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FINAL GRANT REPORT

for

NASA-Ames Grant NAG2-317

The Infrared Spectrograph During the SIRTf Pre-Definition Phase

November, 1984 through September 1987

Dr. James R. Houck, Principal Investigator
Cornell University

Christopher A. Leidich, Technical Monitor
NASA - Ames Research Center

September 30, 1988

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TABLE OF CONTENTS

	Page
TECHNICAL ACTIVITIES REVIEW	6
CONCLUSIONS	7
BIBLIOGRAPHY OF GRANT SUPPORTED PAPERS	14
APPENDICES	
Progress Report 1, November 1, 1985	
Progress Report 2, May 10, 1986	
Progress Report 3, March 10, 1987	
Progress Report 4, January 31, 1988	

Technical Activities Review

Progress Report 1

The first progress report, dated October 1985, detailed the first efforts in the detector development and testing effort. The original Ball and Rockwell RFP's appear as appendices. BIB performance parameters to date (10/1/1985) are included. The activities of the three co-investigators are briefly discussed.

Progress Report 2

The second progress report, dated May 1986, goes into considerable detail of the detector testing program development at Cornell. Appendices include a review of Operations subgroup activities, a review of a December, 1985, meeting at Rockwell International, and Rockwell progress reports numbers 1 and 2. Two additional appendices detail a new spectrograph concept and an in-depth discussion of resolution issues raised by this new design.

Progress Report 3

The third progress report, dated March 1987, details detector progress to date. A brief recap of grant management activities and progress towards a SIRTf Phase I contract is given. An extensive review of the Cornell detector test effort, specifically computer software and testing facility hardware, is included as an appendix. Other appendices include Rockwell progress reports 4,5, and 6, three Ball SERs (Relay Optics, Reflective Relay Optics, and a Czerny-Turner-Type High Resolution alternative to relay optics), and three brief reviews of co-investigator activities.

Progress Report 4

The last progress report was submitted in January 1988. Its focus was fairly narrow as most of the work being done under the grant was completed by this time. Appendices include a review of the preamplifier constructed in late 1987 and a revised schematic of the detector evaluation facility and Rockwell progress reports 7 through 11. A draft copy of Watson and Huffman's paper reporting initial Ge:Ga BIB results is also included as a final appendix.

CONCLUSIONS

Cornell University

The goal of the Cornell technical development activities under the grant was to evaluate Rockwell Si:As BIBIB (Back-Illuminated Blocked-Impurity-Band) detectors. This involved the construction of hybrids for testing at Rockwell and the setup of a testing facility at Cornell to evaluate the arrays.

The Rockwell fabrication effort was a two-step process begun under the grant. The first phase of this program was to produce hybrid detector arrays using its standard techniques. The second phase of the program, continuing under the SIRTf contract, is to increase the short wavelength responsivity of the hybrid arrays to simplify (by reducing the detector count) the SIRTf focal plane. The Si BIBIB detectors have the potential to entirely fulfill the mid-band detector needs of the IRS which covers 4-30 μ m. Arrays are produced and tested at Rockwell, and delivered to Cornell for evaluation under SIRTf conditions, that is, the low backgrounds appropriate for SIRTf.

The setup of a test facility for evaluation of the Rockwell hybrid arrays was begun under the grant. Accomplishments included the construction of a test dewar, a ten-channel preamplifier, and a clock conditioning and DC signal box. The test dewar allows low-backgrounds to be achieved, and is being modified under the contract to allow for external (calibrated) illumination of the detectors, as well as active thermal control. The preamplifier has externally programmable gain and bandwidth, and also has a dynamic offset capability to inject offsets before full gain is applied to eliminate the baseline slope of the array output. This allows maximum gain to be achieved with the array and hence best dynamic range on the A/D converter. The clocking box provides filtering and level adjustment of the high and low levels of the clocking signals, and delivers the required DC levels to the array.

A data acquisition and control computer was assembled. A single board computer (SBC) is downloaded with software from the main computer. This SBC delivers clocking and control signals for running the array multiplexer. The data acquisition computer then samples the conditioned output of the array through a 16-channel A/D converter. Software was written to control the array, and take, store, and analyze array data. More details on the Cornell test facility can be found in past progress reports.

Initial tests have been geared toward determining dark current and read noise for the array. The array achieves a read noise of about 80 electrons at 20 Hz, however; an increase in read noise with integration time is observed. For a ten second integration time the read noise is 200-250 electrons. The measured dark current appears to vary with operating mode, and may be influenced either by trapped

charges within the reset MOSFET or intrinsic properties of the detector. At integration times of 200 seconds operating in a burst read mode, a mean dark current of 80-100 electrons per second is seen. Linearity tests indicate that the output of the hybrid array is non-linear, however this behavior (claimed to be mainly due to the multiplexer by Rockwell) appears to be very reproducible and hence can be calibrated. The issue of whether this non-linearity actually represents a change (decrease with high signal levels) in quantum efficiency has yet to be investigated, although Rockwell thinks that this should not be a major effect.

The results generated thus far indicate that the Rockwell Si BIBIB hybrid arrays show great promise in meeting the specifications necessary for use in the infrared spectrometer; however there is a need for further testing. The evaluation begun under the grant is continuing under our SIRTF contract. Further evaluation of the read noises and dark currents is needed. Since a primary motivation behind the original development of BIBIB arrays was to produce radiation hardened devices, these arrays show strong promise of providing detectors for SIRTF which behave well in a space environment. Testing under SIRTF radiation conditions needs to be performed, however. Measurement at the short wavelengths of quantum efficiencies of the enhanced detector and investigation of flat fielding noise will both be made.

California Institute of Technology

The principal goals of the far-infrared detector development effort at Caltech under the SIRTf/IRS grant were to establish the feasibility of Ge:Ga BIB detectors, and to demonstrate the performance of an eight-element linear arrays of Ge:Ga and Ge:Be photoconductors with individual modular integrating cavities. Very good performance was obtained from the initial few batches of Ge:Ga BIB detectors, and this detector concept will continue to represent the main development effort at Caltech. Work on the photoconductor array has proceeded more slowly, owing to the rapid progress of the BIBs. The Caltech far-infrared detector characterization facilities have been upgraded with the addition of a microcomputer-based data acquisition system and extensive modification of two liquid-helium cryostats under the auspices of the grant. At this point the Ge BIB concept is promising enough that it is considered the "baseline" far-infrared detector technology for the IRS focal plane; however, the work on extrinsic germanium photoconductors will proceed in parallel with Ge BIB development in case tests of monolithic arrays of the latter detectors under the SIRTf background and radiation conditions reveal unexpected problems.

The grant-phase Ge:Ga BIB development effort was carried out as a collaboration between Caltech and the Rockwell International Science Center (Anaheim, CA). The BIB structure selected for initial study was ultrapure intrinsic Ge epitaxy on impurity-banded substrates, fabricated into individual detector elements for testing. Caltech was responsible for provision and electrical characterization of the impurity-banded Ge:Ga substrates, fabrication and packaging of the individual detectors, and all far-infrared detector characterization. Rockwell was responsible for the chemical-vapor-deposition epitaxial Ge growth, materials characterization of the epilayers and substrates (e.g., X-ray crystallography, spreading resistance depth profiling), and ion-implantation of electrical contacts. The devices produced in this initial attempt achieved performance competitive with that of the state of the art. Peak quantum efficiencies of 4% were obtained, implying background-limited sensitivity within a factor of three of the very best Ge:Ga photoconductors. The operating conditions of the BIBs (e.g., temperature, demands on preamplifiers) are essentially the same as that for photoconductors, but the active volume was verified to be 1000 times smaller, leading to the promise of high radiation hardness and low crosstalk in monolithic 2-D array formats. Prospects for improved performance, perhaps even surpassing the best discrete Ge:Ga photoconductors, seem extremely good.

The following is a summary of the characteristics of the two initial batches of Ge:Ga BIBs:

1. For devices with a gallium density of $3 \times 10^{16}/\text{cm}^3$, the threshold wavelength is 190 μm , in agreement with simple

theoretical estimates based on the broadening of the gallium impurity bands with increasing density. A peak responsivity of 5 A/W is achieved near 140 μm , corresponding to a quantum efficiency of 4%. The quantum efficiency varies little above threshold.

2. NEP measurements at moderate backgrounds are consistent with background-limited sensitivity at the above quantum efficiency.
3. Measurements of capacitance as a function of bias voltage verify the formation of a depletion region in the Ge:Ga BIB that gets wider as the bias voltage increases and collapses abruptly at breakdown. The maximum width of the depletion region is 2 μm , consistent with the observed values of quantum efficiency. The donor concentration in the active region is derived from the $C - V$ measurements to be $3 \times 10^{12}/\text{cm}^3$. The $C - V$ measurements also allow a determination of the electric field distribution in the BIB; a breakdown field strength of 65 V/cm is obtained for the blocking layer. The breakdown voltage of the present devices is about 40 mV.
4. The devices are very uniform in all of their characteristics; the five detectors tested had the same responsivities, depletion region depth, threshold wavelength and blocking-layer breakdown field strength to well within 10%.

Modest-size arrays (6 X 6) have been constructed from the same material for further testing, particularly of dark current. The second phase of this program, which will involve epitaxial growth of the absorbing layer as well as the blocking layer, will proceed as soon as the IRS and MIPS SIRTf Phase I contracts are completely in place. (The first phase of this program was supported by the IRS team [75%] and the MIPS team [25%] with a total of \$80,000 of pre-SIRTf Phase I funds.)

A paper describing the Ge:Ga BIB performance in detail has been included in this Final Grant Report as part of Appendix A (Watson and Huffman 1988, submitted to *Applied Physics Letters*).

Although the operation of the eight-element linear arrays of discrete integrating-cavity-mounted extrinsic germanium photoconductors has not yet been demonstrated, the individual detector-cavity modules have been assembled and tested, and perform acceptably. The next step in this project is to interface them to their integrating preamplifiers and conduct low-background tests. This is planned to take place during the first year of the IRS development contract, and will generally be assigned a lower priority than the BIB work.

University of Rochester

The long-term goal of the Rochester technical development program for SIRTf is to provide detectors with low dark current (<1 atto Amp), high quantum efficiency, and low read noise (goal <100 e- RMS) in a large format (of order 64x64 or larger) for the IRS and IRAC. These detectors should maximize the signal-to-noise ratio in astronomical observations under the low background SIRTf conditions. Equally important are the detector's imaging characteristics, i.e. lack of blooming, calibratable output, freedom from ghosts. In short, high quality, calibrated, reliable images from the detectors are required. Under the grant, Rochester's short-term goal was to test and evaluate InSb and Si:In infrared detector arrays and their associated CRC 228 58x62 readout from Santa Barbara Research Center (SBRC) for their possible applicability to the IRS and IRAC experiments on SIRTf.

InSb photovoltaic detector material was selected for evaluation in the 2 to 5 micron region because of its proven performance in earlier detector arrays. For the SIRTf conditions, SBRC recommended using low-doped material, to minimize the dark current and maximize the quantum efficiency at low temperatures. Under a contract from SAO they built and performed preliminary tests on 58x62 arrays from Cominco low-doped InSb mated to the CRC 228 SFD switched-MOSFET readout. These arrays were to be compared to Si:In photoconductive arrays, sensitive from 2 to 8 microns.

In conjunction with the grant, Rochester hired a post doctoral research assistant (Zoran Ninkov), a graduate student, and a computer programmer and trained them in infrared detector array technology. A dewar for testing arrays was constructed, which includes interference filters and CVF's covering the 1 to 8 micron region and allowing testing at low, SIRTf class backgrounds. Temperature measurement and control for the 6-50K range was provided. A low noise amplifier (gain of 50) inside the dewar prepared the detector signals for introduction to the signal processing electronics, which was provided by SBRC (blue boxes). The SBRC drive electronics (blue boxes) were tested, debugged, and wired to the array. A computer system consisting of hardware and software to control the array readout and convert the detector signals to digital numbers for further analysis was developed. It is based on the DEC LSI 11/73 cpu with two Data Translation 110 kHz 16 bit A/D converters with DMA and a Peritek 512x512x8 bits video card for display of array images. The programming is in the FORTH language, based on our previous experience with the SBRC CRC 121 32x32 InSb arrays.

Three of the InSb arrays were evaluated during the grant period. The first, FPA 17, was a high-doped engineering array helpful in debugging the testing system. It showed an extreme loss of quantum efficiency below 50K, characteristic of SBRC arrays from this material. Preliminary tests were performed on two low-doped ($2E14/cm^3$) arrays. The first, SCA 01, had reasonable quantum efficiency at 31K, but at 7K the performance was greatly degraded. At the same time, the temperature necessary for low dark current appears to be below 31K. However, these tests should be repeated because they were originally performed with an incorrectly connected wire present. SCA 02 is the most promising InSb array that was tested. It delivers reasonable quantum efficiency (30%, not yet A-R coated) at 8K and unmeasurably low dark current ($< 2.4 e^-/sec$ with 500 sec. integrations). The read noise was about 240 e- RMS using 0.1 to 500 sec integrations.

During this time initial testing of one 58x62 Si:In array was begun. It is believed that the multiplexer on this array is defective, limiting test efforts in the area of read noise minimization. It was shown that a very high bias voltage, namely 56V, is necessary to bring the quantum efficiency photoconductive gain product up to 5% at 8K. The dark current at this temperature was $< 1 \text{ aA}$ and 60 e- read noise for short integration times was achieved.

The arrays tested to date show some promise for SIRTf, but at the same time there are problems. The loss of QE at low temperatures and the high dark current at high temperatures indicates flaws in the SBRC InSb array technology. Rochester plans to continue this testing program under the SIRTf Phase I contract, but will at the same time survey for possibly superior detector materials.

Ames Research Center

During the grant phase, tests were made of discrete front illuminated Si:As BIB detectors manufactured by Rockwell in order to determine their suitability as detector types for SIRTf. In general, the claims the vendor made for these devices were verified, encouraging us to investigate their new 10x50 backside illuminated Si:As BIB arrays. The discrete devices were tested in a specially modified test facility that allowed testing under the very low background conditions expected in the SIRTf IRS. The readout electronics consisted of standard TIA amplifiers and load resistors for most of the tests, although some testing was done using direct readouts with a MOSFET reset switch. The typical responsivity of these devices was found to be 10 A/W with dark currents of 3×10^{-14} A.

A new detector test facility was constructed as part of the grant to test Silicon array detectors in the 58x62 format using the CRC 228 multiplexer. This test facility employs a single board 68000 based computer together with a Sun Workstation and a MacIntosh to read out and analyze the data. As the grant period came to a close, the first results were just being obtained from this test facility using a Si:Sb array; these results have been sent on to the CU/IPO and included in monthly progress reports issued under the contract.

During the grant period a SIRTf operations sub-group was formed to consider operations and data handling issues in an early time frame. This group met in January 1985, January 1986, and August 1986. An important issue considered at these early meetings was the problem of commonality of the data handling hardware and software. In the course of these meetings the sub-group recommended to the SIRTf SWG that a single, basic computer system be employed by all of the instrument teams, and chose the languages of FORTRAN and C as the common languages to be used by all of the teams in their data handling software.

Bibliography of Grant Supported Papers

The only paper funded by this research effort was prepared by Dan Watson of the California Institute of Technology and James Huffman of Rockwell International Science Center. The paper, entitled Germanium blocked-impurity-band far-infrared detectors, has been published by Applied Physics Letters.

PROGRESS REPORT 1

for

NASA-Ames Grant NAG 2-317

The Infrared Spectrometer During the SIRTf Pre-Definition Phase

through October 1, 1985

November 1, 1985

INFRARED SPECTROMETER GRANT REPORT

This report covers the activities on the IRS Grant up to 1 October 1985, the activities at Ball Aerospace as well as the IRS co-investigators. The report is broken down by institution, so there is some minor overlap as to the coverage on various tasks.

University of Rochester (W. J. Forrest)

A contract was initiated with SBRC for the delivery of an InSb array. The current delivery date for the array is 1 December 1985. The test dewar is being modified for the new array. Bill has hired a post-doc to do the actual detector testing. He will be arriving in November.

FRACTION OF TASK COMPLETED	50%
FRACTION OF FUNDS COMMITTED	80%
ESTIMATED COMPLETION DATE	1/1/86

Pennsylvania State University (D. Weedman)

Dan has been developing a model for the extragalactic sky as seen by IRAS with the aim of developing an observing strategy for the IRS.

FRACTION OF TASK COMPLETED	80%
FRACTION OF FUNDS COMMITTED	90%
ESTIMATED COMPLETION DATE	1/1/86

Caltech (K. Matthews, B. T. Soifer, and D. Watson)

In the reporting period, progress has been made in several areas. Soifer, Matthews, and Watson attended the IRS science team meeting held in Ithaca at the end of May. Watson has built a detector test dewar, and has begun characterizing the performance of Ga:Ge detectors under SIRTf-like backgrounds. This work has been carried out with an undergraduate assistant. Watson and Matthews have begun discussions as to how to interfact an array of Ga:Ge detectors to the near-infrared array data acquisition system. Soifer spent August in Ithaca and discussed many SIRTf issues with Houck and Herter. Among these was the operations concept proposal drafted by Witteborne. Soifer assisted Herter and Houck in the selection of the data acquisition work station for Cornell for use in detector evaluation. Soifer has been working on deep surveys from IRAS, and will be the IRS representative on the Rieke committee to study the issue of a substantial time commitment for a deep survey with SIRTf.

FRACTION OF TASK COMPLETED	80%
FRACTION OF FUNDS COMMITTED	75%
ESTIMATED COMPLETION DATE	1/1/86

Cornell University (S. V. W. Beckwith, T. Herter, and J. R. Houck)

Cornell's responsibilities during the Pre-Phase B activities of the infrared spectrometer effort has been:

- 1) Overall project coordination and direction.
- 2) Preparation of reports and proposals to NASA Ames.
- 3) Leading meetings with spectrometer science team members to discuss ideas and strategies on relevant management, science, and technical topics.
- 4) Facility preparation for evaluation of mid-band (5-30 micron) detectors.
- 5) Preparation of Requests for Proposals (RFPs) to Ball Aerospace and Rockwell International.

1.0 MANAGEMENT ACTIVITIES

1.1 Revised Proposal

A revised proposal was submitted to Ames in August 1985. This included revisions due to the changed timeline of SIRTf activities, revisions to the originally submitted technical science proposal in accordance with suggestions by the SIRTf Science Working Group (SWG) and the IRS science team, and a study plan for Phase B activities.

A second draft of the revised proposal will be submitted to take into consideration the latest schedule for SIRTf activities as well as comments from the evaluation by NASA Ames.

1.2 Ball RFP

Ball Aerospace will be performing the design and construction of the spectrometer under the supervision of the science team. An RFP was drafted (15 August 85) and sent to NASA Ames for evaluation and approval. A copy of this RFP is enclosed as Appendix A.

We are currently awaiting detailed comment by NASA Ames (and a fixing of the SIRTf schedule) prior to releasing this RFP to Ball.

1.3 Rockwell RFP

A major task of the Predefinition Phase of SIRTf designated by the SWG is the technology evaluation effort. In accordance with the SWG and the detector subgroup, Cornell has been chartered to

study 5-30 micron-detector array technology. In conjunction with Craig McCreight of NASA Ames, Cornell released an RFP and has negotiated a contract with Rockwell International to evaluate Si:As Back-illuminated Blocked-impurity-Band (BIBIB) hybrid arrays. This subcontract starts approximately 1 October 85 and will run for two years. For details see Appendix B.

BIB PERFORMANCE PARAMETERS

Characteristic	SIRTF Goal	Rockwell Current Performance	BIBIB Hybrid Projected Performance
Operating Temp. (K)	2-10	4.3-12	
Phot. Back. (ph/sec/pix)	10-10 ⁴	10 ³ -10 ¹²	
Integration Time (s)	0.01-100	10 ⁻³ (10-12K)	
Node Capacitance (pf)	N.S.	0.4	0.2
Load Capacitance (pf)	N.S.	50	
Pixel Size (micr.)	100	125	100
Max. Power (mW)	<1	2 (10 ⁻³ s)	0.1 (10 ⁻² s)
Quant. Eff.	>0.3	0.2 (20 μ m)	>.4 (>10 μ m)
Photo-Elect. Gain	>0.5	0.5-10	
Read Noise (elec/read)	<100	260 (10 ⁻³ s)	100-150
Dark Current (elec/sec)	<100	300 (6K)	100 (6K)
Well Capacity (elec)	1. \times 10 ⁶	2.5 \times 10 ⁶	1.6 \times 10 ⁶
Uniformity (%)	5	6.5	2
Dead Pixels (%)	<10	16	<5
Cross-Talk (%)	<2	<1-2.5	<2

Notes:

- 1) Operating temperature selected for best performance.
- 2) A "dead" pixel is defined as an element which has less than a factor of 2 less response (or sensitivity) than average.

