply counts how many of them hold the logic value 1. This count is added to the accumulator, its content is shifted right one bit, and the system is now ready for the next bit-cycle. In the example illustrated in Figure 1, every 7 bit-cycles, the assembly of a new output sample y_m is completed in the output register (consisting of the accumulator and its appended output shift-register). We dump this binary number (in parallel), zero the output register, and are now ready for the next 7 bit-cycles which will construct the next output sample and so on.

Note that with a sufficiently long output shift-register, the whole process is totally error-free (no round-off errors). The only errors afflicting this system are those incurred in the quantization of the input data and coefficients.

When we allow a_i, x_j to be negative, this basic scheme is modified as follows:

(a) We apply the input samples to the radix converter which converts them from the standard binary representation (radix 2) to a negative binary representation (radix (-2)).

(b) The coefficients registers are loaded with the negative-binary (radix (-2)) representation of the coefficients.

(c) Every right shift in the output register is accompanied by a sign-flipping.

In spite of the negative-radix input, the output samples are assembled in the output register in standard binary so that the unusual negative-radix representation is essentially transparent to the user. The conversion of the filter coefficients could be part of the computer program generating them. Alternatively, we could switch the radix converter to the coefficients register while loading the coefficients in the initialization stage. In any case, the radix converter itself is a relatively simple circuit [5] and the area occupied by it on the chip is insignificant.

Removal of the integer constraint on a_i, x_j is trivial and will not be discussed here.

2. VLSI Implementation of the Counting Digital Filter

A study of the counting digital filter from the perspective of VLSI implementation under the constraint of very limited funding has yielded the following implementation guidelines:

(a) The hardware appearing in Figure 1, excluding the accumulator, should be implemented as a single NMOS chip.

(b) The accumulator, which has to add a full word during the time allotted to a 1-bit shift in the rest of the circuit, should be implemented in bipolar technology on a separate chip. Eventually, the two dies could be housed in a common package to yield a single-package filter.

(c) The coefficients registers should be combined into a single shift-register with appropriate switching to allow serial loading of the coefficients when the filter is initialized.

(d) The counter should be implemented as a pipelined interconnection of full-adders. (Note that a full-adder is essentially a 3-input counter.)

(e) The length of the linked shift-registers should be constrained to a power of 3 (to optimize utilization of the 3-input full-adders).

(f) The system, consisting of the counter and linked shift-registers (which occupies most of the area of the NMOS chip), should be partitioned into a number of identical parts (building blocks) with relatively simple interconnections.

(g) The basic building block should be 81-bit long.

Fabrication of the building block mentioned in (g) was the objective of the present tasks. While this is a first step in building the overall filter, its main importance lies in the fact that it provides, for the first time, concrete information regarding the complexity and speed of a counting digital filter that could be realized with current technology.

3. Fabricated Chips

A lot of effort was devoted to reducing the area of the 81-bit building block, since we knew that smaller size would increase both the speed and the processing power of the final chip. This paid off handsomely; we now have a functional chip produced in 4-micron technology (lambda = 2 micron) which operates satisfactorily up to a rate of 8 Mbits/sec. We also have indications that a slightly improved version of this chip will operate up to 9 Mbits/sec. The fact that the size of these chips turned out to be smaller than anticipated encouraged us to check the feasibility of cramming 9 of these building blocks and their interconnections on a single chip. Study and analysis of various candidate architectures has yielded a design which, using the largest die currently allowed by the MOSIS fabrication service (0.311 x 0.362 in.), will accomplish that.

In addition to the above chips, we have also fabricated the 81-bit building block in 3-micron technology (lambda = 1.5 micron). This smaller chip yields satisfactory performance up to 14 Mbits/sec.

C. FUTURE OUTLOOK

As we have just indicated, our results mean that a counting digital filter with shift-register length of 729 (= 9 * 81) can be realized in a large NMOS chip plus a small bipolar chip housing an 11-bit accumulator. This will be a very powerful and flexible signal-procesing device. Let us consider its capabilities. If we denote by C, D the number of (standard binary) bits per coefficient and datum, respectively, then this filter will accommodate any parameters combination constrained by:

$$K(C + D + 1) - D \leq 729 \qquad (2)$$

(See Equation (1) for the meaning of K.) For example, using 8-bit data words and 16-bit coefficients, this device could implement an FIR digital filter of order 29.

We have already pointed out that there are no round-off errors in this device, so that the number of bits available for an output word (P) is given by:

$$P = C + D + 11 \qquad (3)$$

The only limitation here is the number of pins provided by the adopted package. In the example cited above, the output could consist of 35-bit words.

As is hinted in Figure 1, this filter requires that each D-bit long input data word be augmented by (C + 1) zeros and the combination fed serially. This means that if the bit rate is f_{CLK}, then the word rate f, that is, the rate at which input samples can be fed to the filter, is given by

$$f = f_{CLK}/(C + D + 1) \qquad (4)$$

We have seen that f_{CLK} can be as high as 14 MHz in 3-micron technology (9 MHz in 4-micron technology). Whether these values can be maintained with reasonable yields over a reasonable temperature range remains to be seen. However, even if we have to back off somewhat from these values, the resulting device is still quite impressive in its capabilities.

Note that a trivial index change in Equation (1) modifies it from the equation of an FIR digital filter to that of a cross-correlator. This means that our digital filter chip is also a correlator (the index change only affects the way we load the reference function in the correlator initialization). A particularly useful application of our chip as a correlator would be in the real-time quick-look processing of SAR images. It turns out that 3-bit data and 2-bit reference-function coefficients are sufficient for this task [6]. Since this specific application involves complex data and coefficients, we would have to use four correlator chips and six (short) accumulators. This combination would provide SAR processing utilizing a reference function consisting of 122 (complex) coefficients and accepting (complex) input data at the word rate of 2.3 MHz.

D. FINANCIAL STATUS

The FY'83 DDF award for this task was $45,000. This sum is nearly exhausted.

E. PERSONNEL

Al phases of this work were carried out by Shalhav Zohar of JPL.

F. PUBLICATIONS

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[2] S. Zohar, "New Hardware Realizations of Nonrecursive digital Filers," IEEE Trans. Comput., Vol. C-22, April 1973, pp. 328-338.

[3] "Counting Digital Filters," U.S. Patent No. 3732409, issued May 8, 1973.

[4] C. S. Burrus, "Digital Filter Structures Described by Distributed Arithmetic," IEEE Trans. Circuits and Systems, Vol. CAS-24, December 1977, pp. 674-680.

[5] S. Zohar, "Negative Radix Conversion," IEEE Trans Comput., Vol. C-19, No. 3, 1970, pp. 222-226.

[6] Chialin Wu (of JPL), private communication.

G. CONCLUSIONS

The fabricated chips prove that the counting digital filter is a highly promising approach to the goal of a very powerful, very flexible, "filter on a chip." Every effort should be made to continue this endeavor.

TECHNOLOGY DEVELOPMENT FOR A HIGH-RESOLUTION REAL-APERTURE SCANNING RADAR ALTIMETER/IMAGER

Final Report

JPL 730-0269-0-3260

Charles Elachi, JPL
Michael Kobrick, JPL
Kenneth J. Russell, JPL

A. OBJECTIVES

The objective of this task was to investigate the performance characteristics of various state-of-the-art IMPATT diode millimeter wave sources and to assess their suitability to function in the transmitter of a 37-GHz, high-resolution, real-aperture, scanning radar altimeter/imager. This work involved procuring several silicon (Si) and gallium arsenide (GaAs) IMPATT diodes and testing them in various operational modes. It also involved the design and development of test circuits, electronics and hardware necessary for evaluation of the IMPATTs.