The array format is 10 \times 50 (500 elements), of which a complete row of 10 pixels (calling this a row or column is arbitrary) is read out at a time. The current mux design only does destructive reads and the whole array must be read, i.e., no individual pixels addressing. Rockwell saw no a priori reason why this could not be changed to nondestructive read (which was in their earlier mux design) and possibly even individual (at least individual row) addressability (although given nondestructive read capability the latter could be simulated).

1.4 Team Activities

Telecons to discuss IRS activities and current status are held on a regular basis every two to three weeks. These conversations:

- * Update all co-investigators on the activity of others (providing essentially a verbal progress report from each group of the IRS),
- * Discuss the current SIRTF schedule and its impact on IRS activities,
- * Discuss priorities and strategies for the IRS activities including management activities, instrument concepts, technology priorities, funding priorities, and content and status of RFPs and contracts.

Personnel:

J. Houck, with the aid of S. Beckwith and T. Herter (and submissions and comments by other science team members), prepared the revised proposal to Ames. Houck and Herter prepared both the Ball and Rockwell RFPs.

2.0 TECHNICAL ACTIVITIES

As discussed in Section 1.3 above, Cornell will be testing detector arrays for the 5 - 30-micron wavelength range of the spectrometer and has secured a contract with Rockwell International who will supply BIBIBs for evaluation. In preparation for this activity a test facility is being designed and constructed. The design of this system is based on the test requirements outlined by the detector subgroup of the SWG and involved numerous discussions with team members, other array test facilities, manufactures of detectors, and Craig McCreight of NASA Ames. The current state of this system is as follows:

- * The data acquisition and analysis computer system has been selected and the main components have been purchased. Data analysis software capable of operating on 2-d array data is being purchased and supplemental software is also being conceptually designed. We await the delivery of compilers before actual programming will start.
- * The test dewar is in the final stages of machining and should be ready in approximately four to six weeks.
- * Initial testing of the level shifters required for the clocks has been performed.
- * The clock drive circuitry is presently being selected. We are awaiting results of tests in McCreight's lab before final selection is made.

- * An A/D board from Burr-Brown which integrates into the data computer has arrived.

Rockwell is providing us with a partially working (approximately half detector elements are "dead") BIBIB array to "smoke test" (debug) our evaluation system. We expect delivery of this device within one to two months. The testing facility will be operational in two to three months. Testing will proceed over the next two years.

Personnel:

Responsibility for the development of detector testing facility is assumed by T. Herter, with the aid of S. Beckwith and J. Houck. Beckwith will work closely with Herter carrying out detector testing at Cornell when the test facilities become available. A hardware/software computer technician, Chuck Fuller, has been hired to help with the design, fabrication, and implementation of the data acquisition and analysis system. Dewar design and fabrication, construction of the front-end analog electronics, and integration of the detector into the system are the responsibility of George Gull.

Data Acquisition and Analysis System:

FRACTION OF TASK COMPLETED	40%
FRACTION OF FUNDS COMMITTED	70%
FRACTION OF COMPLETION DATE	1/1/86

APPENDIX A

IRS-20-002
Rev. B

REQUEST FOR PROPOSAL
FOR THE DEFINITION PHASE
OF AN
INFRARED SPECTROMETER FOR SIRTf

August 15, 1985

ISSUED BY:

CORNELL UNIVERSITY
Astronomy Department
Space Science Building
Ithaca, NY 14853

SIRTF INFRARED SPECTROMETER

REQUEST FOR PROPOSAL
FOR DEFINITION PHASE

TABLE OF CONTENTS

SECTION	PAGE
1. General Information	1
1.1 Purpose	
1.2 Proposals	
2. Engineering and Design Requirements	2
2.1 General Requirements	
2.2 Design Requirements	
3. Fabrication Plans	2
4. Reliability and Quality Assurance	3
5. Program Management.	3
6. Reporting	3
7. Design Phase Procurement Schedule	3
8. Proposal Evaluation Criteria.	4
9. Proposal Contents	4
9.1 Engineering and Design Approach	
9.2 Plans for Fabrication	
9.3 Plans for Reliability and Quality Assurance	
9.4 Plans for Testing	
9.5 Management Plan	
9.6 Relevant Experience	
9.7 Applicable Facilities	
9.8 Cost Estimate	
9.9 Schedules	
9.10 Key Personnel	
9.11 Contract	
9.12 Exceptions	
10. Applicable Documents	7
11. Other Contractual Provisions	8

SECTION 1

GENERAL INFORMATION

1.1 PURPOSE

Cornell University requests your proposal for the concept definition and conceptual design of an Infrared Spectrometer (IRS) for SIRTf, NASA's Space Infrared Telescope Facility. The instrument has been conceived and a preliminary design study conducted by a team organized by Prof. James R. Houck. This team has been selected by NASA to complete a detailed conceptual design and to produce an instrument implementation plan. It is expected that the IRS team will then be given approval to proceed with final development and operation in space of the planned instrument.

This solicitation is for proposals to apply high-quality space-oriented engineering expertise to the study, trade-off analysis, and conceptual design of an instrument meeting the needs of the scientific team and following the concepts set forth in "An Infrared Spectrometer on SIRTf" (IRS-1-001, enclosed herewith).

1.2 PROPOSALS

To be considered, proposals must be received before 2:00 p.m. EST on September 24, 1985. They are to be sent to the address shown below, with a notation on the outside wrapper that they are "IRS Proposals."

Elizabeth M. Bilson, Executive Officer
Center for Radiophysics and Space Research
Cornell University
Ithaca, NY 14853-0355

It is the express desire of the IRS program to minimize costs. To this end, it is requested that proposals be brief, simply produced, and avoid costly features such as color, elaborate bindings, and unnecessary material, except in those cases where their addition is critical to the communication of information needed in the evaluation.

Proposals shall be in two volumes, one dealing with technical, engineering and programmatic matters, the other providing cost data. Proposed schedules shall be included in both volumes to facilitate the reviews.

Fifteen copies of each volume are required. The cost proposals should be separately packaged from the technical proposals, and each package identified as to contents.

Questions concerning the bidding process, contractual requirements, or other non-technical or non-engineering issues should be directed to:

Mr. Peter Curtiss (607) 256-5014

Questions of an engineering or scientific nature should be addressed to team scientists:

James R. Houck (607) 256-4806 or
Terry L. Herter "

SECTION 2

ENGINEERING AND DESIGN REQUIREMENTS

2.1 GENERAL REQUIREMENTS

The concept for the Infrared Spectrometer has been established by the IRS team. It is described in "An Infrared Spectrometer on SIRTf" (IRS-1-001). This document contains the scientific goals of the IRS team and defines at least one approach to the instrumentation necessary to achieve those goals. Other approaches may be possible and should be considered, but their advantages over those proposed by the team must be well established to be accepted. The instrument design finally adopted must be capable of supporting the scientific goals put forth in the IRS document and those of SIRTf. A preliminary Statement of Work (IRS-20-003) for the instrument development subcontractor is included as a part of this request for proposal package.

2.2 DESIGN REQUIREMENTS

To be accepted for development, the IRS must meet all the design requirements of the SIRTf program. Some of these have yet to be fully defined. First-quality aerospace design principles must be invoked. Mitigating against the the highest possible reliability is the limited budget that must be assumed, so extreme demands will be placed upon the designers to produce a cost-effective, reliable system.

Design boundary conditions are:

1. Compatibility with the interfaces dictated by the SIRTf program. These include mechanical, electrical, and thermal considerations.
2. Science requirements for accuracy, sensitivity, precision, and repeatability of data measurements produced by the IRS system in the specified SIRTf environment.
3. Cost limitations imposed by the SIRTf program.
4. Schedule limitations imposed by the SIRTf program.

SECTION 3

FABRICATION PLANS

A major output of the definition phase will be an Experiment Implementation Plan, which will be used in part to guide the instrument development subcontractor in building the instrument housing, optical bench structure, optics, electronics, assembling the system, and testing and integrating the system to SIRTf. Some of the subsystems will be delivered by team members, who are currently developing the necessary technology in such areas as stressed detectors and arrays. Ongoing work in these areas is described in document IRS-1-001. The implementation plan must establish a system for coordinating these efforts. Responders should indicate ability to develop and apply plans for such collaborative efforts.

SECTION 4

RELIABILITY AND QUALITY ASSURANCE

Reliability and quality assurance programs must be proposed to meet the requirements of NASA and SIRTf instruments. Existing programs are to be used wherever possible and appropriate.

SECTION 5

PROGRAM MANAGEMENT

The instrument definition subcontractor will be expected to establish an efficient management relationship with the IRS Program Office in Ithaca. Management costs shall be minimized without risking programmatic breakdowns due to insufficient management oversight.

SECTION 6

REPORTING

Monthly cost reports are required. Cost data shall be reported on Form 533M and Form 5330, or an alternative proposal will be considered. In addition, progress will be reviewed in accordance with Section 4.2 of the Statement of Work (IRS-20-003).

SECTION 7

DESIGN STUDY PROCUREMENT SCHEDULE

RFP Release	August 15, 1985
Proposal Due at Cornell University	2:00 p.m. EDT, Sept. 14, 1985
Subcontractor Selection	Oct. 24, 1985
Subcontract Award	Upon award of NASA Contract to Cornell University
Design Phase Completed	NASA Contract start date, plus 24 months

An overall project schedule for SIRTf is included as Figure 1; a more detailed schedule of the definition phase is shown in Figure 2 of the Statement of Work, IRS-20-003. It is anticipated that NASA will schedule periodic reviews that must be supported by the IRS team and its instrument definition subcontractor. Bidders shall assume that four formal reviews will be held at Ames Research Center during the course of the contract, as listed in Section 4.2.2 of the Statement of Work.

SECTION 8

PROPOSAL EVALUATION CRITERIA

Criteria for selection of the instrument definition subcontractor include: 1) responsiveness to this RFP; 2) experience and performance in the design and development of spaceborne instrumentation (especially infrared and cryogenic systems); 3) proven ability to work with and respond to university personnel; 4) cost and schedule performance on previous instrument development programs; 5) availability of key personnel and facilities; 6) understanding of the goals and requirements of the IRS and SIRTf programs; 7) reasonableness and realism of the proposed costs; 8) independently funded internal company efforts that will assist in the IRS definition at reduced cost to the program; 9) geographical proximity to the Project Office and other team members; and 10) potential benefits to SIRTf.

Although this solicitation is for instrument definition only, the IRS team recognizes the desirability of maintaining continuity between definition and development. Therefore, selection criteria will include the ability of the subcontractor to support the continuing development and implementation of the instrument and its integration into SIRTf. Should it be deemed to be in the best interests of the IRS program, Cornell retains the option to select the definition phase subcontractor for all or part of competition.

SECTION 9

PROPOSAL CONTENTS

This section described the minimum contents required of proposals presented in response to this solicitation. Additional material may be included if it is directly applicable to the proposed IRS program. However, brevity and cost effectiveness are desired by IRS Program Office. Please note that the contents of proposals need not be the order listed below, as long as all required material is included.

9.1 ENGINEERING AND DESIGN APPROACH

Describe briefly how the requirements of the IRS science will be met within the framework of the instrument described in "An Infrared Spectrometer on SIRTf" (IRS-1-001). Alternative design approaches may be proposed if they hold promise of real improvement in the performance of the instrument, in cost effectiveness, in economy of spacecraft resources, or in other significant factors. A major design effort for the proposal is neither required nor desired; emphasis should be on the approach that will be taken to solve any anticipated design problems.

9.2 PLANS FOR FABRICATION

Indicate applicable process control procedures and describe how the company shall ensure that the final product conforms to the approved designs.

Note that various subsystems (detector arrays, for example) will be produced and delivered by members of the IRS team. Proposers should describe how they plan to accommodate this decentralization and how testing will be conducted to avoid confusion of responsibility.

Experience in fabrication of cryogenic systems is critical to the effective design of new cryogenic systems. Proposers should indicate experience, facilities, and other capabilities that attest to their ability to produce and test functional cryogenic hardware.

9.3 PLANS FOR RELIABILITY AND QUALITY ASSURANCE

Proposal shall contain a description of reliability and quality control programs that would be applicable to the IRS design and development. If such programs have been successfully applied to other space programs, these should be cited.

9.4 PLANS FOR TESTING

The testing of large cryogenic instruments for low-background infrared detection poses substantial technical difficulties. The proposer shall specifically address the problems associated with evaluating detector and other critical components as they would be received from suppliers, with obtaining and verifying alignment of cryogenic optics, and with full system testing and qualification.

9.5 MANAGEMENT PLAN

The successful proposer will have demonstrated in his proposal an understanding of good management practice, cost consciousness, and effective university relations.

9.6 RELEVANT EXPERIENCE

Describe recent company experience in the design, fabrication, and support of space experiment equipment, especially experience on programs in which the company was a subcontractor to a university. Also of relevance are cryogenic experience and electro-optical expertise. Describe any proprietary or previously used electronics techniques or designs that might be applicable to the IRS program, especially if their use would reduce design efforts and cost.

9.7 APPLICABLE FACILITIES

Describe the facilities necessary to complete successfully the proposed IRS definition and development, with emphasis on any that are unique to the company or that are sufficiently unusual that they would make the company particularly attractive to the IRS program. Distinguish among facilities that are: 1) at the prime subcontract plant; 2) elsewhere within the company; 3) available from other companies; 4) available through the government; and 5) needed for the IRS definition or development but not yet available. Include test and calibration facilities as well as manufacturing or other facilities.

Discuss the possibilities for cost reductions using existing government-furnished facilities available to the company. Indicate, in the case of any facility necessary for the program but not available to the company, the advantages and disadvantages of renting or leasing as opposed to purchasing.

9.8 COST PROPOSAL

Some of the most critical elements of the instrument will be defined in studies by members of the instrument team at their home institutions. Costs for the definition phase subcontractor must reflect the frugality imposed on the entire SIRTf program by the limited funding and the necessity for fundamental work to define key instrument elements by IRS team members. The level of funding available for the definition phase is not known accurately. For the purpose of evaluation of responses to this RFP, it shall be assumed that no more than \$350,000 is available to support all definition subcontractor activities.

The cost proposal shall provide detailed estimates of the total cost for the effort to be accomplished during the definition phase by the definition phase subcontractor. The cost proposal shall be submitted with Form SF1411, Contract Pricing Proposal Cover Sheet, or equivalent, and prepared in accordance with the attachment to the SF1411, Table 15.3, Instructions for Submission of the Contract Pricing Proposal. Each cost element shall identify the individual tasks from Section 3.2.2 of the Statement of Work (IRS-20-003) which are included in that cost element. The cost proposal must include the following elements as a minimum:

- a. Total cost by year.
- b. Fee or profit. (Note that the University intends to withhold an appropriate percentage of cost, pending successful completion of the subcontract.)
- c. Annual costs broken down into appropriate categories, including but not limited to: labor (by class), supplies and materials, travel, computing, other direct costs, labor burden(s), indirect costs, unusual costs including major subcontracts or consulting fees.
- d. Hourly rates for all labor classes applied to the program.
- e. Monthly costs for the first year, and quarterly costs for the second year of the program, broken down as in item "c."

All costs and rates are to be expressed in 1985 dollars. Any rates that are known to be changing during the period of performance should be identified along with the date(s) of anticipated change(s) and the new rate(s).

A certificate of current pricing will be required upon completion of pre-award negotiation.

Proposals shall include data on actual costs versus estimated costs for nonmilitary, space-rated equipment delivered by the company in the past four years.

9.9 SCHEDULES

Proposers shall submit a schedule of milestones, including design and progress reviews, in keeping with the proposers plan of work and consistent with the overall schedules in Section 7 of this RFP and Section 2 of IRS-20-003.

Schedule slippages may occur for reasons beyond the control of the IRS team and the instrument development subcontractor. Proposers should show how they plan to minimize the impact of such slippages. In particular, proposers shall address the effect on their proposed effort of a slip in the contract starting date for the definition study.

Any anticipated difficulties in meeting the required schedule should be specifically stated, along with possible tradeoffs that would keep schedule. Alternative schedules that would reduce cost are desired, must be explained in detail, and should include an estimate of the potential cost reduction.

9.10 KEY PERSONNEL

List the key personnel proposed for the design phase effort, together with the qualifications of each to a sufficient depth to enable a proper evaluation by the proposal evaluation team. The University reserves the right to approve or disapprove any reduction in the effort of key personnel (resignations, retirements, and disability excepted) or any substitutions of key personnel.

9.11 CONTRACT

It is anticipated that the contract between NASA and the University will be a cost-reimbursement research and development contract at no fee. The nature of the IRS program is such that a fixed price, no fee contract should be attractive to both the University and the instrument definition subcontractor. The University will entertain proposals for other types of contracts.

9.12 EXCEPTIONS

Proposers should state that their proposals are fully responsive to this RFP, or should provide a list of specific exceptions. Exceptions will be considered by the review team, and will not automatically disqualify a proposer.

SECTION 10

APPLICABLE DOCUMENTS

Reference No.	Title
IRS-1-001	"An Infrared Spectrometer on SIRT Cornell University

IRS-20-003

Statement of Work for Definition Study of IRS
August 15, 1985
Cornell University

The following listed documents are suggested as reference material:

AO No. OSSA-1-83	Shuttle Infrared Telescope Facility (SIRTF) May 13, 1983 Amendment, September 12, 1983
PD-1006	SIRTF Free Flyer Phase A System Concept Description May 3, 1984 NASA-Ames Research Center
NHB 5300.4(1A)	Reliability Program Provisions for Aeronautical and Space System Contractors April 1970 NASA
NHB 5300.4(1B)	Quality Program Provisions for Aeronautical and Space System Contractors April 1969 NASA

SECTION 11

OTHER CONTRACTUAL PROVISIONS

General contractual requirements that will be imposed upon the University by NASA will, in turn, be applicable to the definition phase subcontractor. These will include (but not be limited to):

- a) Invoicing and payments
- b) Approval for presentation and publication of scientific and technical papers and reports
- c) Audits
- d) Final payment
- e) Alterations in contract
- f) Royalty information
- g) Certified cost or pricing data
- h) NASA financial management reporting
- i) Rights of the government
- j) Small business and small disadvantaged business subcontracting plan (Said plans are to be submitted with the offerer's proposal)
- k) Pre-award, on-site equal opportunity compliance
- l) Government-furnished property
- m) Rated or authorized controlled material orders
- n) Contracting Officer's authority
- o) Contracts between NASA and former NASA employees

Further, upon entering into final negotiations with any bidder(s), the following standard Representations, Certifications, and Other Statements will be invoked:

- a) Contracts between NASA and former NASA employees

- b) Small business concern representation
- c) Small disadvantaged business concern representation
- d) Women-owned small business representation
- e) Certification of non-segregated facilities
- f) Previous contracts and compliance reports
- g) Affirmative action compliance
- h) Buy American certificate
- i) Percent foreign content
- j) Contingent fee representation and agreement
- k) Type of business organization
- l) Authorized negotiators
- m) Clean air and water certification
- n) Cost accounting standards notices and certification
- o) Place of performance
- p) Insurance -- immunity from tort liability

(End of Request for Proposal)

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3

Astronomy Department
Cornell University
Ithaca, New York 14853

**STATEMENT OF WORK FOR THE DEFINITION STUDY OF
AN INFRARED SPECTROMETER FOR SIRTf**

April 12, 1985

**SECTION 1
SCOPE**

1.1 GENERAL

The Space Infrared Telescope Facility (SIRTf) is NASA's next major infrared space project. The instruments selected for the focal plane are a high-spatial resolution photometer, a wide field camera, and a spectrometer. James R. Houck of Cornell University heads the science team that is responsible for the construction of the Infrared Spectrometer (IRS). This instrument will operate from 2.5 to 200 microns and be capable of both a low-resolution ($R = 50$ from 2.5 to 120 microns) and a higher resolution ($R = 1000$ from 4 to 120 microns and $R = 500$ from 120 to 200 microns), allowing a wide range of scientific problems to be investigated.

1.2 EXPERIMENT OBJECTIVES

The IRS is intended to be a general-purpose instrument for SIRTf. It is to provide reliable and calibrated measurements and achieve the natural background limits when operating in the low-resolution mode.