B. PROGRESS AND RESULTS

IMPATTs for evaluation were obtained from Hughes, Nippon Electric Co. (NEC), and Raytheon. The Hughes IMPATTs comprised 0.25-W, 0.5-W and 1-W diodes. The Hughes IMPATTs were made of Si and designed for CW operation, but, as mentioned later, also to function in pulsed operation. THE NEC IMPATTs are also made of Si for CW or pulsed operations at 0.4 W. The Raytheon IMPATTs are made of GaAs and designed for pulsed operation at 5-W peak power with 290 nsec pulses at ~30% duty cycle. To test these IMPATTs, K_a-band millimeter wave test equipment was obtained and test circuits were developed. A reduced-height waveguide/coaxial K_a-band test circuit (mount) was obtained to test the Hughes diodes. A Kurokawa style waveguide cavity test mount was obtained for the Raytheon IMPATTs. The different manufacturers' diodes have different package designs, which complicates testing in a given mount. Modulators to provide pulsed bias to both the Si CW and GaAs pulsed IMPATTs were developed.

The tests performed with the IMPATT diodes and test mounts included operation in pulsed and CW operational modes both as free-running and injection-locked oscillators. In the pulsed mode of operation, pulse widths from 1 to 30 μsec and duty cycles from 0.6 to 25% were measured with the Hughes Si IMPATTs. Reduced power operation was also investigated. The Hughes IMPATTs performed well in pulsed operation even though they were designed for CW. One reason is that the IMPATT thermal time constant is short enough so that the IMPATT is operating in near CW conditions for most of the pulse. Low duty cycle operation coupled with short duty cycles (which produces low average temperatures) gave the poorest performance. For these tsets, the IMPATT bias current was fixed. If the current is allowed to rise, this power loss can be regained and even more power can be obtained than in CW conditions. However, in this operating regime the pulse width must be kept small enough that the design junction temperature is not exceeded. For fixed IMPATT bias currents (370 mA), a 1-W Hughes IMPATT produced output ranging from 1.05 W for a 30- μsec pulse width and 25% duty cycle to 0.59 W for a 1- μsec pulse width and 0.6% duty cycle and 0.98 W for a 1 μsec pulse width and 25% duty cycle. The output power can be reduced by at least a factor of 5, without increasing the spurious output levels, by reducing the bias current level. Tuning of the test mount has a marked impact on spurious output from the IMPATT source. When properly tuned, the IMPATT demonstrated noise performance superior to a backward-wave oscillator (BWO) used in injection-locking experiments. The noise performance of the IMPATT was improved by operating at less than maximum power. Because of the poor noise quality of the BWO locking source and its low output power, experiments with injection locking the IMPATTs were limited to demonstrating that locking was possible. The delivery of a better source (a YIG-tuned FET oscillator) and repair of a failed TWTA did not occur in time to be used in these injection-locking experiments (but will be used in later locking experiments under a companion program).

The Raytheon IMPATTs were tested as oscillators, and gave performance near that indicated by the manufacturer though different tuning was required than Raytheon used because the mount is made in WR-22 waveguide while JPL's test circuitry is in WR-28 waveguide (a transition between waveguides is on order). These IMPATTs are designed for pulse applications where the pulse width is short ($\leq$ 300 nanoseconds) compared with the thermal time constant and the duty cycle is high (20% to 30%). The manufacturer does not recommend them for long pulse or CW applications. Their use at low duty cycles may require preheat to get the temperature up before RF turn-on. These diodes produced output in the 4.0- to 4.5-W peak output power range during JPL tests with 290 nanosecond, 20% duty cycle pulses.

This effort's results indicate that a multistage, IMPATT, injection-locked oscillator is feasible for the transmitter portion of the scanning radar altimeter, from a power and pulsed operation viewpoint. Initial indications on a spectrum analyzer indicate that the noise performance is also satisfactory, however, more detailed tests should be done with suitable locking sources and test equipment.

C. FUTURE OUTLOOK

The technology for an injection-locked K^a-band amplifier started in this task is being continued under NASA funding for the MGCO/Titan mapper missions. A 5- to 10-W, 37-GHz solid-state transmitter will be developed for a radar altimeter application for the MGCO in 1985. The technology learned will next be applied in 1985 and 1986 to a radar altimeter for a Titan mission. Then a proposal for a scanning radar altimeter for a shuttle experiment will be made to NASA in 1986 to 1987.

D. FINANCIAL STATUS

The total DDF funding for this task from FY'83 resources was $40,000. All funds had been obligated as of the end of September 1984.

E. PERSONNEL

The principal investigator for this effort was Charles Elachi. Co-investigators were Michael Kobrick and Kenneth J. Russell.

F. PUBLICATIONS

None.

G. CONCLUSIONS

This activity has demonstrated the applicability of high-power IMPATTs for radar transmitters. It opens the possibility of developing three radar systems which are important for future JPL flight and research activities: 1) a high-resolution altimeter for MGCO, 2) a Titan radar mapper for the Cassini Mission, and 3) a scanning radar altimeter for global land topographic mapping.

ANALYSIS SYSTEMS AND INFORMATION EXTRACTION TECHNIQUES FOR IMAGING SPECTROMETER DATA

Final Report

JPL 730-00271-0-3840

Jerry E. Solomon, JPL

A. OBJECTIVE

The objective of this task was to systematically examine various alternative approaches to designing an analysis system suitable for the high (spectral) dimensionality data produced by imaging spectrometer instruments. Specific areas to be addressed in this task were (1) alternative methods for utilizing the spectral information content to extract information about the composition of surface materials, (2) other approaches to efficient interactive exploratory analysis, and (3) new methods for integrating analysis procedures into a "user friendly" interactive system tailored to the needs of remote sensing scientists.

B. PROGRESS AND RESULTS

The spectral dimensionality (>100) of imaging spectrometer data represents a major increase in computational complexity for remote sensing scene analysis. Traditional multispectral clustering and classification algorithms are computationally impractical for this type of data, and new approaches to the multispectral scene analysis problem must be sought. The results of this task show that viable approaches exist, which can overcome the computational complexity problem without requiring the use of super computers, and, thus, provide useful analysis capabilities for a broad range of remote sensing data users.

The general requirements for effective utilization of imaging spectrometer data are:

(1) accurate radiometric rectification;

(2) removal, to first order, of solar spectral irradiance and atmospheric effects;

(3) rapid visual examination of the spectral content of a given scene;

(4) efficient graphics and image display capabilities coupled to fast exploratory analysis algorithms for interactive scene classification and materials identification;

(5) integration of data management and data analysis capabilities into a "user friendly" interactive system.

This work has concentrated on the last three categories, and the results are summarized below.

1. Analysis of Spectral Information

The utilization of the full information content of an imaging spectrometer scene requires the development of new, computationally efficient techniques for multispectral analysis. Given that the spectroscopic resolution and sampling rate are sufficient to define a spectral signature, we have developed some new techniques for spectral signature matching. Two new methods appear very promising both from the standpoint of computational speed and accuracy.

The first technique is the use of the Walsh-Hadamard transformation in the spectral direction for the purpose of dimensionality reduction and signature identification. The use of linear transformations in multispectral analysis is of course not new; but, traditionally, the emphasis has been in stochastic transformations based on statistical properties of the multivariate data, e.g., principal components decomposition. Stochastic methods are generally computationally expensive and require re-computation of the transform kernel for each new scene to be analyzed. Deterministic linear transforms such as Fourier, Walsh-Hadamard, Haar, etc., possess fast numerical implications, and are natural candidates as feature-selection operators for spectroscopic data. Initial evaluations were done using Fourier, Walsh-Hadamard, and Haar transforms, as well as a Chebyshev polynomial representation on laboratory reflectance spectral data. Based on the results of this evaluation, the Walsh-Hadamard transform was chosen primarily because of its ease of implementation and computational speed advantage. Further tests using both laboratory data and image data obtained with JPL's Airborne Imaging Spectrometer (AIS) demonstrated that the Walsh-Hadamard transform allowed a dimensionality reduction of at least eight-to-one, while yielding clustering and classification results comparable to those obtainable with a principal components decomposition. Computationally, this method is two to three orders of magnitude faster than the traditional principal components transformation approach.

The second approach is essentially a nonlinear transformation to accomplish high speed pattern matching. The algorithm consists of a binary encoding of the spectral information followed by a binary cross-correlation for spectral matching and identification-using Hamming distance as a similarity measure. Consider that a pixel at spatial position (i,j) may be represented by an L-dimensional vector, $\vec{X}_{ij}$, whose elements $\{x_1, x_2, \ldots, x_L\}_{ij}$ are intensity values at each of the measured wavelengths. For AIS data $L_{max} = 128$. The optimal encoding threshold was found to be the spectral mean, thus

$$\mu_{ij} = \frac{1}{L} \sum_{\ell=1}^{L} X_{ij}(\ell),$$

is used as the binary encodng threshold.

A binary valued L-element vector $\vec{Y}_{ij}$ is then constructed from

$$\vec{Y}_{ij} = H\{\vec{X}_{ij} - \mu_{ij}\},$$

where

$$H\{\alpha\} = \begin{matrix} 1, \alpha \geq 0 \\ 0, \alpha < 0 \end{matrix}$$

Cross-correlation between a prototype binary encoded spectral vector, P_k, and a test spectral vector Y_{ij}, is implemented using bit-wise exclusive-OR, thus the separation between Y_{ij} and P_k is

$$(\vec{Y}_{ij}, \vec{P}_k) \quad DH = \sum_{\ell=1}^{L} Y_{ij}(\ell) \oplus P_k(\ell),$$

where $\oplus$ denotes the exclusive-OR operation and D_H is just the Hamming distance between the two vectors. Since in practice one does not expect a perfect match ($D_H = 0$), an acceptance threshold, T, is set such that $\vec{Y}_{ij} = P_k$ if $D_H \leq T$. This algorithm has been implemented for use in AIS data analysis on a Sun Microsystems workstation, and yields good results as a fast spectrum identification tool in geology applications. The algorithm has also been extended to include one-bit encoding of spectral slope information, with significant improvement in accuracy and only a slight loss in speed.

In addition to approaches for performing spectral signature analysis, we also examined the issues involved with spectral signature distortion due to atmospheric transmission, topography, and mixing. We found that topographic modulation effects may be largely eliminated by normalizing the spectra for equal energy. This normalization has also proved useful in enhancing the visual presentation of AIS imagery. Normalizing the data in this fashion allows direct spectral shape comparisons that are not affected by he overall albedo or illumination variation effects. In addressing the mixed pixel problem, we found that a number of approaches have been developed by various investigators over the past five or ten years. All of these approaches rely on the assumption of linear mixing and attempt to devise means of identifying the end-members present in a given sample population. Since any approach to solving the mixture problem must involve the use of physical models, it would appear that a "generate-and-test" procedure in the context of an expert system provides a nearly ideal method for handling this problem, and a discussion of this is given in Section 3, Systems Integration, below.

2. Interactive Exploratory Analysis

As the spectral dimensionality of image data increases, the difficulty of visually interacting with the data increases, and it becomes important to develop efficient means for quickly evaluating the information in a given scene. Using AIS as prototype data, we have examined several approaches to enhancing the ability of investigators to interact with imaging spectrometer data. Discussions with remote sensing geologists have led to a set of requirements for interactive display of imaging spectrometer data.

These requirements include the ability to time-sequence scan through successive spectral bands, the ability to cursor designate spectral plotting for single pixels or averages of a group of pixels, and the ability to rapidly find all the pixels in a given scene having similar spectral signatures. In addition, it was suggested that the ability to input laboratory reflectance spectra of field samples for direct visual comparison with image spectra would greatly aid the process of ground truth verification. These capabilities have been implemented for use by investigators with AIS data.

3. Systems Integration

Given the high resolution and breadth of spectral coverage produced by imaging spectrometer instruments, the volume of data and complexity of analysis are likely to overwhelm potential users who do not have access to large computing resources and support personnel. The sample approaches described above enable one to make some headway; however, what is needed is a comprehensive integrated analysis/management system, which can be implemented on medium sized computing facilities. The functional requirements for such a system include (1) operation in a distributed processing environment; (2) global and local data base management, includng intelligent selection of spectral bands for particular analysis objectives; (3) user-transparent management of available resources; (4) intelligent guidance for users in selection of analysis strategies to achieve specific goals; (5) interactive in nature and oriented around visual display of image, spectral, and statistical data; and (6) provide a user-interface (language) which is flexible, can be quickly grasped, and is easy to use. This is certainly an extremely difficult set of requirements for a software system; however, current developments in applications of expert systems offer the potential for realizing these requirements in the very near future.

Although the actual design of such a system was beyond the scope of this task, a structural definition of the system has been completed. Conceptually, the system is actually a hierarchy of expert subsystems each of which handles a specific set of functional requiremens. A block diagram illustrating the basic concept is shown in Figure 1. The diagram does not represent data flow, but rather functional relationships within the system. At the lowest level is the subsystem concerned with a specific application area, in this case geology. Above this, and more or less on an equal footing, are two subsystems dealing with (1) general remote sensing knowledge and (2) computational aspects of image processing. The expert systems approach offers several advantages over traditional methods, the principal one being that it provides a rational basis for the inclusion of specific user knowledge into the analysis of multispectral image data, e.g., the inclusion of contextual information such as spatial association "rules" relating to natural distributions of rock and mineral types. It also provides a rather natural framework within which one may incorporate models of various physical processes of interest, such as mixtures and atmospheric effects. The system would operate in three basic modes which are best described as (1) dumb; (2) intelligent, and (3) expert. In the first mode, the system behaves very much like an imaging processing executive system where the user simply inputs commands to perform various operations on the imgae data; the user makes <u>all</u> decisions and receives no advice from the system. In the "intelligent" mode, the user states the analysis objective and the system provides advice on the selection of analysis operations which will best achieve his objectives given the available data and resources. The system, thus, behaves much like an analysis advisor in this case. Finally, in the "expert" mode, the user states his objectives and the system automaticaly makes the analysis decisions and carries out the required operations from beginning to end. In this case, the output would consist of the requested product (e.g., a rock and mineral map of the scene) together with confidence estimates and a trace of the operations performed to achieve the objective.

C. FUTURE OUTLOOK

Work is continuing on development of both linear and non-linear transformation methods to enhance the speed and accuracy of pattern recognition with imaging spectrometer data. Funds have been made available from NASA OSSA to support this work through 1987. Design and software implementation of an expert system to satisfy the requirements described above has begun. Funding support from NASA OAST has been obtaind to support this work FY'84 through FY'86.

D. FINANCIAL STATUS

The DDF award for this task was $50,000 in FY'83 and funds were exhausted at the end of September 1984. Additional funds of $200,000 from OSSA, Code EI, and $350,000 from OAST Code RC, have been obtained to support significant extensions of this work in FY'85.

E. PERSONNEL

The principal investigator for this task was Jerry E. Solomon; the original co-investigator, Manouher Naraghi, is no longer with the Laboratory. Development of systems requirements was helped greatly by discussions and input from A. F. Goetz, J. Conel, H. Lang, and E. Paylor of JPL; and J. Adams and M. Smith of University of Washington, WA, R. Arvidson, Washington University, MO, and R. Singer, University of Hawaii, HI.

F. PUBLICATIONS

1. J. E. Solomon, "Analysis Methods for Imaging Spectrometry," National Telesystems Conference, San Francisco, CA, October 1983.

2. J. E. Solomon, "Hyperspectral Image Processing," Pecora IX Symposium, Sioux Falls, SD, October 2, 1984.

3. A paper, originally prepared for submission to Applied Optics, is being revised to include results of slope encoding, and will be submitted to Applied Optics, December 1984, as J. E. Solomon and M. Lee, "Binary Encoding Techniques for Imaging Spectrometer Data Analysis."