**SECTION 2
PROGRAM PHASING**

The design of the IRS will be conducted in a number of phases as defined in the following sections. Figure 1 shows the phasing of various elements of the SIRTf project, assuming a start of the final design and development phase in FY 1989. Figure 2 shows the period previous to FY 89 in greater detail, with emphasis on concept definition and conceptual design of the focal plane instruments.

2.1 PRE-DEFINITION PERIOD

The IRS team is currently working to identify and develop key technologies for the instrument.

2.2 DEFINITION (CONCEPT DEFINITION PLUS CONCEPTUAL DESIGN) PHASE

The definition phase is to last for 24 months and is expected to begin on October 1, 1985. It is divided into two parts: a concept definition period and a conceptual design period.

2.2.1 CONCEPT DEFINITION PERIOD

During the first 11 months, which will comprise the concept definition period, the definition subcontractor and the IRS team shall demonstrate all relevant technologies for the success of the instrument and shall evolve a feasible design. The subcontractor shall emphasize requirements analysis and tradeoff studies of the conceptual designs and systems level cost/performance drivers. At the end of this phase, there shall be an Instrument Concept definition Review (ICDR).

2.2.2 CONCEPTUAL DESIGN PERIOD

Following the concept definition period, efforts shall be focused to optimize the conceptual design by concentrating on depth of analysis rather than evaluation of alternatives as was done in the concept definition period. This conceptual design period will last 13 months. The subcontractor shall emphasize generation of cost-effective designs, detailing interfaces and specifications, and developing detailed and definitive plans and cost estimates for the design, development, and operations phases of the program that are to follow. At the end of this period there shall be an Instrument Final Review of Conceptual Design, (IFRCD), and a submittal to NASA of a proposal for instrument design, development, and implementation.

2.3 POST-DEFINITION PERIOD

The IRS team will continue to study the instrument concept following the definition phase and preceding the start of the design and development phase. Two kinds of effort are anticipated: a) the facility definition study will begin during the instrument definition and continue thereafter; instrument refinements may be suggested or required as the facility design matures; b) a variety of instrument improvements may be possible without interference with the basic design; examples include substitution of an improved detector material, and refinement of data analysis software.

SECTION 3 STUDY TASKS SUMMARY

3.1 IRS TEAM TASKS

Although not a part of the Statement of Work for the definition subcontractor, for clarity it is important to understand the tasks in the definition phase for which the IRS team will continue to assume total responsibility versus the tasks for which the IRS team and the definition subcontractor will share responsibility.

3.1.1 The IRS team will discharge the responsibility to attend and respond to Science Working Group (SWG) meetings, except that it may on occasion be desirable to have a representative of the definition subcontractor present to expedite the flow of technical information.

3.1.2 The IRS team will generate, maintain, and update the Experiment Implementation Plan, the Work Breakdown Structure (WBS) and WBS Dictionary, the Experiment Implementation Cost Estimates Document, and the Conceptual Design

Document. Significant definition subcontractor input to these plans will be required, including detailed cost estimates, especially with regard to ground support equipment (GSE), data formats and rates, etc. The Experiment Implementation Plan will contain detailed plans for all elements of the investigation, including such topics as project management (including schedules, facility requirements, work breakdown structures, responsibilities and delegations, risk assessment covering technical, schedule, and cost risks, configuration management, etc.), system engineering, produce assurance (including reliability, quality assurance, testing, and safety), design and development, manufacturing, verification, integration and launch operations, and mission planning operations. The Conceptual Design Document will cover all hardware and software including the ground system required to support instrument operations at the vehicle and payload operations control centers; it will contain layout and preliminary design drawings, preliminary procurement specifications for extremely long lead time items, a preliminary hazard analysis, payload mass properties, instrument performance data, a preliminary instrumentation list (showing hardware functions, estimated data rates, number of wires, types of cable, etc. required for commands, housekeeping data, caution and warning signals, etc.), a master equipment list for all subsystems, a spares requirements list depicting the needs for normal instrument development, a technical risk assessment, an alignment plan, a contamination analysis, and a specification of the design and performance requirements for the end item.

3.1.3 The technology for the infrared detectors and the first stages of the cryogenic readout electronics will be developed by the team. The division of the electronics between the team's responsibilities and those of the definition subcontractor will be estimated according to the experience and expertise of the subcontractor; in any case, the subcontractor will be responsible for the design of the warm, or ambient temperature electronics. The definition subcontractor's involvement in the detector technology will depend upon his experience and expertise.

3.2 DEFINITION SUBCONTRACTOR'S TASKS

Tasks required as part of this Statement of Work are described below. Cost is to be a parameter in all tradeoff considerations. The instrument description in "An Infrared Spectrometer on SIRTf", IRS-1-001, is to be used as the instrument technical baseline starting point of this study. (That document is based upon the proposal submitted by the IRS team in response to NASA's Announcement of Opportunity, AO No. OSSA-1-83.)

3.2.1 Tasks During the Pre-Definition Phase

The definition subcontractor will not be under contract in time to significantly contribute to the Pre-Definition Phase.

3.2.2 Tasks during the Definition Phase

The tasks to be performed by the definition phase subcontractor shall include, but not be limited to the following:

a) Assist in the analysis of the tradeoff studies between the various designs and technical approaches for the instrument system and subsystem elements, including ground support equipment (GSE), to achieve the scientific performance, reliability, and cost objectives.

b) Assist in analysis, breadboard tests, and field trials as necessary to demonstrate concept feasibility.

c) Assist in determining the achievable performance parameters and limitations for the instrument and the design values and tolerances of the major elements, including weight and power margins.

d) Assist in determining and maintaining compliance with evolving interfaces between the IRS instrument and the telescope facility, and between the IRS instrument and its GSE.

e) Assist in updating and maintaining the SIRTf Infrared Spectrometer (IRS) Performance and Related Requirements (STF-815) document.

f) Assist in the preparation of conceptual design drawings, performance specifications, and design criteria for the instrument, including configuration drawings, interface drawings, and flow drawings.

g) Assist in the preparation of descriptions of high risk and long lead-time-procured items and areas which are performance, cost, and schedule critical. For those areas identified as critical, assist in the evaluation of alternate means of satisfying the requirements.

h) Assist in the preparation and documentation of the reviews called for in Section 4.2.2 of this Statement of Work.

i) (Not applicable.)

j) (Not applicable.)

k) Assist in the preparation of a conceptual design for the instrument, including recommendations for specific components and their configuration in critical areas, calibration and monitoring devices, and mounting and shielding arrangements.

l) Assist in the identification of any critical or unique materials or processes required for hardware fabrication.

m) Assist in the estimation of instrument design weight, volume, shape, and center of gravity for both the warm electronics assembly and the cryogenic assembly.

n) Assist in the definition of environmental control methods and resultant temperature ranges.

o) Assist in the definition of instrument power requirements and generation of a warm electronics assembly power profile and cryogenic assembly power dissipation profile.

p) Assist in the definition of instrument housekeeping measurement requirements.

q) Assist in defining requirements for GSE and associated software that will simulate the instrument and monitor the performance under simulated

flight operational conditions in ground tests.

r) (Not applicable.)

s) Assist in the evaluation of radiation effects on the performance of the IRS instrument.

t) Prepare required documentation including (but not limited to) monthly progress reports, monthly and quarterly progress reports, summaries of the results of the required studies and analyses, design drawings, specifications and related documentation, and materials for reviews scheduled by NASA.

u) Participate in and document the Instrument Final Review of Conceptual Design before the end of the definition phase. The documentation will include a conceptual design, results of analyses and tests, and plans for experiment implementation suitable for review by outside, independent engineering specialists or consultants and NASA.

v) Prepare a Failure Mode, Effects, and Criticality Analysis (FMECA) for the entire IRS instrument.

w) Assist in the preparation of a proposal, including cost, to NASA for the design and development phase.

x) Assist in defining the details of mission operations and the data reduction and analysis efforts.

3.3.3 DETAILED TASK OUTLINE

The subcontractor shall provide analyses and consultation relating to the optical, mechanical, cryogenic and electronics design of the spectrometer. This work shall be performed in conjunction with the under the supervision of the IRS science team. Particular attention shall be given to (1) the instrument requirements for meeting the science goals and the impact of these requirements on instrument design, (2) instrument simplification (for example, reducing detector array count, reducing number of moving parts, and raising tolerances) to increase reliability, lifetime, and reduce cost, and (3) accurate cost estimation for Phase C/D. With cryogen replenishment, SIRTf is expected to operate for ten to fifteen years so that instrument lifetime and reliability are key issues.

Below we outline the tasks Ball shall perform during the IRS Phase B. The tasks are categorized under the Concept Definition and Concept Refinement periods of Phase B:

3.3.3.1 CONCEPT DEFINITION

a) Study the impact on design and cost of proposed extension of wavelength coverage down to 2.5 microns, i.e., the addition of a 2.5- to 4-micron low resolution ($R = 50$) spectrometer.

b) Study how an image rotator can be included in the spectrometer design so that the appearance of the entrance slit on the sky can be rotated (in lieu of SIRTf not being capable of roll about the line of sight).

c) Consider how the resolution from 4 to 120 microns might be increased from 1000 to 2000, and how the resolution of the long wavelength channel (120 to 200 microns) can be increased to approximately 1000. Particular attention should be given to impacts on design cost.

d) For wavelengths less than 30 microns, study ways to simplify the spectrometer design and decrease cost by reducing the number of detectors arrays, reducing the number of mechanisms and/or taking advantage of echelle designs in which an additional grating (or prism) is used to cross-disperse the echelle orders.

e) Assemble a catalog of optical materials and their properties at helium temperatures to aid in the selection of prism and filter materials.

f) Assess how onboard operation requirements of the spectrometer impact on the electronics design and cost.

g) Define the candidate approach for a high-accuracy, low-power dissipation cryogenic grating drive. Functional requirements shall be determined, including angular resolution, control system bandwidth, lifetime and duty cycle. A review of potential mechanisms and encoders shall be carried out to identify the candidate approach. Tradeoff considerations for the selection of an encoder approach will include resolution, complexity, risk, power dissipation, failure modes and cost. Similar tradeoff studies shall be conducted for the bearing and motor actuator.

3.3.3.2 CONCEPT REFINEMENT

a) Build a device which demonstrates the performance of the candidate approach for the grating drive system identified in task (g) above. The demonstration unit will include the encoder and actuator mounted on a shaft using the candidate bearings, all operated at 7K, with warm control system electronics and appropriate software. The demonstration unit will be evaluated for performance parameters including thermal cycling and a thorough inspection of the demonstration unit after some (TBD) hours of operation.

b) Perform a detailed evaluation of the selected optical configuration. This will include geometrical spot diagrams, scalar diffraction analysis and stray light analysis. In addition, the appropriate operating temperatures will be determined for all elements including the baffles. A complete tolerance analysis will be conducted to serve as an input for the mechanical design.

c) Perform mechanical designs to determine the dimensions and weights of major mechanical, optical and electronics components. These shall then be arranged within the MIC envelope and layout drawings shall be made. Attention shall be given to issues such as strength of the structure, ease of fabrication and assembly, and access for alignment and testing. Appropriate materials shall be identified. A preliminary structural model shall be evaluated using the NASTRAN computer code. Ball shall work with NASA through the science team to identify major IRS/MIC mechanical interfaces. Long lead procurement items shall be identified.

d) Study the operating thermal requirements of the IRS including the detector temperatures, temperature limits set by thermal emission of optical elements and baffles, and operating temperature ranges of the mechanisms. The capabilities of SIRTIF MIC cooling stations shall be evaluated. A thermal design concept which assures thermal performance in all operating modes shall be developed and evaluated using the SINDA computer code.

e) Assess cryogenic properties of all candidate materials and components. Optical performance of refractive elements need to be specified at the operating temperature, and the mechanical properties of the optical materials at low temperatures need to be understood. Structural materials need to be chosen, based on their properties at less than 10K.

f) Cold electronics performance requirements such as noise levels and dynamic range shall be set. Detector readout schemes shall be incorporated into the cold electronics concept. This electronics shall include a cryogenic module for signal conditioning and detector clocking, and ambient electronics for detector drive, signal conditioning and system control. The end result shall be a schematic and preliminary parts list suitable for failure mode analysis and determination of parts procurement/screening requirements.

g) Examine the IRS requirements for telescope beam positioning, focus location, stray light rejection, and optical calibration outside of the internal stimulators of the instrument. A detailed list of tolerances for these quantities shall be generated.

h) Make accurate estimates of the mass, moments, and center of gravity of the IRS. The study will be conducted in enough detail so that we will be able to specify the attachment points for the IRS in the MIC. The study will also estimate the torques and forces generated by the movements of the aperture/filter wheels and the grating/mirror actuators.

i) Estimate the electrical power, voltage, current, and stability requirements for both the warm and cold electronics of the IRS. In addition, the maximum EMI acceptable for proper spectrometer performance shall be estimated along with the EMI that will be generated by the instrument itself during operation. The number and types of electrical wires that will be needed shall also be determined.

j) Accurate estimates will be made of the thermal power generated by the IRS at the different temperature heat sinks in both the operational and standby modes. The maximum sink-temperature variations that could be tolerated by the instrument will also be detailed. Since these issues are a strong driver for the cryogenic performance of the facility, they will be addressed as soon as possible during the study.

k) Provide aid to the science team in assessing the instrument data requirements in terms of rate and format. This will be done for both uplinks of commands to the instrument and downlinks of the data.

l) In parallel with the other activities during the Concept Refinement period, Ball shall provide informatin detailing the cost to complete Phase C/D. These costs will include the following activities which will be costed individually:

- * Detailed Design of the Flight Instrument
- * Component- and subsystem-level testing to verify the design as required
- * Fabrication of the Flight Instrument and spares
- * Design and fabrication of shipping containers
- * System-level, low-background testing to certify the important performance characteristics that cannot be determined by component or subsystem-level testing
- * Support of critical design and performance reviews
- * Supply of three complete sets of all drawings, major design calculations, and assemble and test procedures
- * Design and Fabrication of the Ground Support Equipment (GSE) including a GSE computer and its peripherals and all associated equipment (cables, connector savers, manuals, drawings, schematic diagrams, test procedures, and shipping containers)
- * The integration costs will be determined if sufficient detail is available from NASA of the integration requirements

SECTION 4 STUDY MANAGEMENT

4.1 STUDY PLAN

The Study Plan prepared by the IRS team (see Section 3.2.1) and negotiated with NASA will govern the conduct of the definition phase effort.

4.2 REVIEWS

The subcontractor will be reviewed periodically by both the IRS team and NASA to assess progress in all aspects of the project and to ensure optimum exchange of information.

4.2.1 Informal Reviews

The IRS team will review the subcontractor's progress informally at least once per month. Reviews will be conducted on the fifth working day of each month to synchronize the flow of information with NASA's anticipated reporting requirements. So far as possible these reviews will be conducted at the subcontractor's location, but to reduce travel costs, reviews by conference call may be substituted as appropriate. Additional informal reviews and discussions will be held as needed.

Prior to each monthly review, the subcontractor will be expected to deliver to the IRS Program Office written reports of technical progress and costs which will serve as the foundation documents for that review.

4.2.2 Formal Reviews

It is anticipated that NASA will require four formal reviews during the two years of the definition phase. The subcontractor will be expected to prepare in collaboration with the the IRS team the necessary materials for presentation at each review and the required documentation related to each review. These materials are described in part in Section 3.2.2. The final version of this Statement of Work will contain a complete exposition of required documents and anticipated due dates. It is anticipated that the four formal reviews held by NASA will be structured as shown in the following sections.

4.2.2.1 Instrument Requirements Review (IRR)

Objectives:

- a) Review mission and telescope facility performance requirements as they relate to the IRS instrument
- b) Review instrument performance requirements
- c) Review telescope facility/instrument interface requirements
- d) Review technology development progress and status
- e) Identify and resolve any ambiguous or conflicting requirements
- f) Identify areas in which analyses and tradeoff studies should be initiated
- g) Review the progress of the IRS program to date.

This review is expected to be held four months after the start of the definition phase.

4.2.2.2 Instrument Concept Definition Review (ICDR)

Objectives:

- a) Review the results of the IRS concept definition analyses and tradeoff studies
- b) Review and assess the technical adequacy of the IRS design concept
- c) Review risk assessments
- d) Review identificatin of and procurement planning for long lead time items
- e) Review technology development, progress, and status, including the results of technology tradeoffs
- f) Review the progress of the IRS instrument program to date

This review is expected to be held at the end of the concept definition period, 11 months after the start of the definition phase.

4.2.2.3 Instrument Interim Review of Conceptual Design (IIRCD)

Objectives:

- a) Review the baseline IRS conceptual design and principal options
- b) Review hardware and software design concept of IRS subsystems
- c) Review systems and subsystem performance capability provided by the instrument conceptual design

- d) Review interface definition description
- e) Review system operability, testability, and refurbishability provided by the conceptual design
- f) Review technology development progress, status, and readiness
- g) Review development risk areas and techniques for minimizing risks
- h) Review the preliminary version of the Experiment Implementation Plan
- i) Review the Project Risk Assessment Plan, which is part of the Experiment Implementation Plan
- j) Review conceptual design progress to date, problem areas, and action items remaining to complete the design phase in accordance with the Study plan.

This review is expected to be conducted 18 months after the start of the definition phase.

4.2.2.4 Instrument Final Review of Conceptual Design (IFRCD)

Objectives:

- a) Describe and review updates to the instrument conceptual design and instrument performance characteristics
- b) Describe and review updates to the hardware and software design of instrument subsystems and their performance characteristics
- c) Describe and review instrument interface definitions
- d) Review of system and subsystem operability, testability, and refurbishability characteristics
- e) Describe and review changes to the Experiment Implementation Plan
- f) Review technology development progress, status, and readiness assessment
- g) Identify areas requiring further study prior to initiating the Design and Development Phase.

This review is expected to be held about 23 months after the start of the definition phase, which is one month before completion of the definition phase.

SECTION 5 EQUIPMENT, FACILITIES, AND SERVICES TO BE SUPPLIED BY NASA

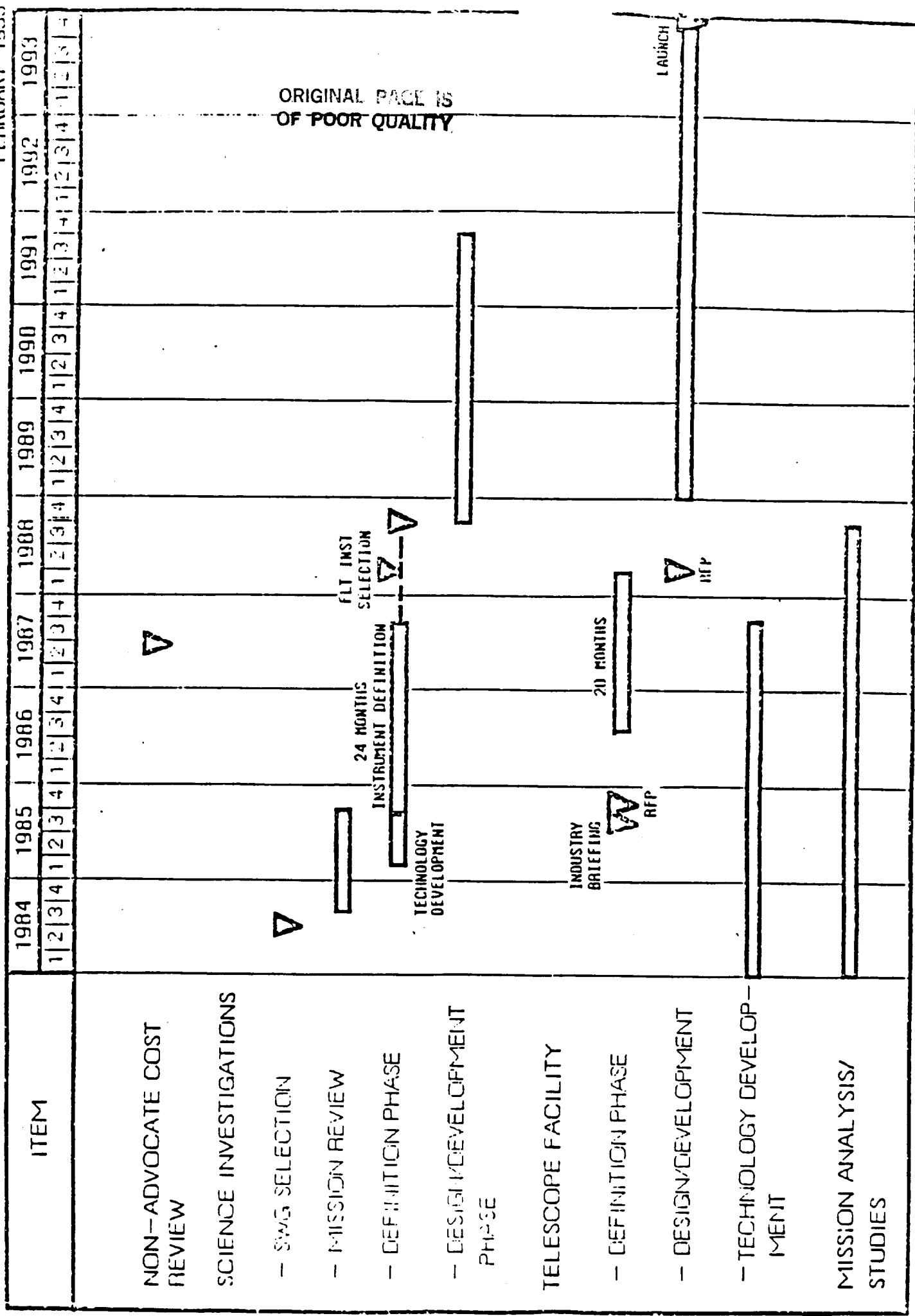
The SIRTf Project (NASA) will provide and be responsible for the following functions and documentation:

- a) Planning and coordinating the mission, development of telescope facility systems, integration of science instruments, systems-level testing, and launch and flight operations.
- b) Appropriate specifications and guidelines to all contractors to govern telescope facility/science instrument interface definition, design, development, integration and test requirements, launch and flight operations, and data analysis.