G. CONCLUSIONS

The results of this task have shown that viable techniques for analysis of imaging spectrometer data exist and can be implemented with modest computational resources in spite of the very high spectral dimensionality of the data. The algorithms discussed above have in fact been implemented in software and are being used for analysis of AIS imagery. Furthermore, an examination of the functional requirements for an analysis system capable of handling imaging spectrometer data indicates that such a system could be developed using current expert system methodologies. Work is now underway to complete the design and software implementation of this system in a distributed processing network environment.

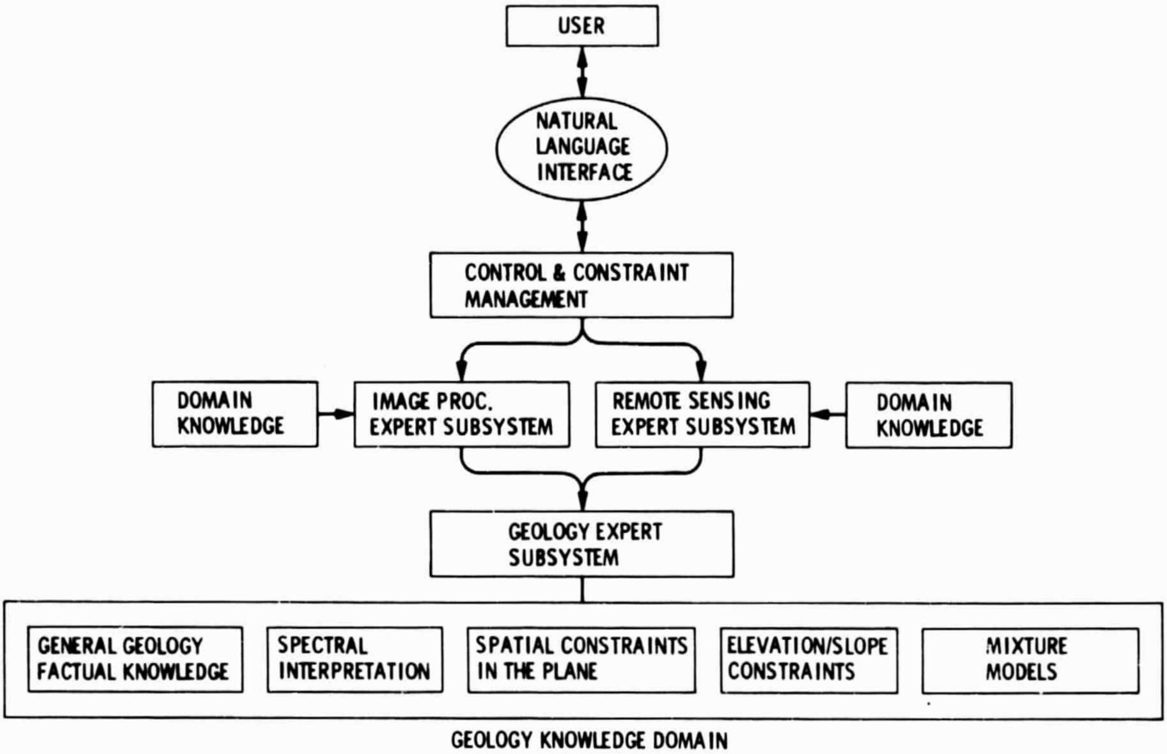

Figure 1. Structural Block Diagram for Multispectral Scene Analysis Expert System.

MESOSPHERIC WATER VAPOR MEASUREMENTS

Final Report

JPL 730-00275-0-3830

William J. Wilson, JPL
Paul N. Swanson, JPL
Sam Gulkis, JPL
Richard M. Bevilacqua, NRL
Phillip R. Schwartz, NRL

A. OBJECTIVE

The objectives of this task was to make measurements of the 22,235-MHz water vapor atmospheric emission line and to use this data to estimate the vertical distribution of mesospheric water vapor. These measurements were to be compared with previous H_2O measurements, which showed that H_2O mixing ratios decreased more rapidly than expected above 65 km. Measurements were to be made over an extended time span to determine day-to-day and seasonal time variations.

B. PROGRESS AND RESULTS

The DSN K-band maser, receiver, and phase-lock system were assembled into a complete water-vapor radiometer measurement system. A block diagram of the complete system is shown in Figure 1. Because of the complexity of the system, it was decided to operate the system at JPL (instead of Goldstone) where it was easier to provide the required technical support. The system was installed in Building 262 located on the mesa.

The observing method was to beam-switch, at a 5-Hz rate, between the signal horn at 13° elevation and a reference horn at zenith. A variable attenuator in the reference path was used to balance the power levels. A noise diode injected into the signal line was used for system calibration. A 64-channel filter spectrometer, with 62.5-kHz filter bandwidths, was used to measure the H_2O spectrum over a 4-MHz bandwidth at the line center. This provided information on the mesospheric (low pressure) portion of the H_2O mixing ratio.

The entire radiometer system was controlled by an HP9816 computer. The computer controlled the beam switching, calibration, power-level balancing, reading of the filter bank data, and data reduction and recording. At the end of each 10-minute data scan, the averaged data was recorded on removable disks and status information was printed. During the measurements, the computer controlled everything so that no operator was required. Once a day, the system was checked for proper operation of the maser, radiometer, and computer system. The completed data disks were sent to the Naval Research Laboratory (NRL), where the final data reduction and inversion of the spectra was done.

Development of this system started in October 1983, and the first observations were made on March 17, 1984. Measurements were made and analyzed during the time periods of March 27 to April 11, 1984, and from May 4 to July 1,

1984. The April gap and suspension of the observations in July were due to failures of the maser refrigeration system. The H_2O measurements are of excellent quality, and this data set is the longest continuous record of mesospheric water vapor currently in existence.

The water vapor spectral data was integrated into 1-day averages. This integration was necessary to achieve signal-to-noise ratios sufficiently high to produce reliable spectral inversions. The 1-day average spectra were then calibrated to remove tropospheric effects, folded about their center point, and, finally, inverted to produce corresponding mesospheric water vapor profiles using a Twomey modified Chahine inversion technique. An error analysis of the retrieved water vapor profiles has also been performed. Figure 2a shows a typical spectrum which was obtained on May 15, 1984. Figure 2b shows the water vapor profile retrieved from this spectrum. The error bars, which are an estimate of the 1-sigma total uncertainty in the retrievals, range from about 28% at 50 km down to a minimum of 24% at 65 km and again up to 28% at 85 km.

In Figure 3, we compared the average mesospheric water vapor profile obtained over the 3-month JPL experiment with the range of mixing ratio values inferred from the previous Haystack Observatory water vapor experiment. The error bars in the figure represent the standard deviation of the individual 1-day retrievals, which form the average profile. Therefore, they include both the random component of the errors in the profiles along with real atmospheric variations. The JPL profile lies everywhere within the rather large Haystack measurement range. This reinforces the conclusion that there are no large baseline or calibration errors involved in either experiment. However, in the upper mesosphere, the JPL profile is distinctly at the high end of the Haystack measurements. It must be remembered, however, that the Haystack measurements span all seasons while the JPL profile is a spring-summer result. With this in mind, we have compared the average JPL profile with each of our previously published Haystack measurements. In the July and September cases, there is fairly good agreement between the Haystack measurements and the JPL profile in the upper mesosphere. In all other cases, the JPL profile indicates much higher mixing ratios above 65 km. Thus, comparisons with the Haystack data set suggest the existence of a seasonal trend in the upper mesospheric water vapor densities with larger values in the summer. Also, the JPL data set itself contains evidence of this seasonal variation. In Figure 4, we have formed monthly average profiles for the 3 months of the JPL experiment. The error bars are not shown below 65 km because of nearly total overlap between the three profiles. This figure shows a clear trend of increasing water vapor mixing ratios from spring toward summer in the upper mesosphere. At 75 km, the increase from the April to June average mixing ratio is very nearly a factor of 2.

We now discuss the individual 1-day average retrievals, which formed the average profiles discussed above. The individual profiles all show the same basic structure expected from our previous measurements. That is, slowly increasing mixing ratios to a maximum around 60 km and a more rapid mixing ratio decrease above this altitude. There is also a good deal of small-scale structure in the daily profiles. For the most part, this structure lies within the error bars; thus, we can place no confidence in its detection. The data does, however, clearly illustrate the upward trend with time in the mixing ratios above 65 km. This increase begins on about 10 May 1984 and continues through the end of the observing period. Below 65 km, there is no indication of this long-term trend.

C. FUTURE OUTLOOK

No further measurements were made during FY'84 because of the pressures of other tasks and problems with the maser refrigeration system. We are working on the maser refrigerator and plan to obtain 2-4 weeks of additional data during the winter season to gain more information on seasonal variations. Based on the success of our measurements in finding evidence for seasonal variations of mesospheric H_2O, we plan to write an RTOP to set up a longer term measurement, possibly at a better site, e.g., Table Mountain.

D. FINANCIAL STATUS

The DDF award for this task in FY'84 was $24,000. As of 30 September 1984, there was $5,100 left in the account. These funds will be used to cover continuing expenses, (e.g., loan pool equipment changes) to obtain a winter measurement of mesospheric H_2O.

Additional FY'84 funding of $20,000 was obtained from NASA OSSA to support these measurements. As of 30 September 1984, there was $4,100 left in this account which will also be used to cover expenses for the winter measurements.

E. PERSONNEL

The technical work at JPL of setting up the experiment and making the measurements was done by W. J. Wilson, W. B. Ricketts, and R. J. Howard. Drs. P. R. Schwartz and R. M. Bevilacqua of the Naval Research Laboratory helped get the experiment operating and were responsible for the data reduction and analysis. Additional technical support at JPL was provided by M. Chavez, M. S. Garrett, M. J. Britcliffe, F. E. McCrea, and M. M. Franco. G. S. Levy coordinate the use of the DSN equipment.

F. FUNCTIONS

A paper on the preliminary results will be presented at the American Geophysical Union (AGU) December 1984 in San Francisco. A short paper will be submitted to JGR (Journal of Geophysical Research) in January 1985 and a longer paper reporting the complete results will be submitted in the summer of 1985.

G. CONCLUSIONS

A sensitive, stable mesospheric water-vapor measurement system was developed and operated from March through June 1984. The data from these measurements has been analyzed in detail.

The water vapor mixing ratios deduced in this experiment agree qualitatively with previous Haystack results. However, the data set contains rather substantial evidence of a seasonal variation with increasing mixing ratios in the upper mesosphere from spring to summer. This is an interesting and new geophysical result, which is consistent with information obtained from several sources including the following: recent 2-dimensional photochemical model studies, mesospheric-stratospheric-tropospheric radar turbulence measurements, and Solar Mesospheric Explorer upper mesospheric ozone measurements.

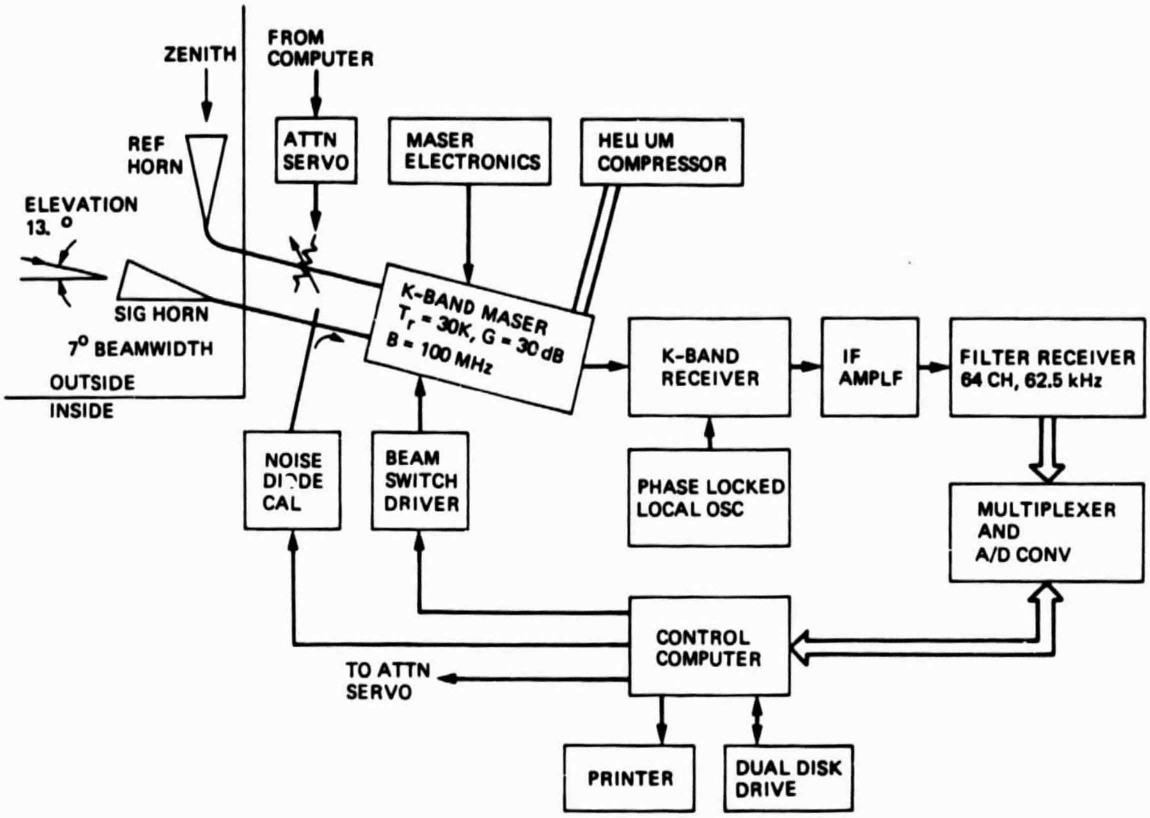

Figure 1. 22.2 GHz Water Vapor Radiometer System Block Diagram

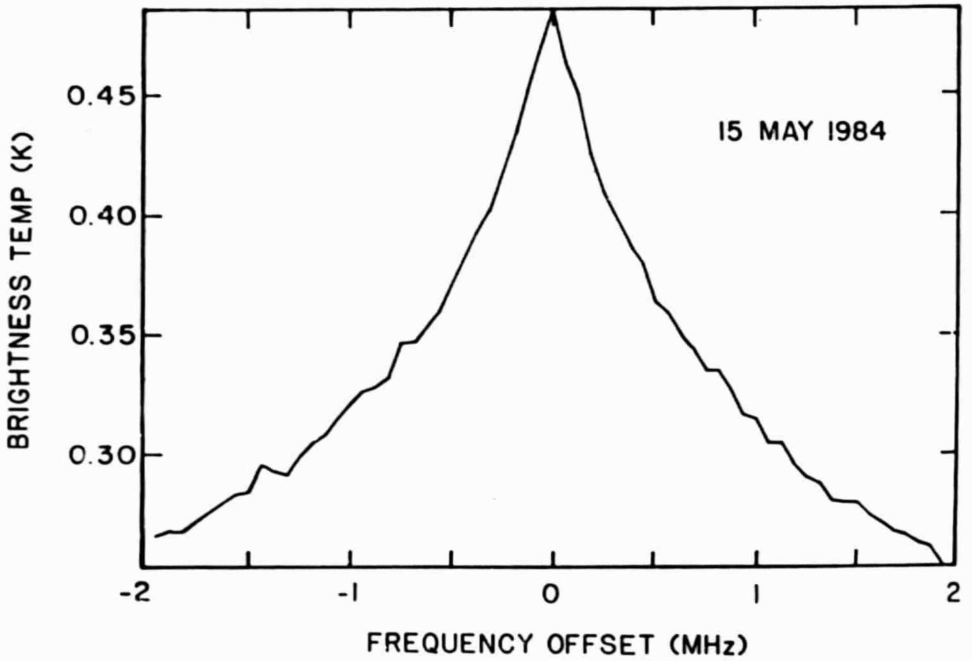

Figure 2a. Mesopheric Water Vapor Spectrum
Data was taken on 15 May 1984 and has been corrected for tropospheric attenuation. The integration time was approximately 19 hours. The center frequency is 22,235.08 MHz.