(End of Statement of Work)

CURRENT OVERALL SIRTIF PROG M SCHEDULE - FY89 START

FEBRUARY 1985

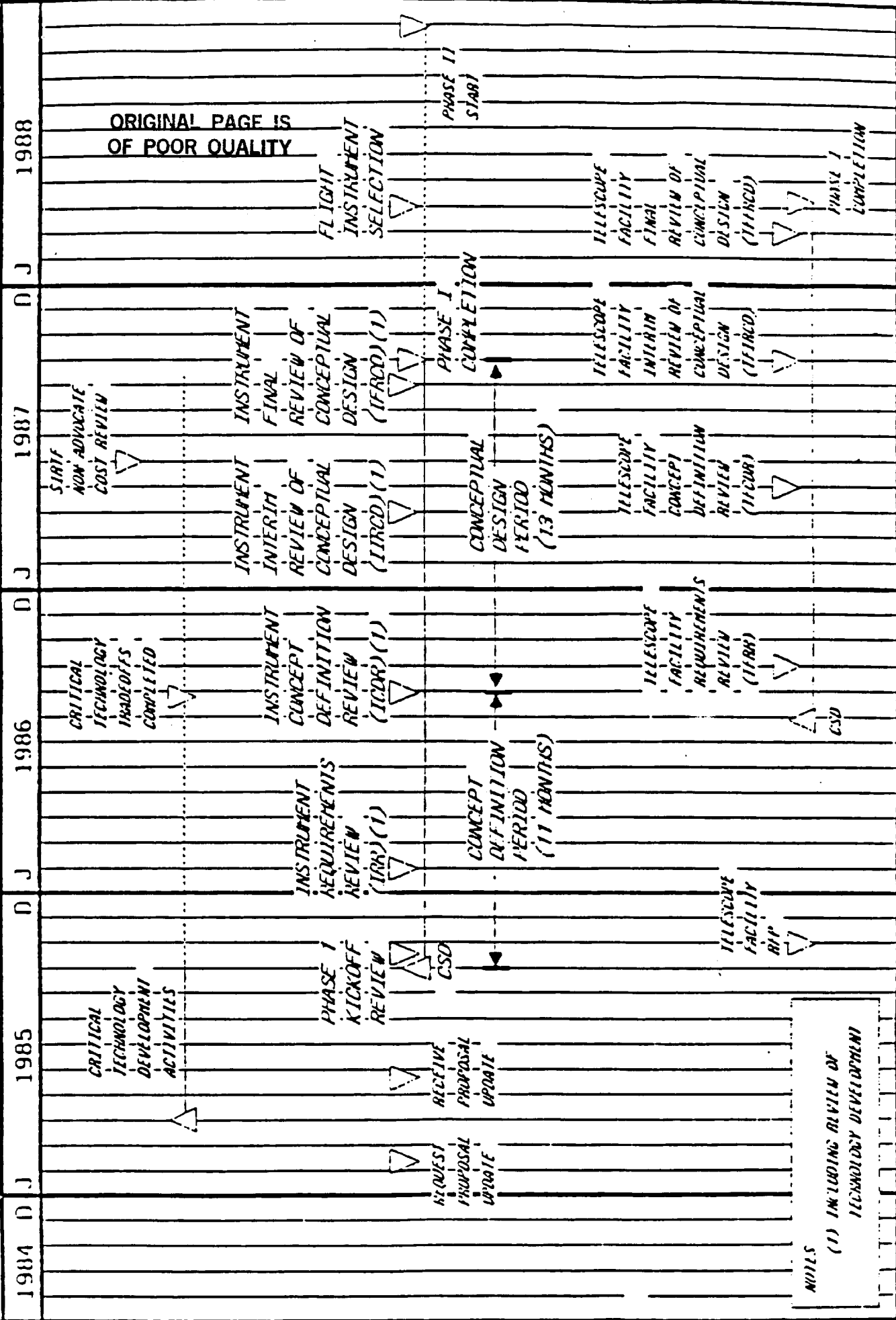


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LAUNCH

PHASE I SIRTF SCIENCE INVESTIGATIONS SCHEDULE SUMMARY

DATE: 2-85



NOTES
 (1) INCLUDING REVIEW OF TECHNOLOGY DEVELOPMENT

APPENDIX B

CORNELL UNIVERSITY

Department of Astronomy

SPACE SCIENCES BUILDING
Ithaca, New York 14853-6801

Telephone (607) 256-4805

July 11, 1985

Science Center
Rockwell International Corporation
P.O. Box 1085
Thousand Oaks, CA 91360

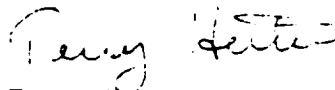
Attention: Mr. R. A. Johnson
Contracts and Pricing

Dear Mr. Johnson:

Please find enclosed a Request for Proposal (RFP) from the Rockwell Science Center to perform a detector hybrid array development and fabrication effort for Cornell University. We look forward to your response.

For further information I may be reached at (607) 256-4806.

Sincerely,



Terry Herter

TH:sc
Enc.

cc: Dr. Dick Florence
Dr. M. G. Stapelbrook
Dr. David H. Seib

REQUEST FOR PROPOSAL

We would like to evaluate Rockwell International produced hybrid infrared arrays operating in the 4 to 28.5 micron region for possible use in the instruments being developed for the Space Infrared Telescope Facility (SIRTF). Our particular instrument (Houck et al.) is a series of grating spectrometers, some of which operate in this waveband. If the evaluation can demonstrate superior performance, it is possible these arrays would also be used in the Fazio et al. camera, and perhaps the Rieke et al. photometer. During the next 2.5 years of "Phase B" development we need to gather enough information and experience to decide on the particular array technology to employ in these instruments.

In particular, we are interested in blocked-impurity-band (BIB) two-dimensional arrays with Si:As photosensors and direct-read-out multiplexer with non-destructive readout capability. It is this technology that holds the highest promise for superior performance in the SIRTF environment. The basic detector characteristics desired are described in the enclosed Appendix I. On SIRTF, any detector operating temperature above 2K is available, though temperatures in the 2-7K range will be most convenient.

We will investigate the imaging qualities, and photometric performance at low backgrounds and the effect of ionizing radiation on overall performance. The detector testing will be performed at NASA-Ames under the direction of Dr. T. Roellig and at Cornell University under the direction of Dr. T. Herter. We will honor the confidentiality of any information which Rockwell International considers to be proprietary. The basic detector performance characteristics, such as dark current, responsivity, noise, imaging and photometric properties must be made available to the other SIRTF teams (i.e. Fazio et al. and Rieke et al.) to aid in their detector selections. Reports on these areas will be made available to Rockwell International for review prior to dissemination. We also wish to present information such as that mentioned above at Craig McCreight's detector meetings, again with prior review by Rockwell.

STATEMENT OF WORK

I. GENERAL

This document describes the work to be performed by Rockwell International Science Center in a detector development/evaluation effort for Cornell University. The effort consists of fabricating multiplexers and Si:As BIB detector arrays to construct hybrid arrays, testing these devices, and supplying these to Cornell University for further testing and evaluation. This work is followed by the fabrication of a "second generation" hybrid array using Rockwell's new epitaxial reactor to produce new BIB detector arrays. The design goals for this latter device are determined by the test results on the first devices and our scientific requirements for SIRTf.

II. TASKS

Rockwell International Science Center shall perform the following tasks:

1. Fabrication:

Fabricate multiplexers and Si:As BIB detector arrays using current photo-mask set and current technology with new BIB array material. Use these components to construct at least four hybrid arrays for delivery. The existing 10x50 Rockwell mux design with 150 micron center-to-center spacing may be employed.

2. Testing:

Test and characterize two of the hybrid devices fabricated in task 1 at the very low photon background levels typical of the SIRTf environment (see Appendix I), with special emphasis on the dark current, photon responsivity, and noise levels under these conditions.

Rockwell shall test the hybrid array at two temperatures, approximately 4.2K and 7K and at two backgrounds, at $< 10^3$ and at approx. 10^5 photons/sec/pixel (i.e., $< 4 \times 10^6$ and 4×10^8 photons/sec/cm²) for the following properties:

- 1) Responsivity (i.e., electrons/photon),
- 2) RMS noise (at the upper and lower limits of the dynamic range),
- 3) At the lower background level, Rockwell shall measure the dark current at the optimum bias point.

The tests shall be made at two wavelengths, 10 and 20 microns, with the array biased so as to maximize the signal-to-noise ratio. On chip integration times of 1-10 seconds and longer are required.

3. Delivery and Consultation:

- a) Rockwell shall deliver, if available, at least two existing mux's early in the program for testing hardware and software of the Houck et al. teams.
- b) Rockwell shall provide a detector array, fabricated under task 1), mounted in a fashion to be defined so that several individual BIB detectors in the array may be tested by the Houck et al. team.
- c) Rockwell shall deliver two tested and two untested hybrid devices for testing and evaluation.
- d) Rockwell shall provide test data from task 2) above to guide our testing.
- e) Rockwell shall provide, on a confidential basis, information and advice to allow the Houck et al. testing teams to operate these hybrid arrays. Included will be pinout description, suggested biasing levels, suggested clocking patterns which Rockwell uses to operate the devices and gather and analyze the detector data. As much of this information as possible will be provided in advance to the Houck et al. team so that hardware and software development can proceed prior to delivery.
- f) Rockwell shall allow the Houck et al. personnel to visit the Rockwell Science Center facility in order that they can become familiar with the operation and testing of the hybrid arrays. The visits will be scheduled at a time mutually convenient to both parties.
- g) Rockwell shall provide on-site consultation at least twice during the course of the contract at times to be defined which are mutually convenient to Rockwell and the Houck et al. team. These meetings shall include no more than three representatives from Rockwell and will take place at a location to be defined (probably NASA-Ames).

4. Optimized device fabrication:

Develop a next-generation BIB detector array, optimized for the SIRTf experiments (see Appendix I) and construct a hybrid array. The array configuration shall be the same as in task 1). Our goals for candidate SIRTf arrays are:

- a) low dark current (< few 100 electrons/sec),
- b) good responsivity at the optimal wavelength (approximately 20 microns)
- c) less than 10% "dead" elements (elements with performance more than a factor of 2 poorer than average),
- d) good quantum efficiency (>50%),
- e) good photoconductive gain (greater than or equal to unity).

Testing, delivery and consultation requirements are the same as those outlined in tasks 2) and 3) with the exception that one tested and two untested, new hybrid devices need be delivered.

We understand, from the information presented by Mike Petroff and others at our October 1984 meeting, that the performance of BIB detectors can be "tuned" for certain desired properties, by selection of doping concentrations, layer thicknesses and geometry, and operating bias. Therefore we would like task 4) development above to concentrate on "tuning" these devices for our SIRTf experiment. The desired characteristics and trade-offs would be arrived at through consultation between the Rockwell personnel and relevant members of the Houck et al. team.

III. SCHEDULE

The total length of the contract shall be 24 months with a mutually agreed upon starting date.

Task 1) shall begin as soon as Rockwell can manage, with delivery of the first two tested hybrids by the end of 13 months after start. The planning for task 4) shall begin as soon as the information from task 2) and the Houck et al. testing allows. The new tested hybrid detector should be delivered by the end of the 23rd month from start of contract. The final month of the contract will be used for compilation and writing of the Final Report (see below under reporting).

IV. REPORTING

Rockwell shall provide the following reports:

- a) A bimonthly technical status report giving progress of work.
- b) A technical report to document work performed during tasks 1) and tasks 2), delivered one month after the second hybrid is delivered (end of 14th month).
- c) A final report documenting existing technology and tests results. To be delivered one month after delivery of the optimized hybrid array (end of 24th month after start).

APPENDIX I

We describe below the environment of SIRTf and the basic detector characteristics needed for meeting our science goals on SIRTf.

Since the SIRTf telescope is to be cooled to around 10K and above the atmosphere, the primary source of background radiation will be the emission from the zodiacal dust. We would prefer that this be the limit to our sensitivity. Failing this, we would like to approach this limit as closely as possible. The corresponding backgrounds experienced by each detector is quite small. Assuming an instrument transmission of 20%, the approximate range for Houck *et al.* spectrometers is 6 to 600 photons/sec/pixel while for the Fazio *et al.* cameras it is around 6 to 6000 photons/sec/pixel. The lowest value of 6 photons/sec/pixel corresponds to 0.001 fA for unity conversion of photons to electrons. Thus, in order to be background limited, the noise due to the dark current must be smaller than 80 electrons for a 1000 second integration.

Another aspect of the SIRTf environment effecting sensitivity is the ionizing radiation present in space. A major source of interference are the high energy protons, with an approximate flux of $1/\text{cm}^2/\text{sec}$ in orbit. One hit from such a proton will totally obscure the signal from our dim astronomical sources. The practical effect of this is to limit the possible integration time before readout of detectors. Therefore, we require detectors with the smallest possible cross section to these particles, to minimize interference. In addition, this drives us to seek a smaller read-out noise from the mux, so that the background or dark-current noise dominates in the reduced integration time available. These particle hits also lead us to desire a non-destructive readout capability for the muxes, so that integration can proceed until a hit occurs.

The optimal array sizes for the two experiments is somewhat different in their proposed configurations, but similar enough to consider common development. For the Fazio *et al.* camera, arrays of 128×128 elements (possibly made up of 4 of 64×64) with 50 micron pixels 2-5 microns, 64×64 elements with 200 configuration more similar to the Fazio *et al.* requirements. We would prefer to have at least 64 detectors along the dispersion, however.

To summarize our need, we desire multiplexed detector arrays of the above description with: high quantum efficiency (>0.3), high photon-electron gain (>0.5), low read noise (in the 100 electrons rms range), small cross-section to ionizing radiation, and small dark current (<100 electron/sec). In addition, in order to assure high quality images and spectra, we require low crosstalk between elements ($<5\%$) and good repeatability (i.e., calibratability) over the full range of signals and backgrounds which will be encountered on SIRTf. Further, we are concerned about any possible long-term deleterious effects which might result from passage through the South Atlantic Anomaly.

ORIGINAL PAGE IS
OF POOR QUALITY

Science Center
Rockwell International Corporation
1049 Camino Dos Rios
P.O. Box 1085
Thousand Oaks, California 91360

(805) 373-4545



**Rockwell
International**

In reply refer to SC4033

August 20, 1985

Cornell University
Department of Astronomy
Space Sciences Building
Ithaca, New York 14853-6801

Attention: Terry Herter, (607) 256-4806

Subject: Cornell University RFP dated July 11, 1985
Impurity Band Conduction Hybrid Arrays for SIRTF
Proposal No. SC4033

In response to the referenced RFP, enclosed is proposal SC4033 for your consideration.

Questions of a technical nature should be directed to R. A. Florence at 714/632-4553,
and those of a contractual or pricing nature should be directed to G. F. Parsons or
the undersigned at 805/373-4404 or 373-4415 respectively.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

R. A. Johnson, Director
Contracts and Pricing

GFP/11e

Enclosures

INFORMATION CONTAINED HEREIN IS PRIVILEGED OR
CONFIDENTIAL INFORMATION OF ROCKWELL INTERNATIONAL
CORPORATION WITHIN THE MEANING OF 5 USC 552 AND AS SUCH
IS EXEMPT FROM THE PUBLIC DISCLOSURE PROVISIONS THEREOF.



Rockwell International

Science Center
Proposal SC4033

Statement of Work - Delivery

Rockwell International Corporation, Science Center, proposes to furnish the necessary personnel, facilities and services to conduct a twenty-four month program on Impurity Band Conduction Hybrid Arrays for SIRTf as set forth in the statement of work contained in the Cornell University RFP dated July 11, 1985.

Type of Contract

Contractor proposes a CPFF contract.

Estimated Cost	\$343,653
Fixed Fee	27,332
Total	\$370,985

Terms

Contractor proposes FAR clauses as mutually agreed.

Proposal Validity

This proposal is valid to 21 September 1985.

Special Provision

Rockwell requests that any ensuing contract contain the following special provision.

"Cornell University acknowledges that certain proprietary information concerning the program may be revealed during the period of performance. Cornell University will honor the confidentiality of such information. It is also agreed that reports that may contain proprietary information will be made available to Rockwell for review prior to dissemination."

Government-Owned Facilities

The contractor does not intend to use Government-owned facilities, industrial equipment or special tooling in performance of a contract resulting from this proposal. Our DUNS number is 05-922-1036.


Administrative Offices

Government contracts are administered by DCASMA-Van Nuys, 6230 Van Nuys Boulevard, Van Nuys, California 91408, telephone 818/710-2405.

Authorized Negotiators

Contract negotiations may be conducted by either G. F. Parsons or the undersigned, both of whom may be reached at the Science Center, 1049 Camino Dos Rios, Thousand Oaks, California 91360, telephone 805/373-4404 and 373-4415 respectively.

ROCKWELL INTERNATIONAL CORPORATION
Science Center


R. A. Johnson, Director
Contracts and Pricing

CONTRACT PRICING PROPOSAL COVER SHEET

1. SOLICITATION/CONTRACT/MODIFICATION NO. FORM APPROVED OMB NO. 3090-0118

NOTE: This form is used in contract actions if submission of cost or pricing data is required. (See FAR 15.804-6(b))

2. NAME AND ADDRESS OF OFFEROR (Include ZIP Code)
ROCKWELL INTERNATIONAL CORPORATION
Science Center
1049 Camino Dos Rios
Thousand Oaks, California 91360

3A. NAME AND TITLE OF OFFEROR'S POINT OF CONTACT
G. F. Parsons, Manager
Contracts & Proposals
3B. TELEPHONE NO. 805/373-4404
4. TYPE OF CONTRACT ACTION (Check)
 A. NEW CONTRACT D. LETTER CONTRACT
 B. CHANGE ORDER E. UNPRICED ORDER
 C. PRICE REVISION/ REDETERMINATION F. OTHER (Specify)

5. TYPE OF CONTRACT (Check)
 FFP CPFF CPIF CPAF
 FPI OTHER (Specify)

6. PROPOSED COST (A+B=C)
A. COST \$ 343,653 B. PROFIT/FEE \$ 27,332 C. TOTAL \$ 370,985

7. PLACE(S) AND PERIOD(S) OF PERFORMANCE
Science Center, Thousand Oaks, CA

8. List and reference the identification, quantity and total price proposed for each contract line item. A line item cost breakdown supporting this recap is required unless otherwise specified by the Contracting Officer. (Continue on reverse, and then on plain paper, if necessary. Use same headings.)