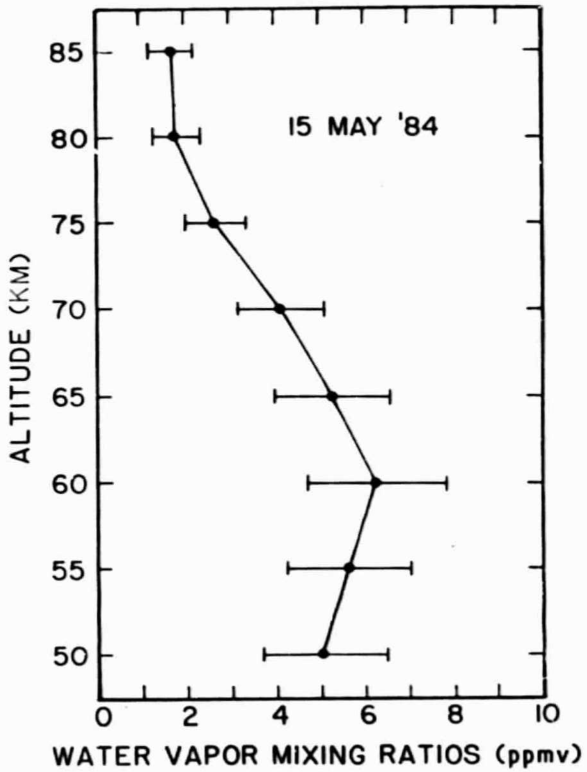

Figure 2b. Water Vapor Mixing Inversion Ratio of data from Figure 2a with 1 sigma error bars.

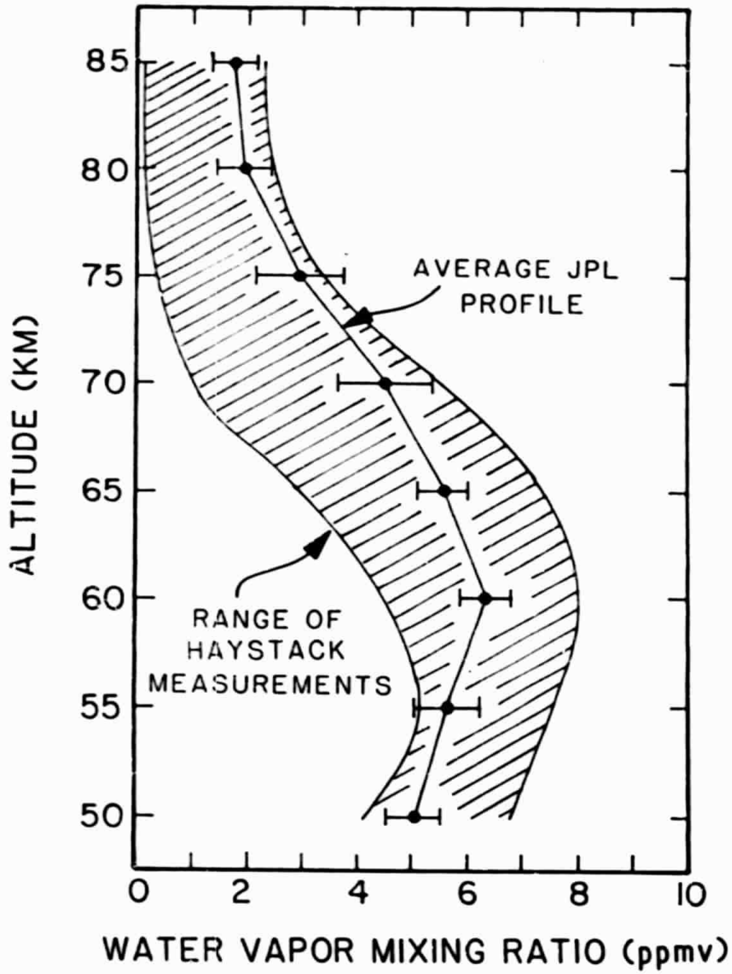

Figure 3. Comparison of Average JPL Mixing Ratio with previous Haystack Measurement Range. Error bars represent the 1 sigma errors for one day's data.

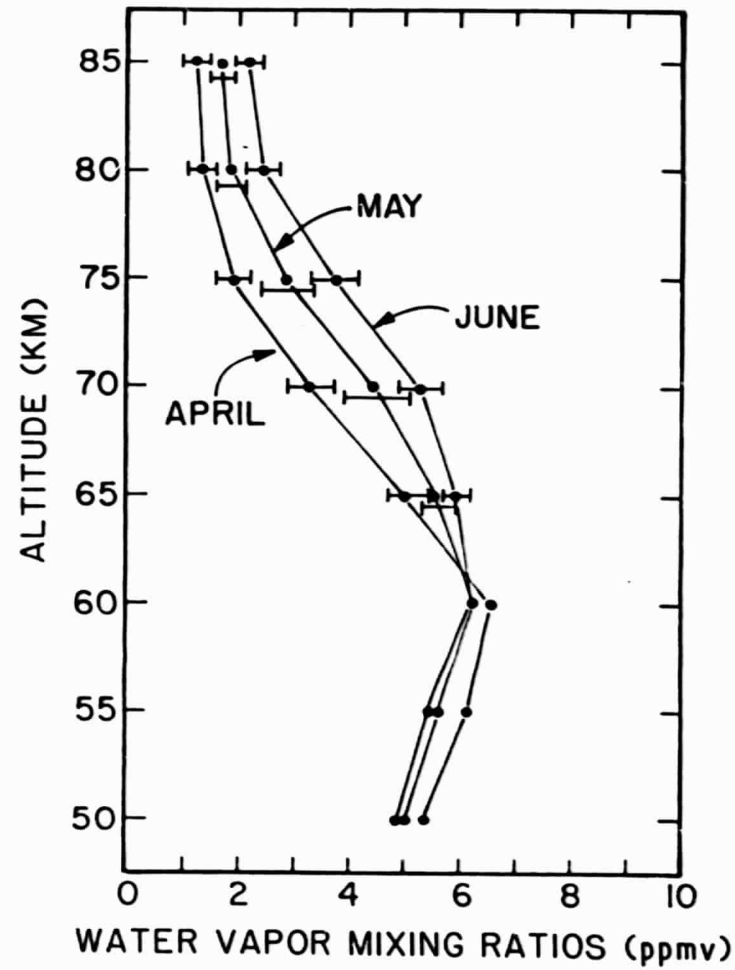

Figure 4. Monthly averages of H_2O Mixing Ratios for Three Months. The 1 Sigma error bars are offset for the May profile for clarity. This data shows the trend of increasing H_2O mixing ratios from Spring to Summer.

OPTICAL SYSTEMS RESEARCH FY'84

Final Report

JPL 730-00286-0-3820

James B. Breckinridge, JPL

A. OBJECTIVE

The objective of this DDF task was to provide continuity of funding for four small optical system generic research tasks begun during the design approach phase of the Imaging Spectrometer task. Contracts had been let to the University of Arizona for engineering research work, which provided graduate student dissertation funding, when cancellation of the Imaging Spectrometer optics research was received. The $60K funds awarded by this DDF were used to phase out or transition the research efforts in an orderly manner.

The four tasks were Integrated Optics Spectrometer, Self-Calibration of Infrared Detectors, Imaging Spectrometer Optical System Design Approach, and Polarization Matrix Analysis Program.

The objective of the Imaging Spectrometer Optical System Design Approach task was to explore a variety of potential designs and, in collaboration with JPL investigators, identify a suitable approach and develop the optical design software tools required to design and analyze the final system.

The objective of the Self-Calibration of Infrared Detectors task was to improve the accuracies of infrared radiometry, using the method of photo-diode self-calibration (Geist, J. (1980)). Specifically, measurements in infrared radiometery are difficult and tedious at best. Even with currently available NBS standards, overall accuracy is achieved only after calibration transfer schemes are carefully employed.

The objective of the Integrated Optics Spectrometer was to make an assessment of the new technologies of integrated optics wavelength multiplexes and demultiplexers, which are now being used in the fiber optics communications industry, in order to determine the suitability of this technology for a focal plane integrated optics spectrometer system.

The objective of the Polarization Matrix Analysis Program is to add a module to the ACCOS V software to compute the field and pupil position dependent polarization transmissivity of simple remote-sensing and measurement systems. Also included is an analysis of the polarization-dependent wavefront expansion aberration terms.

B. PROGRESS AND RESULTS

Progress on each of the four tasks is discussed separately here.

The Imaging Spectrometer Optical System Design Approach task was completed this year. Dr. J. Michael Rodgers completed his PhD dissertation on a new analytical method for the expansion of wavefront aberrations from large mirror surfaces. His work, which enables more accurate modeling of both large and small optical systems, is of significant value in understanding large aspherical surfaces.

The Integrated Optics Spectrometer task was partially completed this year, and then the task was terminated because of lack of continuing funds.

Mr. Mike Nofziger, graduate student of the Optical Sciences Center at the University of Arizona, prepared a separate, detailed report on this task: Self-Calibration of Infrared Detectors. His report is appended here.

The Polarization Matrix Analysis Program task has had this progress: the software module to read direction cosines from ACCOS V is complete, the plot program to display the polarizance is complete, a subroutine to analyze beamsplitters was started, and analysis to expand in terms of polarization dependent wave-front polynomials has started.

C. FUTURE OUTLOOK

Each of these four research topics have been presented to Lee Holcomb and M. Sokoloski (OAST) for continuing funding as part of a generic Optical Systems Research program. A meeting of the NASA sensor working group endorsed optical system research as a technology program critical to the development of sensors.

Self-Calibration of Infrared Detectors and Polarization Matrix Analysis Program are the two tasks that need continuation funding.

D. FINANCIAL STATUS

The original amount of $60K has been completely committed to the University of Arizona to support graduate students in the two remaining tasks. All funds are essentially exhausted. This account will be closed during FY'85.

E. PERSONNEL

The Integrated Optics Spectrometer task was supported by Professor J. J. Burke and graudate student John Meiling.

The Imaging Spectrometer Optical System Design Approach task was supported by Professor Robert R. Shannon and graduate students J. M. Rodgers and D. Ricks of the University of Arizona Optical Sciences Center. Dr. John Stacy of JPL contributed.

The Polarization Matrix Analysis Program task was supported by Professor James C. Wyant and his graduate student Russell Chipman. Dr. John Stacy of JPL made significant contribution to this task.

The Self-Calibration of Infrared Detectors task was supported by Professor William L. Wolfe and his graduate student M. Nofziger.

F. PUBLICATIONS

J. B. Breckinridge spent approximately 20% of his time during FY'84 marketing an Optical Systems Research Program to OAST and OSSA. Although optics technologies are needed and used by each of the three observational elements within OSSA, no one within NASA is willing to assume responsibility for an optics program yet.

Many RTOPs and proposals have been prepared and submitted to Washington during the past three years with no response.

Two papers on the Polarization Matrix Analysis Program were presented at the annual Optical Society of America meeting.

One Ph.D. dissertation was completed by J. M. Rodgers.

G. CONCLUSIONS

These DDF funds provided support during the successful close-out phase of the imaging spectrometer optical systems research task. OAST was presented with a new initiative in Optical Systems generic research. NASA/OAST does not support optical systems research and the initiative was not funded. Optical Systems Research for NASA has been discontinued.

SELF-CALIBRATION OF INFRARED DETECTORS

Addendum to Final Report

JPL 730-00286-0-3820

W. L. Wolfe, University of Arizona
M. Nofziger, University of Arizona
J. B. Breckinridge, JPL

The University of Arizona has been conducting research for the Jet Propulsion Laboratory to improve accuracies in infrared radiometry. The method of photodiode self-calibration[1,2] is being studied and applied to infrared detectors. Based on recent results for silicon detectors (400-800 nm)[3] this method promises to increase the absolute accuracies of present infrared detector standards by at least an order of magnitude.

A. OBJECTIVES

(1) Measurements in infrared radiometry are difficult and tedious at best. Even with currently available NBS standards, the overall accuracy is achieved only after calibration transfer schemes are carefully employed.

(2) The overall goal of this research effort is to apply the photodiode self-calibration method to infrared detectors. Our underlying objective of using self-calibration is to decrease the absolute uncertainty of infrared radiometry to the 0.1% level. In addition, a self-calibrated infrared detector standard could be used more easily at a much lower cost than traditional blackbody or thermal detector standards.

(3) One immediate objective is to obtain an infrared photodiode suitable for attempting a self-calibration. In the initial part of our research we have identified various diode characteristics needed for self-calibration. Much of the research effort is still being directed at obtaining and measuring diodes having suitable characteristics.

B. PROGRESS AND RESULTS

As a result of a separate research program to measure the solar constant at the 0.1% uncertainty level, our laboratory had already established the capabilities for diode self-calibration (at visible stabilized laser source), a stabilized thermal source and monochromator, a standard voltage source for use in bias experiments, various optics for making reflectance measurements, detector preamps, and high accuracy digital voltmeters automated under computer control. With the hardware already in the lab, the funds from this contract have been used to obtain and measure various photodiodes for possible use as infrared self-calibrating standards.

Based on the successes of using silicon photodiodes for self-calibration in the visible spectrum, germanium (Ge) was chosen as the first detector material to use for infrared self-calibration studies. Various attempts at obtaining suitable Ge diodes from commercial manufacturers have been met with little or no success. Fortunately, Professor Richard Schwartz of Purdue University is involved with the research and development of Ge diodes, and has been willing to provide us with diodes more suitable for self-calibration. Our research in the past few months has centered around measuring the initial five diodes sent from Purdue.

The first diode we received was found suitable for performing the bulk reverse bias experiments. Satuation at wavelengths out to 1.8 microns has been observed. However, the device area (1 x 1 mm) is too small for making accurate reflectance measurements; hence, self-calibration has not been possible for this device, even though the top layer is of optical quality.

The next set of four diodes we received seemed more promising for self-calibration. They are of larger areas (2.5 x 2.5 mm and 4.45 x 4.45 mm) and all have to coatings of optical quality. We have used a reflectance scheme[4] to measure the reflectance of one of the diodes, as a function of wavelength from 0.6 to 1.8 microns. These initial measurements are estimated to be accurate to 2%; however, the reflectance scheme is still being developed and perfected.

To obtain as much information as possible from the four diodes, the internal quantum efficiency was measured for the device whose reflectance had also been measured. This was done as a function of wavelength from 0.6 to 1.8 microns by measuring the total flux from our stabilized thermal source and monochromator and by comparing it to measurements made with our electrically calibrated pyro-electric radiometer (ECPR). The values of internal quantum efficiency were found to agree to within 4% of those predicted by Schwartz's computer modeling program at Purdue.

All of these initial results have been sent back to Purdue, to be input to their computer program as an aid in developing the next generation of Ge diodes. In fact, we expect to receive more diodes from Purdue in the next couple of weeks.

Finally, it should be noted that we are also waiting for Ge diodes to be sent to us from Hamamatsu and Germanium Power Devices. These devices will be tested as were the diodes from Purdue.

C. FUTURE OUTLOOK

The possibilities of using a self-calibrating detector in the infrared still seem promising and exciting. There is much work yet to be done on Ge photodiodes before self-calibration will be achieved. The Ge diodes have the most promise because of the efforts of Schwartz at Purdue.

We have considered using other detector materials such as InSb, HgCdTe, or GaAsP for self-calibration. However, until a supplier capable of doing research and deveopment for self-calibration of such devices is found, we will continue to work with Ge diodes.