A. LINE ITEM NO	B. IDENTIFICATION	C. QUANTITY	D. TOTAL PRICE	E. REF.
	Impurity Band Conduction Hybrid Arrays for SIRTF	Lot	\$370,985	

9. PROVIDE NAME, ADDRESS, AND TELEPHONE NUMBER FOR THE FOLLOWING (If available)

A. CONTRACT ADMINISTRATION OFFICE
DCASMA-Van Nuys
6230 Van Nuys Boulevard
Van Nuys, California 91408

B. AUDIT OFFICE
DCAA-Rocketdyne
6633 Canoga Avenue
Canoga Park, California 91304

10. WILL YOU REQUIRE THE USE OF ANY GOVERNMENT PROPERTY IN THE PERFORMANCE OF THIS WORK? (If "Yes," identify)
 YES NO

11A. DO YOU REQUIRE GOVERNMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED CONTRACT? (If "Yes," complete Item 11B)
 YES NO
11B. TYPE OF FINANCING (If one)
 ADVANCE PAYMENTS PROGRESS PAYMENTS
 GUARANTEED LOANS

12. HAVE YOU BEEN AWARDED ANY CONTRACTS OR SUBCONTRACTS FOR THE SAME OR SIMILAR ITEMS WITHIN THE PAST 3 YEARS? (If "Yes," identify item(s), customer(s) and contract number(s))
 YES NO

13. IS THIS PROPOSAL CONSISTENT WITH YOUR ESTABLISHED ESTIMATING AND ACCOUNTING PRACTICES AND PROCEDURES AND FAR PART 31 COST PRINCIPLES? (If "No," explain)
 YES NO

14. COST ACCOUNTING STANDARDS BOARD (CASB) DATA (Public Law 91-379 as amended and FAR PART 30)
A. WILL THIS CONTRACT ACTION BE SUBJECT TO CASB REGULATIONS? (If "No," explain in proposal)
 YES NO

B. HAVE YOU SUBMITTED A CASB DISCLOSURE STATEMENT (CASB DS-1 or 2)? (If "Yes," specify in proposal the office to which submitted and if determined to be adequate)
 YES NO

C. HAVE YOU BEEN NOTIFIED THAT YOU ARE OR MAY BE IN NON-COMPLIANCE WITH YOUR DISCLOSURE STATEMENT OR COST ACCOUNTING STANDARDS? (If "Yes," explain in proposal)
 YES NO

D. IS ANY ASPECT OF THIS PROPOSAL INCONSISTENT WITH YOUR DISCLOSED PRACTICES OR APPLICABLE COST ACCOUNTING STANDARDS? (If "Yes," explain in proposal)
 YES NO

This proposal is submitted in response to the RFP, contract, modification, etc. in item 1 and reflects our best estimates and/or actual costs as of this date

15. NAME AND TITLE (Type)
R. A. Johnson, Director
Contracts and Pricing

16. NAME OF FIRM
ROCKWELL INTERNATIONAL CORPORATION
Science Center

17. SIGNATURE


18. DATE OF SUBMISSION
08/20/85



ATTACHMENT TO STANDARD FORM 1411

Supporting Data

Part 1 - Material and Subcontracts (Engineering Estimates)Task 1.0 - FY1986Materials

Silicon wafers, 100 ea @ \$11.27 ea	\$1,127
Silicon wafers with epitaxy, 100 ea @ \$26.50 ea	<u>2,650</u>

Total Materials - Task 1.0	\$ 3,777
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Subcontracts

Buried contact implant, 100 ea @ \$10.00 ea	\$1,000
Silicon epitaxy, 1 run @ \$13,000/run	<u>13,000</u>

Total Subcontracts - Task 1.0	\$14,000
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Task 2.0 - FY1986Materials

Liquid helium, 1700L @ \$3.85/L	\$ 6,545
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Task 4.0 - FY1987Materials

Silicon wafers, 100 ea @ \$11.27 ea	\$1,127
Liquid helium, 1100L @ \$3.85/L	<u>4,235</u>

Total Materials - Task 4.0	\$ 5,362
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Subcontracts

Buried contact implant, 100 ea @ \$10.00 ea	\$ 1,000
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Attachment to Standard Form 1411

Part 1 - Material and Subcontracts (continued)

Material and Subcontracts Summary

Materials

FY1986	\$10,322	
FY1987	<u>5,362</u>	
Total Materials		\$15,684

Subcontracts

FY1986	\$14,000	
FY1987	<u>1,000</u>	
Total Subcontracts		\$15,000

Part 2 - Direct Labor

The engineering direct labor rates used are a weighted composite utilizing the actual salaries of specific persons together with current projections during the planned period of performance. Upon request, this information will be made available to the Defense Contract Audit Agency.

Part 3 - Fringe Benefits, Labor Overhead, and General and Administrative Expense

	<u>FY1985</u> <u>90 Est.Hrs.</u>	<u>FY1986</u> <u>2644 Est.Hrs.</u>	<u>FY1987</u> <u>906 Est.Hrs.</u>
Indirect Cost	\$33.70	\$35.90	\$38.30
D/L Fringe Benefits	9.40	9.90	10.50
General & Administrative	13.4%	13.4%	13.4%

Current projected overheads used have been submitted to the cognizant ACO for approval.

Part 4 - Facilities Cost of Money (CAS414)

3640 hours FY1985, FY1986 and FY1987 @ \$.55 = \$2,184



Attachment to Standard Form 1411

Part 5 - Travel and Subsistence

1. San Jose, Calif. - Program coordination, 4 persons, 2 trips in FY1986, 1 day each trip

	<u>FY1986</u>
8 R/T air fares @ \$138 ea	\$1,104
8 R/T auto LAX @ \$20 ea	160
8 parking LAX, 1 day @ \$5/day	40
Auto rental \$35/day x 2 days	70
Subsistence, 8 days @ \$30/day	<u>240</u>

Total FY1986 - \$1,614

2. San Jose, Calif. - Program coordination, 4 persons, 1 trip in FY1987, 1 day each trip

	<u>FY1987</u>
*4 R/T air fares @ \$145	\$ 580
4 R/T auto LAX @ \$20 ea	80
4 parking LAX, 1 day @ \$5/day	20
*Auto rental \$37/day x 1 day	37
*Subsistence, 4 days @ \$32/day	<u>128</u>

Total FY1987 - \$845

Grand Total Travel and Subsistence - \$2,459

*Increased 5% for escalation

Science Center
 Proposal SC4033

Cost Breakdown(s)

FY85

	Hours	Rate	Amount
Engineering	90	22.62	\$2,036
Direct Labor Fringe	90	9.40	846
Subtotal			2,882
Indirect Cost	90	33.70	3,033
Subcontracts			0
Material			0
Travel			0
Consultant			0
Subtotal			5,915
General & Administrative		0.1340	793
Subtotal			6,707
CAS 414			50
Interdivision Cost			0
Estimated Total Cost			6,757
Fixed Fee			537
Total Price			\$7,293

FY86

	Hours	Rate	Amount
Engineering	2,644	23.19	\$61,314
Direct Labor Fringe	2,644	9.90	26,176
Subtotal			87,490
Indirect Cost	2,644	35.90	94,920
Subcontracts			14,000
Material			10,322
Travel			1,614
Consultant			0
Subtotal			208,346
General & Administrative		0.1340	27,918
Subtotal			236,264
CAS 414			1,454
Interdivision Cost			16,000
Estimated Total Cost			253,718
Fixed Fee			20,181
Total Price			\$273,899

Science Center
Proposal SC4033

Cost Breakdown(s)

FY87

	Hours	Rate	Amount
Engineering	906	23.72	\$21,490
Direct Labor Fringe	906	10.50	9,513
Subtotal			31,003
Indirect Cost	906	38.30	34,700
Subcontracts			1,000
Material			5,362
Travel			845
Consultant			0
Subtotal			72,910
General & Administrative		0.1340	9,770
Subtotal			82,680
CAS 414			498
Interdivision Cost			0
Estimated Total Cost			83,178
Fixed Fee			6,614
Total Price			\$89,793

Total Program

	Hours	Rate	Amount
Engineering	3,640	23.308	\$84,840
Direct Labor Fringe	3,640	10.037	36,535
Subtotal			121,375
Indirect Cost	3,640	36.443	132,652
Subcontracts			15,000
Material			15,684
Travel			2,459
Consultant			0
Subtotal			287,170
General & Administrative		0.13400	38,481
Subtotal			325,651
CAS 414			2,002
Interdivision Cost			16,000
Estimated Total Cost			343,653
Fixed Fee			27,332
Total Price			\$370,985

CONTRACT FACILITIES CAPITAL and COST OF MONEY

CONTRACTOR: ROCKWELL INTERNATIONAL CORPORATION	RFP/CONTRACT PLAN NO: SC4033
BUSINESS UNIT: Science Center 1049 Camino Dos Rios	PERFORMANCE PERIOD: 09/01/85 thru 08/31/87 plus final report
ADDRESS: Thousand Oaks, California 91360	

1. OVERHEAD POOLS	2. COST ACCOUNTING PERIOD	3. CONTRACT OVERHEAD ALLOCATION BASE	FACILITIES CAPITAL COST OF MONEY	
			4. FACTORS	5. AMOUNT
Engineering D/L Hours	FY85/FY86/	3640	.55	\$2,002
Engineering Overhead	FY87			
Common Overhead				
General and Administrative				
6. CONTRACT FACILITIES CAPITAL COST OF MONEY				\$2,002
7. FACILITIES CAPITAL COST OF MONEY RATE			÷	.10375
8. CONTRACT FACILITIES CAPITAL EMPLOYED				\$19,296

SC4033T

Statement of Work
for

IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRT

Prepared for

Cornell University
Ithaca, New York 14853

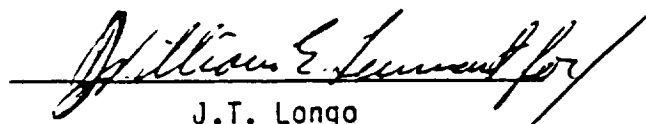
Prepared by

Rockwell International Science Center
P.O. Box 3105
Anaheim, California 92803

Technical data contained in all pages of this proposal shall not be used or disclosed, except for evaluation purposes, provided that if a contract or grant is awarded to this submitter as a result of or in connection with the submission of this proposal, the Government shall have the right to use or disclose this technical data to the extent provided in the contract or grant. This restriction does not limit the Government's right to use or disclose technical data obtained from another source without reservation.

August 1985

Approved by



J.T. Longo
Associate Center Director
Science Center



Rockwell International
Science Center



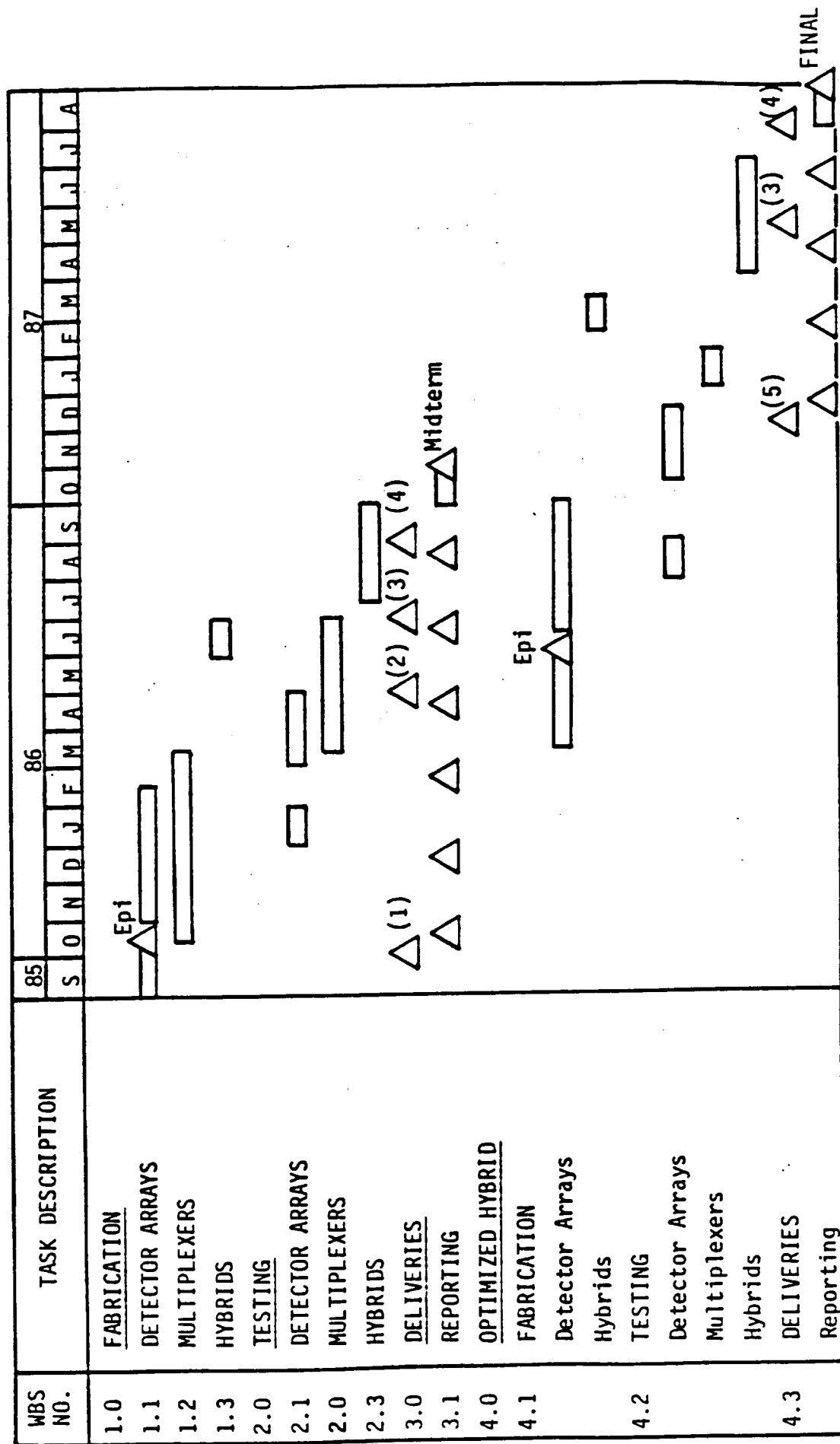
SC4033T

1.0 BACKGROUND

Rockwell International, as the inventor of doped-silicon Impurity Band Conduction (IBC) detector technology, has been developing Blocked Impurity Band (BIB) detectors, detector arrays, and hybrid arrays for several years. Most recently, Rockwell has demonstrated IBC hybrid arrays comprising arsenic-doped back-illuminated BIB (BIBIB) detectors and a switched FET (SWIFET) readout multiplexer. The arrays contain 5-mil square detectors on 6-mil centers in a 10 × 50-element configuration. The multiplexer has 10 separate lines, each reading out 50 detectors.

Because IBC detector technology offers significant advantages over conventional photoconductive detectors for space astronomy (e.g., linearity, repeatability, radiation hardness, and freedom from anomalies), BIBIB detector/SWIFET hybrid arrays are recommended for SIRTf for IR detection in the 5 to 30 μm wavelength region. This proposal outlines a technical approach to provide tested and untested hybrid arrays and components for characterization and assessment by the SIRTf experiment teams. The program schedule is contained in Figure 1.

Figure 1. SCHEDULE - IBC HYBRID ARRAYS FOR SIRTf





SC4033T

2.0 TECHNICAL APPROACH

2.1 Existing Technology

Rockwell International will inventory existing Si:As BIB detector arrays and SWIFET multiplexers fabricated on IR&D programs to identify a detector array and multiplexer for delivery early in the program (see the Schedule in Figure 1). The devices may be untested and are intended to provide familiarization with their operating characteristics by SIRTf team members. Necessary technical information and documentation will be provided with the devices.

As the primary goal of the first phase of this program, Rockwell will fabricate 10×50 BIBIB detector arrays and SWIFET multiplexers. Existing technology and designs will be used. No optimization nor design changes will be performed on either the detector array or multiplexer. Completed wafers will be screened to select devices for delivery to Cornell University (see Fig. 1) and for cryogenic test. Testing will be adequate to qualify wafers for hybrid mating and will be performed using parameter values which approximate SIRTf operational conditions wherever possible. Upon successful mating of several BIBIB detector arrays and SWIFET multiplexers, two untested hybrid arrays will be delivered to Cornell University along with the appropriate documentation. Two additional hybrid arrays will be selected for characterization by Rockwell. Delivery of these hybrids will be on or before the end of the 13th Month After Contract (MAC).

Technical consultations will be provided both at Rockwell's Anaheim, California, facility and at NASA-Ames, Moffett Field, California. A total of two trips to NASA-Ames have been planned for this purpose. Reports documenting technical progress on the program will be prepared and delivered bi-monthly. Complete documentation of work performed during the first phase of the program will be included in a report to be delivered at the end of the 14th MAC.



SC4033T

2.2 Second-Generation Devices

The goal of the second phase of this program is to fabricate improved IBC hybrid arrays. Rockwell will fabricate BIB detector arrays (10 x 50 configuration) using epitaxy layers tailored for the SIRTf experiment. The desired characteristics and trade-offs relative to the BIB detector array will be mutually agreed upon by Rockwell and Cornell University.

Completed wafers will be tested at cryogenic temperatures to select detector arrays for delivery to Cornell University and to qualify wafers for hybrid mating. The multiplexers for mating with second-generation detector arrays will be obtained from wafers fabricated during the first phase of the program (Existing Technology). Four hybrid arrays will be assembled, two for delivery untested (approximately 21 MAC) and two for characterization by Rockwell prior to delivery to Cornell University at the end of the 23rd MAC. Test conditions will be chosen to evaluate hybrid array performance under SIRTf experiment conditions.

Technical information and/or data packages will be provided with each delivered device (see Fig. 1). Bimonthly progress reports will be prepared and submitted during the Second-Generation Device phase of the program and a final report documenting technology status and test results will be delivered 24 MAC.



Cornell University

Office of Sponsored Programs

123 Day Hall
Ithaca, NY 14853-2801

607/256-5014

October 28, 1985

FBO Express Mail

Mr. G.F. Parsons
Manager, Contracts and Proposals
Rockwell International Corporation
Science Center
1049 Camino Dos Rios
Thousand Oaks, CA 91360

Subject: Subcontract OSP 3867 Under NASA
Grant No. NAG 2-317, "The Infrared Spectrometer During
the SIRTF Pre-Definition Phase", J.R. Houck/T.L. Herter

Dear Mr. Parsons:

In accordance with our recent phone conversation/negotiations, I am enclosing a revised subcontract agreement to replace the one you were sent earlier; only the first four pages which have been changed are enclosed.

Hopefully this agreement is now acceptable and you can sign and return one copy. I regret the delay, but it was necessary to obtain clarification of the patent policy from the NASA Counsel.

Please feel free to call me if you have any questions.

Sincerely yours,

Peter A. Curtiss
Senior Grant and Contract Officer

PAC:fw
enc.

cc: J.R. Houck/T.L. Herter ✓
E.M. Bilson
E.E. Salpeter

Progress Report 2

for

NASA-Ames Grant NAG 2-317

The Infrared Spectrograph During the SIRTF Pre-Definition Phase

through May 1, 1986

May 10, 1986

INFRARED SPECTROGRAPH GRANT REPORT

This report covers the activities on the IRS Grant from the period 1 October 1985 through 1 May 1986.

1.0 MANAGEMENT ACTIVITIES

Those activities involving overall project coordination and direction, and preparation of reports and proposals are outlined below:

1.1 Project Manager

A project manager, Keith Duclos, was hired to assume the lead in carrying out the management activities of the IRS team. He has been working part time and will begin full time employment 22 May.

1.2 Ball Statement of Work (SOW)

A statement of work and guidelines for response are being drafted in conjunction with NASA Ames for submission to Ball Aerospace for their activities during Phase B.

1.3 Phase B Study Plan

A study plan is being worked on in anticipation of a NASA RFP release for SIRTf Phase B activities.

1.4 Phase B Budget

Preliminary budget work and coordination between co-investigators to determine budgets for Phase B activities is being carried out.

1.5 Rockwell Contract

The IRS team has been monitoring the status of the fabrication of detector arrays by Rockwell for evaluation by the SIRTf IRS team. This is performed through regular progress reports from Rockwell as well as phone conversations. (see section 2.1)

1.6 Team Telecons

Telecons to discuss IRS activities and current status are held on a regular basis every two to three weeks as necessary. These meetings update all co-investigators on the activity of others, discuss the current SIRTf schedule and its impact on IRS activities, and discuss priorities and strategies for the IRS activities.

1.7 SWG and Operation Subgroup Support

The IRS team has provided support to the SWG and the OPS through attendance of meetings as well as performing activities assigned to the IRS team. A report of an OPS meeting attended by Herter, Roellig and Soifer is given in Appendix A.

2.0 TECHNICAL ACTIVITIES

Technical activities have include continuation of the detector evaluation effort, reviewing the basic instrument concept with the introduction of an alternate concept, and discussion of the optimum resolutions for performing the best science with the spectrograph. The activities are outlined below.

2.1 Si:As BIBIB hybrid array evaluation

Cornell will be testing detector arrays for the 5-30um wavelength range of the spectrograph. In November 1985, a contract was secured with Rockwell International to supply Back-Illuminated Blocked Impurity Band (BIBIB) detectors to Cornell for evaluation. The current status of this contract and Cornell evaluation facility is as follows:

- * In December 1985, T. Herter and G. Gull attended a kickoff meeting a Rockwell. At this time a "bare" multiplexer (mux) was given to Cornell to test the data acquisition and analysis system being developed for evaluation of the BIBIB hybrid arrays. Appendix B contains a report of this meeting.
- * Progress on detector fabrication at Rockwell is detailed in the enclosed progress reports from Rockwell (Appendix C). Both the multiplexer and detector array fabrication steps are completed with final assembly (hybridizing) to take place after test of the individual components. Delivery of a hybrid array is expected this summer.
- * The Cornell data aquisition and analysis system to be used for evaluating the Rockwell hybrid arrays is nearing completion. A schematic of this system is shown in figure 1. This system consists of:
 - 1) A VME bus, 68000 based microcomputer built by Stride Microsystems used for software development, data logging, and data analysis. This system has two terminals (one graphics), a 5.25-inch floppy disk drive and a 20 MByte hard disk.

- 2) A 16 channel Burr-Brown 12-bit, 330 kHz A/D converter sampled by the Stride.
- 3) A FORCE single-board computer (SBC), occupying a single slot in a VME chassis, that provides the clocking pulses to drive the mux through a 24 bit parallel I/O port.
- 4) An analog driver box which converts TTL signals generated by the FORCE board to the correct levels accepted by the mux. This box also provides the DC levels necessary for mux operation.
- 5) A cryogenically-cooled, low-background dewar in which the detector and associated optics and calibration sources are placed for testing.
- 6) A preamplifier which conditions the output signals of the detectors/mux for sampling by the Burr-Brown A/D converter.

The tasks which have been accomplished in facility preparation are outlined below:

- 1) The software to generate clocking pulses (know a FPAC, the Focal Plane Array Controller) with the FORCE SBC has been written and tested. FPAC, is a 68000 assembly language routine which is written and compiled on the Stride microcomputer and downloaded from the Stride to the SBC by the program TOFORCE, a PASCAL routine written for the Stride. This procedure is now routine and changes to the clocking scheme are easy to implement. Frame periods rates from about two milliseconds to several hours can be accommodated.
- 2) The analog driver box that conditions the clocking signals is undergoing final assembly and wiring of the backplane. Shielded wiring is being run for all lines to prevent cross-talk. PC boards have been designed and constructed, and tested.
- 3) A Fanout board has been design and constructed for mounting the BIBIB detector in the test dewar. This board employs liberal use of ground planes and ground runs to separate clocks, DC levels and signal lines to prevent cross-talk and allow ultimate performance to be obtained.
- 4) Software to sample the Burr-Brown A/D converter has been written and tested, and acquisition and display software is being developed.

- 5) Initial operation of the "bare" mux should begin in about two weeks, approximately 26 May, at which time checkout of system hardware and software will be performed in preparation of a BIBIB hybrid detector array delivery.

2.2 Long Wavelength Detector Evaluation

Caltech is responsible for evaluation of detectors which operate longward of 30um. This includes Ge:Be (30-50um), Ge:Ga (50-120um), stressed Ge:Ga (120-200um), and Ge:Ga BIB (120-200um) detectors. Most recent activity has been directed towards negotiating a contract with Rockwell to fabricate Ge:Ga BIB's for evaluation. This effort was originally to be pursued with Hughes but they lacked commitment to the project due to the limited funding available. Rockwell however has expressed a strong interest in developing Ge BIB's. Ge BIB's offer an excellent opportunity for simplifying detector design, improving detector quantum efficiency, and increasing array sizes and formats for the long wavelength channels of the spectrograph. An agreement with Rockwell on a statement of work has been negotiated and a contract should be signed within a few weeks.

Planned activities for the summer include the implementation of an integrating FET preamplifier to allow measurement of dark currents in Ge:Ga detectors with different levels of compensation. Ge:Be will also be tested. Through an IRS/MIPS agreement, consideration is being given to the establishment of a common radiation facility.

2.3 Short Wavelength Array Evaluation

The short wavelength band (2-5um) detector technology of the spectrograph is being evaluated by the University of Rochester. This effort is being funded jointly by spectrometer and IRAC camera team. A detailed report of recent activities at Rochester is given in the IRAC progress report.

2.4 New Spectrograph Concept

A new spectrograph concept is being considered by the IRS team to reduce cost, simplify design and increase reliability. This concept would also allow an increase in the long wavelength channel resolution affording better sensitivity to line detection. This new concept is discussed in detail in Appendix D.

Because the new spectrograph concept offers the opportunity to increase the resolution in all wavebands, the IRS team is determining optimum resolution to strike a compromise between extragalactic source detection sensitivity, weak narrow line detection capability, and ease of extended spectral coverage. This issue is address in detail in Appendix E.

CORNELL BIB ARRAY TEST FACILITY

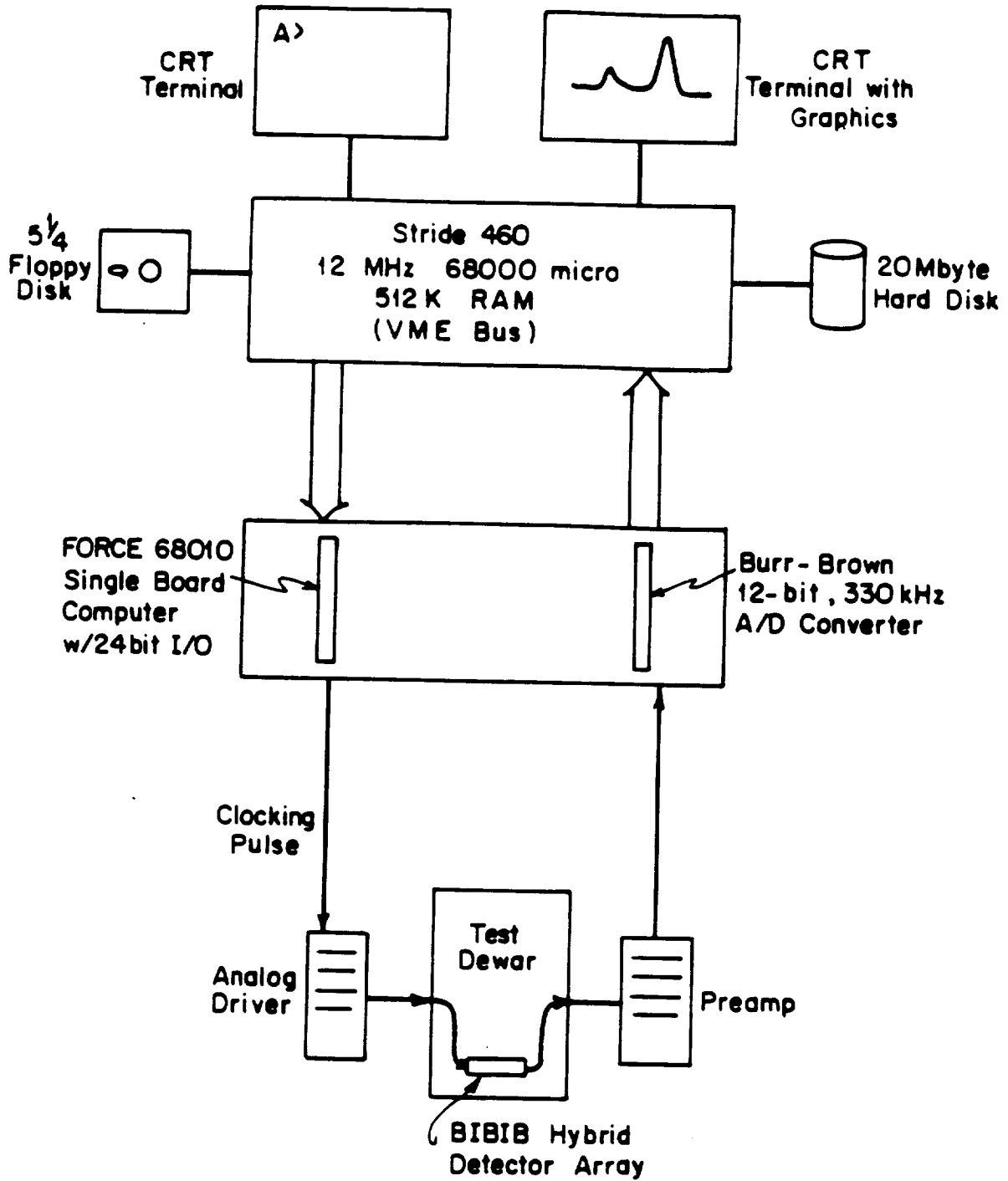


Figure 1 - Schematic diagram of Cornell detector evaluation facility.

Appendix A
Operations Subgroup Activities

To : Operations subgroup

From: Terry Herter

Re : Common computer system recommendation

Here is a redraft of the initial recommendation written by Chas Beichman that common computer systems be purchased for each of the teams and the project. I apologize to Chas for changing this so much from the original version. This draft is a bit longer than the original since I have broken the recommendation up into components and also added some additional motivation for our selections. Please give me your comments within a week (by 27 Jan) or I assume no one has objections to the wording. Responses can be sent via telemail using Jim Houck's mailbox (JRHOUCK) or by calling me (607-256-4806). Dave Koch will be sending me info on microVAX's (cost and hardware). I will include that in the next (and last?) draft.

You will also note a summary of the issues that I felt were discussed at the meeting and what I felt our recommendations were. I am planning on sending this to my Co-I's and would appreciate any comments or additions you might make.

To : SIRTf SWG

From: Operations Subgroup

Re : Recommendation of a common computer system

Background:

At the request of the spectrometer team the SIRTf Operations Subgroup (OPS) extensively discussed whether common computer, operating system, and/or languages should be specified at an early stage in the project. Extensive savings may be possible by avoiding duplication of software that is being developed now for array testing, by providing a common starting point for all groups so that experience can be shared and later problems with system choice are avoided, and by providing an easy transfer of reduction algorithms and software to the Science Operations Center.

Discussion:

It was felt by the OPS that substantial economies would result from the early selection of a common system. The issues that led to this conclusion include:

- 1) There is room for considerable savings in software development costs both for the PI teams and for the project if carry-over of current development work can be performed. Also the hand-off of reduction algorithms and software to the project will be greatly simplified.
- 2) Since it is likely that each group will choose a different computer system unless a specific request for commonality is made by the project, early selection would prevent a divergence of concepts and ideas on computer systems (because of resources committed to different systems) and avoid additional costs of transporting software to a new system.
- 3) The experience of IPAC transporting AIPS and IRAF to their Jupiter system demonstrates that utilizing the same operating system does not imply easy transporting of software to another machine. This implies it is inadequate to specify only a common operating system or language. Identical systems are needed for true portability.
- 4) IRAF can be brought up on the systems (SAO has already done so on the system recommended below). This implies each team

can evaluate applicability of IRAF to their data reduction and analysis needs. The use of IRAF the core for SIRTf data analysis software will make analysis of SIRTf data easy for Guest Investigators. This will also result in a substantial savings in development time if IRAF can handle the analysis for current testing.

- 5) Easy transfer of software between PI teams and the project will not only allow wider evaluation and testing of routines and algorithms but avoid duplication of effort.

Our general feeling that early selection and implementation of a common system will save over the course of development of SIRTf many tens of man years of effort.

Requirements of System:

The OPS recommended the following system requirements for a common computer system:

- 1) Must be sufficiently powerful and have expected evolution and support to be useful for development now as well as in the future.
- 2) Must have I/O capabilities to handle image data, efficiently run IRAF, and be able to transfer software between systems.
- 3) Must have versatile, modern operating system that is not only supported well but viable for the next 10 to 15 years.

Recommendations:

Based on the issues outlined above the OPS makes the following recommendations

- 1) Purchase of common computer systems now to prevent divergence of the teams and the project. Suggest immediate purchase of one system per team plus one for the project and within the next 2 years purchase another one for each of these groups.
- 2) Selection of DEC microVAX 2 with following hardware
 - 2 Mbyte memory
 - 100 Mbyte disk
 - tape drive (6250 bpi capability?)
 - laser printer with graphics capability
 - terminals
 - color graphics display

- 3) Program development in C or FORTRAN under UNIX 4.2 (Ultrix)
- 4) Establishment of user's group with two representatives from each PI team and two representatives from the project that will be responsible for recommending hardware and software upgrades for the computer systems and for effecting the sharing of software. This group will establish policy for controlling compatability of the systems.
- 5) Documentation and commenting (within source code) are critical to the effective implementation of this scheme. By participating in this effort each group must assume responsibility for these activities. A set of be efficient documentation standards should be adopted to enforce this policy.

To : IRS Co-investigators

From: Terry Herter

Re : 16 January 1986 Operation Subgroup (OPS) meeting

A meeting of the Operations Subgroup was held at Ames on 16 January. In addition to myself, attending the meeting were

Fred Witteborn (chairman)
Tom Soifer
Dave Koch
Mike Jura
Chas Beichman
Nick Gautier
Tom Roellig
Mike Werner
Bob Jackson
Larry Manning
Jim Murphy

Below is a summary of the issues raised at the meeting and what I feel the recommendations and comments of the subgroup were:

- 1) The details of how the PI teams will provide hardware and software expertise and transfer their knowledge of instrument operation to the Science Operation Center (SOC) must be discussed early in the program.

OPS Recommendations:

Software - recommended algorithms and sample routines for reduction of data be provided to the project by the PI teams with documentation and monitoring by instrument teams to ensure project routines are functioning properly.

Hardware - not discussed (this is how knowledge of operation and monitoring of instrument is transferred).

- 2) Establishment of common computer system and/or operating system early in program to reduce development costs.

OPS Recommendation:

See attached note.

- 3) Providing data analysis software to Guest Investigators will be extremely important since otherwise GIs will develop software themselves at a substantial additional cost to NASA (through support of postdocs, graduate students, etc).

OPS Recommendation:

Select IRAF as analysis program and provide modules for IRAF that handle special requirements for SIRT

data analysis.

- 4) Observing modes of SIRTf. The following modes outlined by the project were discussed.
- a) Point-offset from 2 stars.
 - b) Point-offset from 1 star, depend on roll gyro.
 - c) Point-peak up on IR, depend on all gyros.
 - d) Offset from star outside FOV, depend on all gyros.
 - e) Raster scan using secondary mirror only.
 - f) Raster scan with telescope, "stop motion" with secondary.
 - g) Raster scan "step and integrate," telescope moves.
 - h) Survey (Continuous slew, variable rates, position monitoring.
 - i) Non-sidereal tracking.

Comments:

The above list of modes was accepted by OPS. Only MIPS expects to use all modes. IRS will not use e) or h), and IRAC will not use c) or h). Roll control for polarimetry was briefly discussed however this is a project and SWG issue. It was noted that the spectrometer will need to provide its own method for adjusting slit orientation, if adjusting the slit orientation is a concern.

- 5) The Science Operations Center (SOC).

Comments:

The project (Witteborn) will incorporate PI team comments into the SOC concept in preparation for the next meeting. Also see item 1) above.

Appendix B
December 1985 Rockwell Meeting

December 23, 1985

To : IRS Co-Investigators
From : T. Herter
Re : Rockwell BIBIB development effort

The is a report on a recent meeting we held with Rockwell discussing the BIB effort we have with them. Please keep this report confidential. Rockwell will be sensitive to results of their recent work being given to their competitors (i.e. Hughes, etc). We do not wish to violate their trust in us and jepordize what appears to be the start of a good working relationship.

On Monday 16 December 1985 George Gull and I met with Rockwell at the Science Center in Anaheim to discuss our BIBIB Switched-FET hybrid detector development effort with them. People we talked to include:

David Seib	- Program manager (/mux expert)
Dutch Staplebroek	- BIB coinventor
Steve Stetson	- Handling mux modification design
Dave Reynolds	- Testing
John Speer	- Handling detector fabrication
Dan Rawlins	- Technical/Cryogenic expert

We also briefly met Dick Florence and Mike Petrof. In the morning we had a quick briefing on:

- * Some of the BIBIB theory along with recent (12/04/85!) results on a new lot of 10x50 arrays (Staplebroek).
- * Mux./hybrid performance (Seib).
- * Mux mask mods to include non-destructive capability (Stetson).
- * Briefing on Cornell lab status and SIRTF performance goals and detector concerns (Herter).

The afternoon was spent in their lab playing with array from their most recent lot. It was essentially untested. The array was temperature controlled and mounted in a "dark" dewar. An LER (light emitting resistor, a 5.1K carbon resistor) could be turned on to verify that the detector was working and a reference calibrated Si:As photoconductor was mounted next to the array to measure the background level. A 10.6 micron filter was placed between the LER and the array. The tests we performed were

completely spontaneous and produced some interesting results.

We lowered the operating temperature from Rockwell's nominal operation point of 10K to 4.2K. This showed no noticeable (< 10%) change in response. At the lower temperature we increased the integration time from their usual 1.5 milliseconds to 300 seconds! We were able to set a limit to the dark current of < 125 electrons/second. This is only an upper limit because they do not know how dark their dewar is. On the negative side, they could only produce about 300 electrons read noise. This was due to pickup on the two of the voltage lines to the FET's (I believe these are the voltage supplies to the reset and read FET's). It appears to be essential that these lines must be filtered extremely well. An FFT of the noise showed definite pickup problems (60Hz, 120Hz, etc.). You could also see the noise on the scope. Without the pickup spikes the read noise looked like it would be about 180 electrons.

It was also apparent from the lab demonstration that running these arrays is a bit of an art and it will take some time to learn how to use them properly when we receive them. On the array we saw, Dave had not yet completely optimized the operating parameters. He claimed also that this was the worst read noise he measured for this lot thus far. It is not clear as yet how read noise will vary with operating temperature of the array.

We also had a brief look at their SSPM (Solid State Photomultiplier). It really does behave like a photomultiplier. Quite impressive. Finally, Rockwell gave us a 10x50 mux developed on their IR&D program to "smoke test" our system.

Results:

I discussed the results of our lab visit first because they were the most interesting and relevant for SIRTf. I will now give a quick summary of the morning briefings and George's discussions with Dan Rawlins.

The meeting went very well. They were responsive to our questions and very liberal with answers. They have produced a new lot of hybrids and done some preliminary testing since the detector advisory committee (McCreight, Houck, Fazio, Low, etc.) met with them at the end of September.

All of their testing has been done at temperatures of 10 - 12K. Their original tests (6/84) showed a typical dark current of 100 pA at 12K with 5-10% of the detectors having dark currents > 400 pA. The new lot (12/03/85 tests) showed complete uniformity with 30 pA of dark current at 12K. At 11K with their 1.5 msec frame rates they could not measure the dark current. One of their test arrays with 2V bias showed a responsivity of 3.3 amps/Watt (with a sigma/mean of 6.8%) at 1.0×10^{12} phot/sec/cm² at 10.6 microns (approximately 137x137 micron detectors on 150 micron centers). Another array operating at 10K

gave 4.5 amps/Watt with a sigma/mean of 3%.

Staplebroek showed us the expected (calculated) quantum efficiency for a BIBIB (for a given doping concentration, IR active layer thickness, etc). From 2 to about 31 microns the q.e. should be greater than 10%, and the q.e. looked to be about flat and on the order of 50% for wavelength from 10 to 30 microns (some channel fringes due to the IR active layer are expected). Their test results yielded a actual q.e. of about 25% at 10 microns. They can make the q.e. increase at the shorter wavelengths (i.e. flatten out the curve) by increasing the doping concentration but at the penalty of higher dark currents. The preliminary results from our afternoon in their lab indicate this may not be a problem.

They measure a (typical?) Zero Bias Noise which they call the read noise of the mux of 240 electrons with a 336 msec integration time and a 300 kHz preamp bandwidth. Increasing the integration time to 15 msec and decreasing the bandwidth to 3 kHz yields a read noise of 125 electrons. These numbers assume a gain in the source-follower output of 0.6 and a node capacitance of 0.46 pf. As stated above we were unable to reproduce these results in their lab; however my feeling is that with tuning of the driving voltages and better line noise isolation these numbers do not seem unreasonable.