D. PERSONNEL

The following persons are either directly involved with or available for information relating to photodiode self-calibration:

William L. Wolfe	:	Principal Investigator
Mike Nofziger	:	Graduate Student Research Assistant
Jim Palmer	:	Advising Faculty Member
Eustace Dereniak	:	Advising Faculty Member
Richard Schwartz	:	Device Manufacturer and Consultant, Purdue University
Jon Geist and Ed Zalewski	:	Developers of self-calibration, Consultants to our research efforts, National Bureau of Standards

E. PUBLICATIONS

Lee, Sung Muk, "Investigation and Extension of Self-Calibration, Radiometry," Ph.D. Dissertation, University of Arizona, Tucson, Arizona (1983).

Palmer, James M., "Near-infrared Limitations to Silicon Photodetector Self-Calibration," presented at the SPIE Annual Technical Symposium, San Diego, CA, August 21, 1984.

F. REFERENCES

1. Geist, J., "Quantum Efficiency of the p-n Junction in Silicon as an Absolute Radiometeric Standard," Appl. Opt. 18, 760 (1979).

2. Geist, J., E. F. Zalewski, and A. R. Schaefer, "Spectral Response Self-Calibration and Interpolation of Silicon Photodiodes," Appl. Opt. 19, 3795 (1980).

3. Zalewski, E. F., and J. Geist, "Silicon Photodiode Absolute Spectral Response Self-Calibration," Appl. Opt. 19, 1214 (1980).

4. Booker, R. L., and J. Geist, "Induced Junction (inversion Layer) Photodiode Self-Calibration," Appl. Opt. 23, 1940 (1984).

LARGE DEPTH-OF-FIELD INTERFACE PROBE
USING SYNCHROTRON RADIATION

FINAL REPORT

JPL 730-00290-0-3640

MICHAEL H. HECHT, JPL
FRANK J. GRUNTHANER, JPL
P. PIANETTA, STANFORD UNIVERSITY

A. OBJECTIVE

The objective of this task was to apply variable energy photoemission spectroscopy in the medium energy x-ray range (1-4 KeV) to problems in silicon interface studies. Recent development of a vacuum beam line in this energy range at the Stanford Synchrotron Radiation Laboratory (SSRL) presented an opportunity to vary the photoelectron escape depth over a range from 0.5 to 5 nm, which has the effect of Varying the spectroscopic depth-of-field over the same range. This allows chemical and structural analysis of material variations in the near interfacial region.

B. PROGRESS AND RESULTS

Approximately 10 days of beam time were allocated for this work in April 1984. Data collected at this time supplemented and replicated initial data, which were collected in June 1983.

The utility of the experimental system for photoemission studies was limited principally by the lack of incident flux stability and reproducibility, and secondarily by low count rates due to inappropriate electron optics. The system proved adequate, however for the proposed purpose.

Thin thermal oxides of silicon were prepared by chemically etching conventional device quality oxides. The core levels of oxides of several thicknesses were examined as a function of incident photon energy. In addition, radiation hard and soft oxides were compared. Analysis of the data indicated changes in the density-escape-depth product (DEP) for the oxide as the interface was approached. This difference was clearly shown to be greater for the radiation soft sample. This result has been reported in the literature and at scientific meetings. In addition to demonstrating the feasability and utility of the technique, it set to rest a concern related to the experimental method we have applied to the same problem in house - the concern that comparison of films of different thicknesses with fixed photon energy was biased by the tendency of the thinner films to mechanically relax. We have previously reported that the DEP is a measure of strain in the oxide network resulting from the mismatch with the substrate crystal lattice (F.J. Grunthaner et al, IEEE Trans, on Nucl. Sci. NS-29, No. 6, p. 1462, 1982). This result supports the previous conclusions.

We have used portions of the allocated beam time to explore two related avenues of research. The first is a Surface-Extended-X-Ray-Absorption-Fine-Structure (SEXAFS) analysis of thin and thick oxide films, in order to directly measure differences in the geometrical arrangements of the atoms. This data is currently under analysis and will be reported at an upcoming meeting. The second study was prompted by a serendipitous discovery during the SEXAFS measurement. A strong threshold resonance, easily observed with photoemission spectroscopy, was found near the K edge of silicon. This resonance is driven by a transition between the core electron and a core-exciton state in the band gap of the material. The resonance was seen to be extremely strong in silicon dioxide, and relatively weak in elemental silicon. From this data, the binding energy and relative localization of the exciton could be determined. Such an excitonic state is relevant to a range of chemical processes including radiation damage and etching. This result has been reported at scientific meetings, and further analysis is underway.

C. FUTURE OUTLOOK

Due to the scarcity of beam-time at synchrotron radiation faccilities, it is essential for experimenters to prioritize their research activities. At the present time further research on excitonic resonances appears to offer the greatest opportunities for significant scientific advances. We will pursue this work collaboratively with researchers at other institutions. For the time being, we will restrict activities to those consistent with existing group funding. Specific support for synchrotron radiation activity and for further analysis of existing data will be sought in the coming year. Arrangements have been made for continuing allocation of beam time at SSRL for this purpose.

D. FINANCIAL STATUS

The initial request for this DDF project was $44,671. Actual funds granted were $10,000. The task was accomplished by restricting the scope of the work to areas directly relevant to existing task objectives, and using the funds incrementally to explore the new technologies. In practice, this meant that the funds were used to cover travel expenses, computational services, minor capital equipment procurements, and a small amount of salary. The funds were completely expended in FY'84.

E. PERSONNEL

The work was a collaboration between Drs. Hecht and Grunthaner at JPL and Prof. P. Pianetta at SSRL. In addition, students and associates of Prof. Pianetta, including M.L. Shek, P. Mahowald, J. Woiczik, L.I. Johansson, Y. Cho, and S. List assisted in the data acquisition. Prof. I. Lindau of Stanford University also collaborated in this work.

F. PUBLICATIONS AND PROFESSIONAL PRESENTATIONS

1. M.H. Hecht, F.J. Grunthaner, P. Pianetta, L.I. Johansson, I. Lindau, "Electron Escape Depth Variation in thin SiO_2 Films measured with Variable Photon Energy", J. Vac. Sci. Technol. A2, P. 584 (1984).

2. M.H. Hecht, F.J. Grunthaner, P. Pianetta, L.I. Johansson, I. Lindau, "XPS Study of the Si/SiO_2 Interface with 10-50A Probe Depth Using a Double Crystal Monochromator", Presented at the Symposium on Materials Science Using Synchrotron Radiation at the Nov., 1983 meeting of the Materials Research Society (Boston, MA).

3. M.H. Hecht, "JUMBO Photoemission Spectroscopy", Invited presentation at the Oct., 1984 Stanford Synchrotron Radiation Laboratory Users Meeting.

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6. M.H. Hecht, F.J. Grunthaner, P. Pianetta, H.Y. Cho, M.L. Shek, P. Mahowald, "The Role of Two-Electron Threshold Resonances in Si Near Edge Structure", Presented at the International Conference on EXAFS, July, 1984 (Stanford, CA). Proceedings to be published.

Additional publications are in preparation.

G. CONCLUSIONS

We have successfully completed three experiments in the allocated beam time at SSRL:

1. We have measured the DEP of thin silicon dioxide films, directly demonstrating for the first time that this parameter decreases near the silicon interface in a process dependent fashion.

2. We have recorded SEXAFS spectra from both thick and thin silicon dioxide films as a means of directly measuring bond angle variations near the interface. Such variations are assumed to be responsible for the observed DEP variations.

3. We have discovered a resonant excitation in silicon compounds which will be a valuable tool in characterizing excitonic structure in these materials. This tool will be utilized in future studies at SSRL.

In additional to the above, we have accomplished our original goal of demonstrating the feasibility of quantitative photoemission spectroscopy in this energy range, and have identified areas of potential improvement in signal strength, resolution, and stability.