Crosstalk, measured by shining a spot on a pixel and comparing the signal measured in the "hot" pixel with an adjacent one in the next row, is < 2%. This is an upper limit because some effects due to spreading of the spot may be present.

George discussed several topics with Rawlins which I will mention briefly:

- 1) They run micro-coax from the outside of their dewar to the work surface and flux with Stay Clean flux (very corrosive).
- 2) They use a greatly modified Textool 68-pin leadless carrier for mounting the array. They went over in detail how to mount and heat sink the array.
- 3) We did not find out how their heater arrangement worked but plan on calling them to discuss this. (George tried calling Rawlins already but could not get ahold of him.)

If you would like more information on their hardware call either George or me.

Appendix C
Rockwell Progress Reports

Science Center
Rockwell International Corporation
3370 Miraloma Avenue
P.O. Box 3105
Anaheim, California 92803-3105



Rockwell
International

In reply refer to SC86-701

January 16, 1986

Cornell University
Attn: Thomas R. Roger
123 Day Hall
Ithaca, New York 14853-2801

Re: Bi-Monthly Progress Report No. 1
For Period 10/21/85 through 12/20/85
Sub-Contract No. OSP 3867
Document No. SC5452.BMR

In accordance with the above referenced contract, enclosed
please find subject report.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

D. H. Seib
Manager
Focal Plane Technology

January 1986

SC5452.BMR

IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRTF

Bi-Monthly Progress Report No. 1
For Period 10/21/85 through 12/20/85

Subcontract No. OSP 3867

General Order No. 5452

Prepared For:

Thomas R. Rogers
Cornell University
123 Day Hall
Ithaca, New York 14853-2801



D.H. Seib



Rockwell International
Science Center

IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRTf

1.0 GENERAL

The IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRTf program (hereafter referred to as the SIRTf/IBC program) was begun by the Rockwell International Science Center in October of 1985. The purpose of the program is to fabricate, test and deliver state of the art BIBIB/SWIFET long wavelength hybrid focal plane arrays for characterization and assessment by SIRTf experiment teams. The devices fabricated and delivered are to be optimized and tested for conditions relevant to astronomical applications.

The following key personnel assignments for the program have been made:

Program Manager	Dr. David H. Seib
Responsible Engineer- Detector development	John J. Speer
Responsible Engineer- Multiplexer development	Scott B. Stetson.

Initial effort on the program has been concentrated upon establishing specifications and arrangements for the epitaxial growth of Si:As material which will be used for the Blocked Impurity Band (BIB or IBC) detectors; modification of the existing SWitched mosFET (SWIFET) multiplexer design to incorporate a non-destructive read-out capability; and initiation of a multiplexer device lot. The first technical interchange meeting for the program was held between Rockwell International personnel and T. Herter and G. Gull of Cornell University on Dec. 16, 1985.

2.0 DETECTOR DEVELOPMENT

Specifications were determined for the epitaxial growth of Si:As material which will be used to fabricate BIBIB detectors for the SIRTf/IBC program. These specifications are based on the parameters of epitaxial runs that have recently resulted in BIBIB detectors with excellent uniformity and performance. (The properties of these detectors are described further in section 4.0 below). The epitaxial run planned will be non-matrixed, i.e. only one set of parameters will be used for all wafers processed. Arrangements have been made to conduct the epitaxial run during the last part of January.

3.0 MULTIPLEXER DEVELOPMENT

The multiplexer device to be used for the hybrid arrays fabricated for the program is an existing SWIFET design with a 50 by 10 element array format. Readout of the device is controlled by an on-chip four phase shift register; pulses for

accessing and resetting the device columns are generated on chip by the shift register outputs and the clock voltages. As a result, when a detector output is read, it is immediately reset. For the SIRTf application, it is advantageous to have a non-destructive read capability, that is the capability to access (read) a pixel output without automatically resetting it. The possibility of modifying the existing design to incorporate a non-destructive read capability was therefore studied. Three approaches were identified and one was chosen for implementation, after discussion of the implementation and associated trade-offs and risks with Cornell University. The method chosen involves the introduction of reset and (reset complement) lines which are supplied by external clocks and control the resetting of the pixels. The method chosen gives the added flexibility of allowing correlated triple sampling to be performed for possible noise reduction. Furthermore, this method was successfully implemented and demonstrated on a previous SWIFET multiplexer design; therefore there is minimal risk associated with this modification. Two mask changes (to mask layers used toward the end of multiplexer processing) have been made to complete the redesign and a SPICE simulation of the circuit operation was performed. Some rerouting of the lines and re-assignment of the pads was necessary; the resulting chip layout is shown in figure 1. The multiplexer with the non-destructive read modification will be designated 14546 NDR.

Processing of a 12 wafer lot of SWIFET multiplexer devices was initiated on November 25, 1985. This lot will utilize the cryogenic NMOS process previously developed for these devices. The lot has progressed to the application of the first polysilicon layer at the end of this reporting period. The scheduled completion date is February 28, 1986.

4.0 TECHNICAL INTERCHANGE MEETING

The first technical interchange meeting for the SIRTf/IBC program was held at Rockwell on Dec. 16. Dr. Terry Herter and George Gull represented Cornell University. The subjects covered included program overview and schedule, BIBIB detector status, hybrid array test procedures and test results, multiplexer modifications for non-destructive read operation, and Cornell test plans and desired detector parameters. The updated program schedule, reflecting the actual start date of the program, is shown in Figure 2. Delivery to Cornell of an existing multiplexer device, bonded in a package, was made at the meeting. Therefore all activities are on schedule at this time.

After briefings and discussions, a laboratory demonstration was conducted. An operating BIBIB/SWIFET hybrid reflecting the latest BIBIB detector technology was demonstrated. The array had 500 (100%) low dark current pixels. Operating temperature was reduced to 4.2 K, allowing an integration time of 300 sec to be achieved (under dewar background limited conditions). An upper limit to the dark current of 140 electrons/second was

established for these conditions. From this data and an assumed read noise of 200 electrons (which has been observed in other measurements), an NEP of approximately $1.3 \times 10^{-18} \text{ W}/\sqrt{\text{Hz}}$ @10 microns can be inferred.

5.0 PLANS FOR NEXT PERIOD

In the next reporting period, growth of the epitaxial layers needed for the BIBIB detectors will be accomplished. Processing of a device lot of detectors will be initiated. SWIFET multiplexer processing will be continued and the two masks needed for the non-destructive readout modification will be fabricated and delivered.

NON-DESTRUCTIVE READ DESIGN

MULTIPLEXER LAYOUT

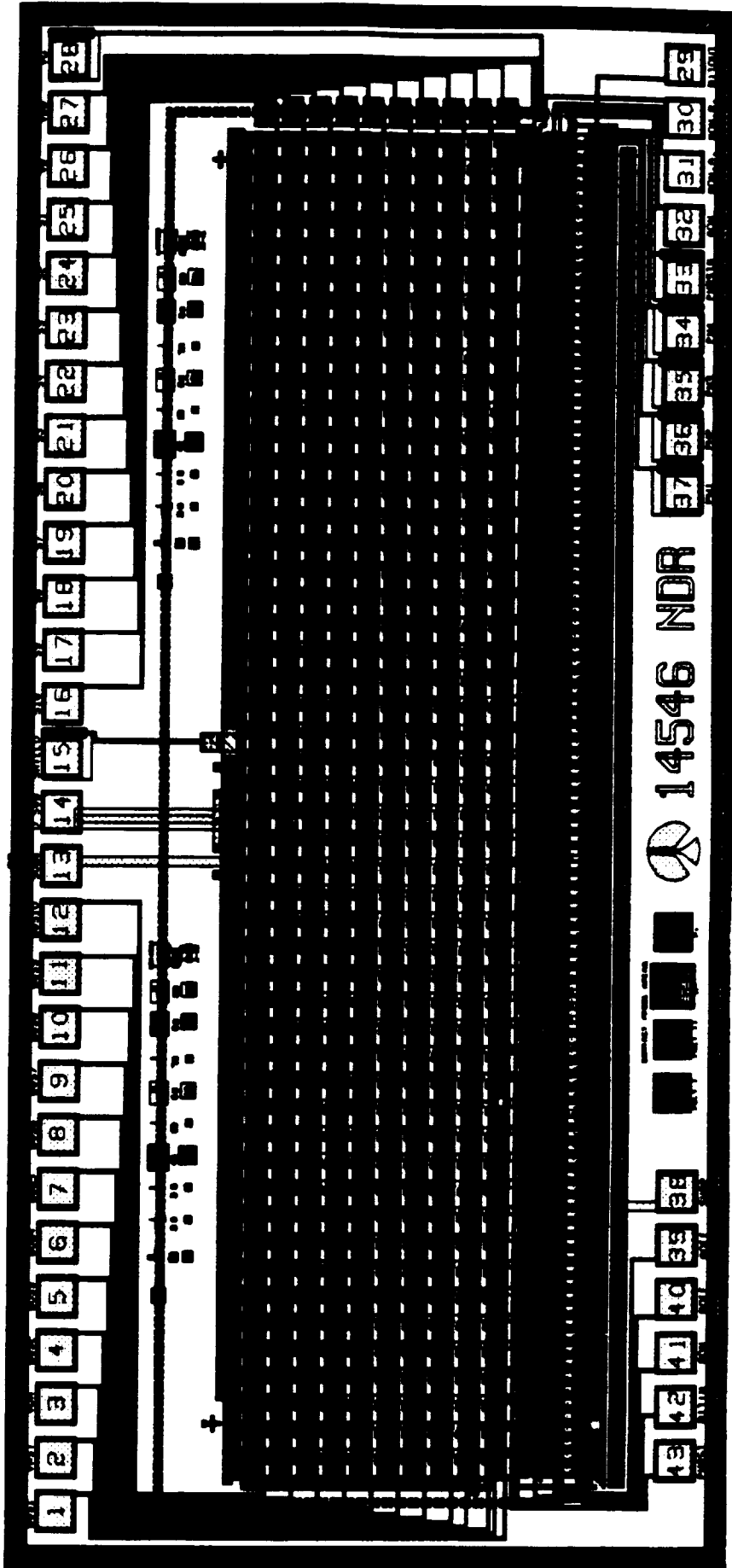
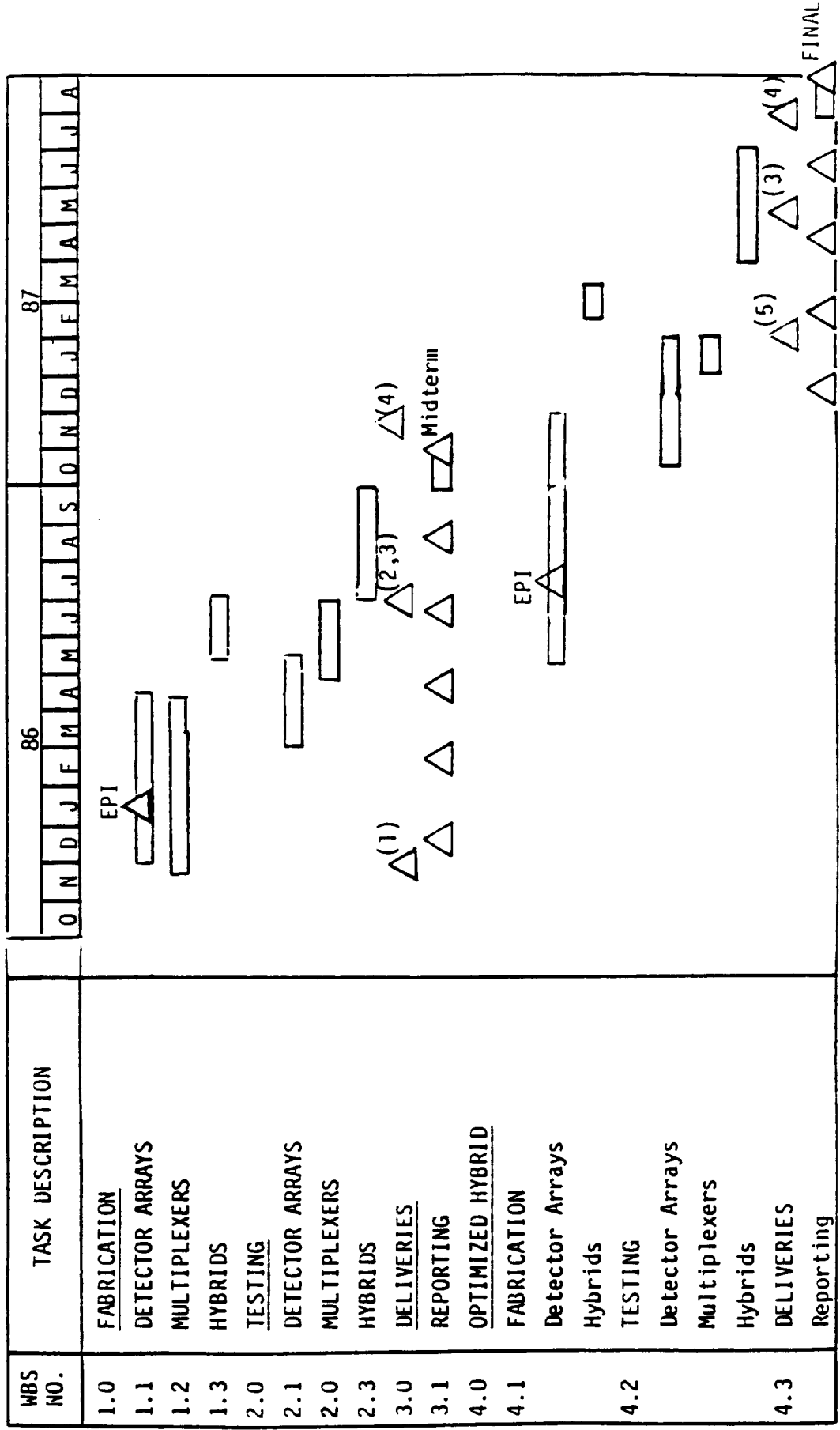


FIGURE 1

Figure 2 SCHEDULE - IBC HYBRID ARRAYS FOR SIRTIF



- (1) Existing Detector Array and Multiplexer
- (2) New Detector Array and Multiplexer
- (3) Untested Hybrids
- (4) Tested Hybrids
- (5) New Detector Array (Optimized)



Science Center
Rockwell International Corporation
3370 Miraloma Avenue
P.O. Box 3105
Anaheim, California 92803-3105



Rockwell
International

In reply refer to SC86-705

March 28, 1986

Cornell University
Attn: Thomas R. Rogers
123 Day Hall
Ithaca, New York 14853-2801

Re: Bi-Monthly Progress Report No. 2
For Period 12/21/85 through 02/20/86
Sub-Contract No. OSP 3867
Document No. SC5452.BMR

In accordance with the above referenced contract, enclosed
please find subject report.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

D. H. Seib
Manager
Focal Plane Technology

IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRTF

1.0 GENERAL

In the last reporting period, effort on the SIRTF/IBC program emphasized growth of epitaxial layers needed to fabricate BIBIB detectors, initiation of the first lot of BIBIB detectors, and continued processing of a lot of SWIFET multiplexers. These activities are discussed in more detail below. Permission was requested from the Kuiper Infrared Telescope Experiment (KITE) program office to release information regarding preamplifier and readout electronics developed for SWIFET/BIBIB hybrids to Cornell University. Permission was granted and a schematic diagram of the electronics was furnished. Two front illuminated BIB detector chips were sent to Dr. T. Herter for evaluation. One chip contains four detectors of different areas while the other chip is a linear array with ten elements.

2.0 DETECTOR DEVELOPMENT

An epitaxial run with the BIBIB epitaxial structure was successfully made at the end of January. Target doping profiles and carrier concentrations were achieved. From the epitaxial wafers, 14 were selected for BIBIB detector array fabrication. These wafers have infrared active layers with thicknesses in the range 15-16 microns and with arsenic doping concentration from 4 to 5.6×10^{17} . A process follower for the lot was developed and device fabrication was begun. The estimated completion date for this lot is April 15, 1986.

3.0 MULTIPLEXER DEVELOPMENT

Processing of the multiplexer device lot that was initiated in November of 1985 has continued. Processing was completed through deposition of the oxide layer prior to contact etch on February 7. At this point, the lot was put on hold to await new contact and aluminum etch masks. New versions of these masks were designed in order to implement non-destructive readout. Considerable delay was encountered in obtaining these new masks because of a combination of equipment problems in the mask making facility and data formatting errors in the computerized data base. These problems have all been rectified and the masks are expected March 20, 1986. The lot is expected to be available for initial testing (after aluminum etch) on April 4, 1986.

The redesigned circuit (for incorporation of the non-destructive read option) was successfully simulated using the SPICE 2G circuit simulation program. Shorts/opens and functional test procedures have been modified to accommodate the new device design and a new probe card has been obtained.

4.0 PLANS FOR NEXT PERIOD

In the next reporting period, both the detector and multiplexer lots will complete fabrication to the point where initial testing can begin. Initial testing of the detector arrays involves visual inspection and grading, followed by bonding up individual test devices on the chip for cryogenic test. Cryogenic tests are used to measure detector dark current and photocurrent on a sampled basis in order to evaluate the lot. Initial testing of the multiplexer devices involves shorts/opens tests followed by a rudimentary, room temperature functional screen test. These tests establish that the devices work properly at this stage. Given proper functionality, the multiplexer devices will be returned to processing for deposition of indium bumps.

Appendix D
New Spectrograph Concept

A NEW HIGH RESOLUTION SPECTROGRAPH DESIGN

Optical Design

A schematic design of the optical system is shown in Figure 1. It consists of a Czerny-Turner (CT) system operating at the telescope's focal ratio ($f/17$) with a complement of three small (1" X 1") diffraction gratings. Mirror M4 simultaneously converts the output focal ratio to $f/10$, reimages the exit pupil of the CT onto the entrance pupil of the following echelle and corrects the astigmatism of the first section. This mirror has a toric surface but ray traces have shown that an aluminized spectral lens has sufficient surface quality to achieve all of the above goals. We have successfully used lenses of this type in other optical systems in the past. The high resolution is achieved by the echelle system operating at $f/10$. The optical system is an off axis Cassegrain with an aperture of 4.5". The echelle operates in the Litrow mode with an 60 degree angle of incidence. The Ge:Be detectors are mounted in the focal plane of the echelle in small cavities. The BIB array is fed by a reimaging system that increases the speed of the beam on the detectors to $f/3$. The echelle, its off axis optical system and their mounting fixtures are to be made of aluminum to reduce the effects of thermal contraction. The optics in the CT section including the gratings can be made of glass to reduce cost.

The system can be used in low resolution by inserting a concave spherical mirror in front of the convex mirror in the echelle section. In this way the echelle is bypassed and the light from the low resolution system is directed onto the array. If a plane mirror were positioned into the grating spot then the system will work as a camera as well!

Optical Raytrace

The design described above has been extensively raytraced using an optical design program we have developed. The program runs on an IBM PC and allows general conic, eighth order aconic, tipped, and/or decentered refractive and reflective surfaces. Gratings, prisms, central obscurations and toric surfaces are also allowed. The program outputs spot diagrams, rms image sizes and the normal Sidel aberation coefficients. The program has been used to analyse a number of complex systems several of which have been built. The code has also been checked against the results of about half a dozen other codes. We are confident of its accuracy.

Figure 2 shows the spot diagram in the echelle focal plane for a point source illumination of the entire system. In this example mirror M4 is spherical. In this case the system is seen to be diffraction limited down to about 12 microns. The size of the plotted box corresponds to four (2x2) pixels of the Rockwell

BIB array. The aberations are clearly small enough to meet the needs of the proposed application. By substituting a toric surface for M4 the system will be diffraction limited to about 3 microns making the system a powerful tool for conventional groundbased or 5 to 8 micron airborne research.

The resolution of a diffraction grating spectrograph that is limited by the slit width is given by

$$R = \frac{2 \tan(b)}{db}$$

where:

R = the resolution, $\lambda / \Delta \lambda$ (full width half maximum)

b = the angle of incidence (in our case 60 degrees)

db = the angle of the slit as seen from the echelle (In our case of a 30 arc second slit this is 0.0011 rad).

therefore:

$$R = 3200$$

The optical system provides two detector pixels in the reimaged size of a 30 arc second entrance slit. Therefore, by reducing the entrance aperture to 15 arc seconds the resolution is boosted to 6400. In the former case there are two measurement points per resolution element at each exposure while in the second case one needs to make two exposures to have two points per resolution element. Of course the post optics could be designed to have one resolution element per pixel.

WAVELENGTH COVERAGE

Several gratings are mounted on the GRATING #1 mount so that they each work only in first order. With four gratings it should be easy to work over a factor of 4 in wavelength. Over this range the echelle will go from about fifth to fortieth order. We have not worked out the scheme in full but I think that should be ok.

With two of these units we should be able to go from 4 to 200 microns (4 -32 microns and 30 to 200 microns) at both the high and low resolution. By adding a fifth low resolution grating to the short wavelength module we can add the 2.5 to 4 micron low res function as well.

DETECTORS

Obviously this scheme is saving of detectors. The short wavelength section needs only a single BIB array assuming we can

stand some loss in the quantum efficiency at the shortest wavelengths. The long wavelength module would require two or three arrays but each having many fewer detectors. Stressed and unstressed Ge:Ga would be a minimum; the addition of Ge:Be would help in the 30 to 50 micron region.

RESOLUTION

In the above analysis it was assumed that the echelle had an aperture of 4.5 inches. This is somewhat larger than the 3 inch optics now used in the high resolution units. The larger aperture combined with the much larger angle of incidence leads to a higher resolution by a factor of about 5 for the same slit width. Among other things this gets us to a resolution of about 2,000 for the 120 to 200 micron band. I am sure we could fit two 4.5 inch modules into the MIC. We may be able to fit two 6 inch ones if the aperture does not go too much below the 85 cm mark.

THE GRATING SHAFT PROBLEM

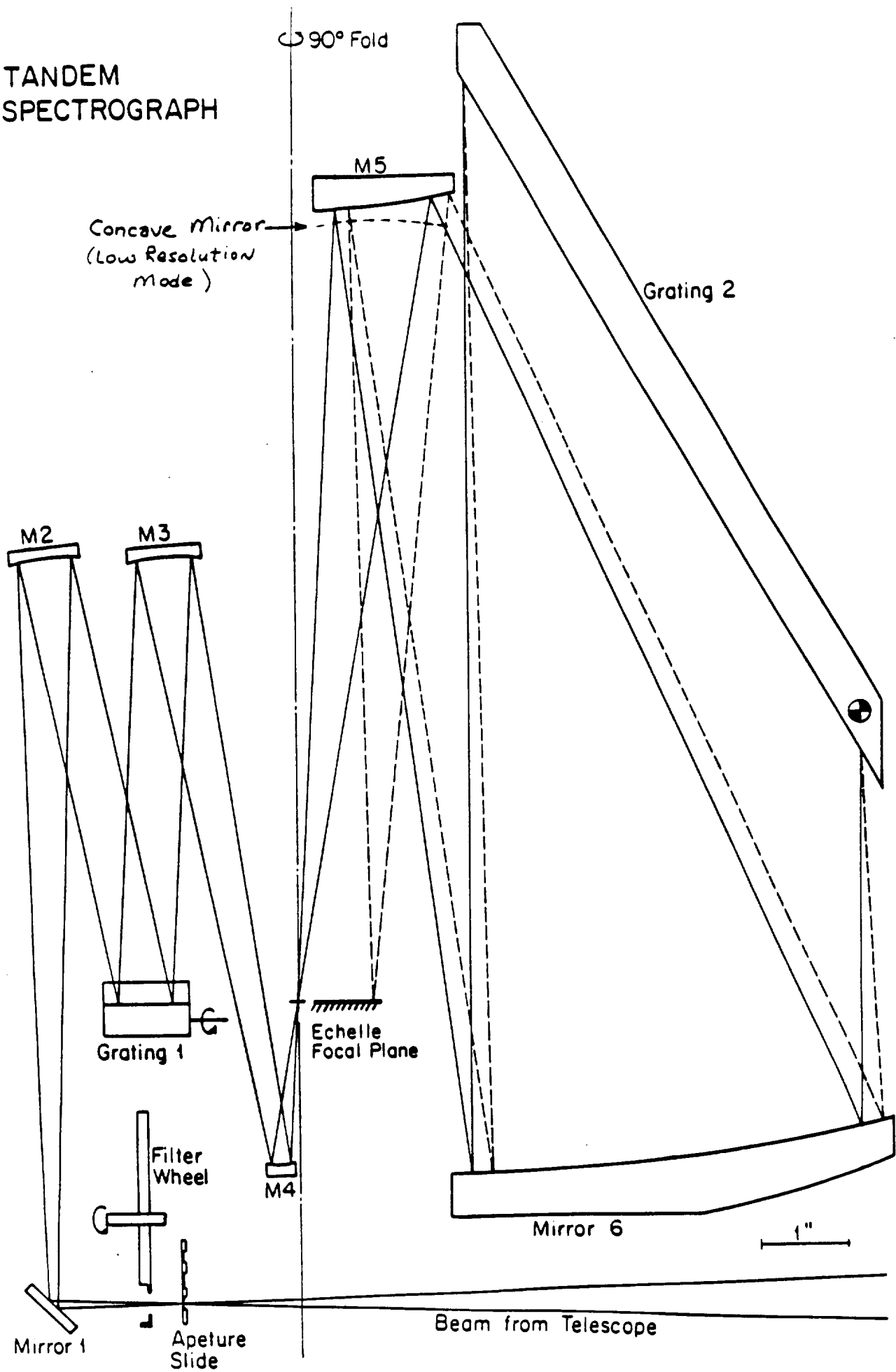
In this design we no longer have the need to be able to measure the angular position of the shaft to high accuracy over a wide range of angles. The echelle only needs to be turned by about 5 to 10 degrees. This could be done with a cam on the end of a stepping motor. Heatsinking the echelle will be easier than cooling the grating shaft for the same reason.

SOME RANDOM THOUGHTS

I have been talking about a system with two separate modules each having a low resolution section and an echelle section. It seems to me that we could get by with a single low resolution section with the order of 9 or 10 gratings working in first and second order. Mirror M4 would then be mounted on a flip flop mechanism that would feed the light to either the long or shortwavelength echelle.

MECHANISM	NUMBER OF POSITIONS	RESOLUTION
ENTRANCE APERTURE/SLIT	6	1/10 of smallest slit
FILTER WHEEL	16	2 degrees
GRATING CAROUSEL	10	.1 degree
FEED MIRROR	2	.5 degrees
POST SLIT	6	.1 OF SMALLEST
FLIP IN SPHERE	2	TBD
EHELLE DRIVE	NA	.1 deg on cam

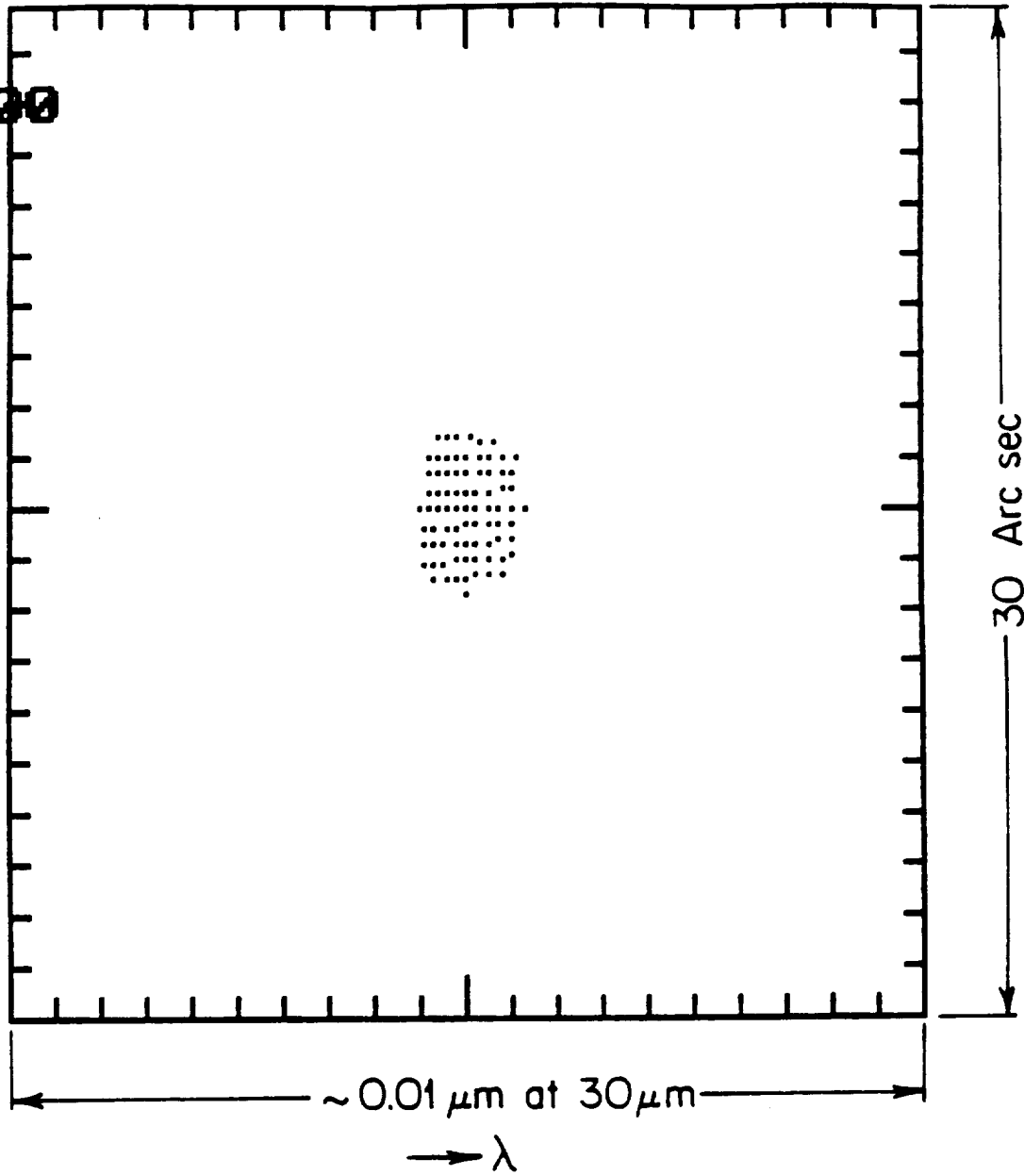
TANDEM SPECTROGRAPH



Scale:
0.0025000
per Tic

Done

<cr>
for
Stats



Typical spot diagram in the focal plane of the echelle using a spherical mirror for M4. The box represents the area of four pixels (2x2) on the BIB array. By using a toroidal mirror for M4 the spot size can be reduced to approximately one-fifth the linear size shown here over the entire field of view covered by the 10x50 BIB array.

Appendix E
Spectrometer Resolution Issue

Resolution Issues and Choices for the High-Resolution Mode of the IRS

Resolution Investigation Group:

T. Herter, Dan Watson, and D. Weedman

Introduction

The new spectrometer design put forward by Jim Houck can enable us to increase the resolution of the IRS, particularly at the longer wavelengths where resolution in the old design is only modest (approximately 400). This reopens the question as to the optimum resolution to strike a compromise between extragalactic and galactic desires, and broad versus narrow line sensitivity limits, if indeed a compromise is preferred or required. This report summarizes the issues discussed over the past month by the IRS team regarding the resolution issue.

Scientific issues

The following scientific issues regarding performance have been raised:

1) Distant extragalactic objects:

- a) To achieve ultimate sensitivity on faint extragalactic objects, the lines should not be resolved. Typical lines widths should be 200-300 km/sec implying a limiting resolution of 1500-1000.
- b) To verify redshifts determinations made with the low-resolution spectrometer using the high resolution spectrometer (by measuring at least two lines) requires the wavelength range spanned by a single setting of the high resolution spectrometer to be enough to cover the likely redshift range in a line chosen to confirm and improve the redshift estimate (see Appendix A).

2) Nearby galaxies and galactic sources:

- a) To achieve the highest sensitivity and to improve the line-to-continuum ratio for detection of weak lines in narrow line sources, the resolution should be increased as much as possible. For useful velocity information to be gained velocity resolutions of at least 60 km/sec ($R = 5000$) are probably necessary. This is much higher than that desired for extragalactic work.

Technical Issues

The following technical issues have been raised in discussions with the co-investigators:

1) Read Noise and BLIP:

- a) Although the read noise that can be achieved with the IRS is highly uncertain and will vary with waveband, it can have a significant impact on ultimate performance. The expected sensitivity of the IRS for different read noises, integration times and resolutions is given in Appendix B. For integration times expected for SIRTf, the resolution necessary to achieve background limited performance (BLIP) for a given read noise is also computed. These results are given in Appendix B.

2) Sampling interval:

- a) There should be at least two points per resolution element (PPRE), the number of pixels covering the projected aperture in the detector plane, to ensure accurate velocity and flux information. Appendix C discusses the effects of sampling at more than one PPRE on the IRS sensitivity.

3) Decreased efficiency at higher resolution:

- a) The time required to obtain a partial or complete spectrum will scale according to the resolution. This does not seem to be a major issue. As discussed by the Power Investigation Group (PIG) report, obtaining full spectra in the high-resolution mode will probably be a heavily used only during the first stages of IRS operation (the "discovery" phase).
- b) The possibility of multiple lines in one exposure is decreased with increasing resolution. As an example, the coverage at 150 μ m using a resolution of 1000 with 20 detectors sampling two points per resolution element is 1.5 μ m. There are no closely spaced lines we are likely to look for in weak sources that are effected in this manner so this seems to be a non-issue.

4) Flat-fielding problem:

- a) The problem of detecting lines and features against source continuum and natural backgrounds is influenced by the choice of resolution. This problem, known as the flat fielding problem, is the same as that encountered in optical spectroscopy which is limited by how well the backgrounds can be subtracted. Flat fielding effects may cause our sensitivity limit to be above that expected for BLIP (See Appendix D).

Conclusions

The results of Appendix B indicate that it is quite likely that the spectrometer will achieve or be near background limited performance (BLIP) for wavelengths greater than about 20um for reasonable desired resolutions (1000-3000). This means that from a purely BLIP viewpoint, resolution is not an issue with respect to broad lines since pixels can be co-added with no loss in detectability.

The question of flat fielding however is a more serious concern (Appendix D). It appears that at the longest wavelengths our sensitivity will be limited by how well the continuum from the source or natural backgrounds can be removed. Note that the problem of line contrast for broad lines may not be effected as much by increasing the resolution as one might at first expect. Once the resolution becomes great enough to begin to resolve the line, the background and line levels will scale together so that although the flat fielding problem does not get better by increasing the resolution, neither does it get worse. This may tend to push the spectrometer towards higher resolution to increase contrast (and sensitivity) for weak lines although the importance of ease in obtaining total wavelength coverage and of confirming redshift measurements with the high resolution spectrometer must be considered.

APPENDIX A

Redshift Confirmation

For a redshift measurement performed with the low-resolution spectrometer the uncertainty is given by

$$\Delta z = f_{LR} \frac{\Delta \lambda_{LR}}{\lambda} = \frac{f_{LR}}{R_{LR}}$$

where f_{LR} is the fraction of a resolution element to which measurement can be made (note that this could be 1 or 2). The range covered by a single setting of the high-resolution spectrometer is given by

$$\begin{aligned} \Delta z &= \frac{N_d}{2} \frac{\Delta \lambda_{HR}}{\lambda} \\ &= \frac{N_d}{2} \frac{1}{R_{HR}} \end{aligned}$$

where N_d is the number of detectors and the factor of 1/2 enters because the spectrum is sampled at two points per resolution element. Setting the two equations equal yields

$$R_{HR} = R_{LR} \frac{N_d}{2f_{LR}}$$

Taking $R_{LR} = 75$, $f_{LR} = 1$, and $N_d = 20$ yields

$$R_{HR} = 750$$

Note that the estimate of R_{HR} probably depends more critically on how well we feel the low-resolution mode can determine redshift, i.e., how small f_{LR} can be taken to be, rather than changes in the number of detectors, since doubling the number of detectors will be difficult.

APPENDIX B

Sensitivity Estimates

The limiting 1- σ flux limit of the IRS is computed for different resolutions, read noises and integration times. The backgrounds are assumed to be

	<u>Emissivity</u>	<u>Temperature</u>	
Zodiacal	2.3×10^{-7}	246 °K	ecliptic plane
Solar	7.9×10^{-14}	4500	
Galactic	1.0×10^{-4}	15	
Telescope	0.1	7	

Zodiacal	7×10^{-8}	275	ecliptic pole

Although calculations were performed for the ecliptic plane only, the zody pole is included in the table for reference. Read noise is included by modifying the noise component in the equation for F_{BLIP} (Appendix D) to

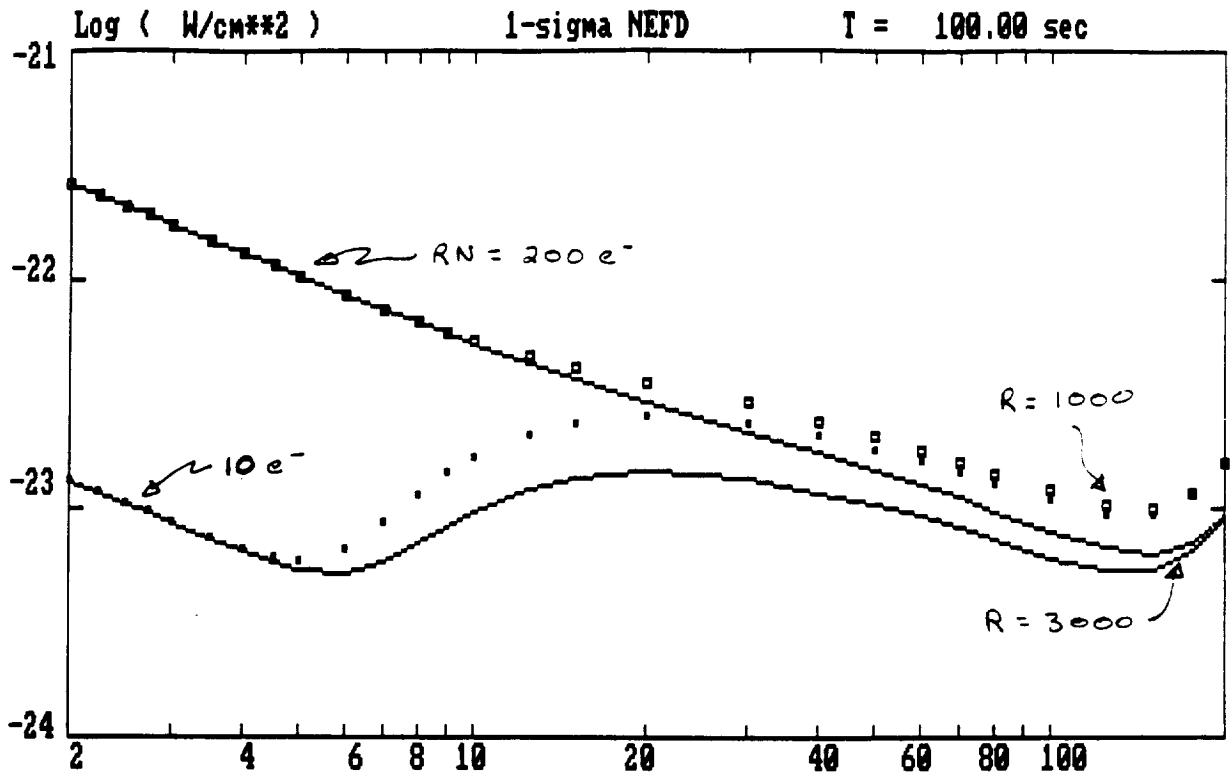
$$N_{ph} \rightarrow N_{ph} + \frac{(RN)^2}{4}$$

where RN is the read noise. The factor of 1/4 is included because the BLIP noise component has a factor of 2 for g-r noise and another factor of 2 for conversion of bandwidth to integration time. A table of the

parameters varied for each of the figures B-1 through B-6, and is given below:

Figure	Units	Resolution		Read Noise		Integration Time	
		1000	3000	100e ⁻	200e ⁻	100 sec	500 sec
B-1	W/cm ²	x	x		x	x	
B-2	W/cm ²	x	x		x		x
B-3	W/cm ²	x	x	x		x	
B-4	W/cm ²	x	x	x			x
B-5	mJy	x	x	x		x	
B-6	mJy	x	x	x			x

All calculations assume that the detectors sample at one point per resolution element (PPRE). See Appendix C for a discussion of how the sensitivity is effected by an increase in the number of PPRE.



B-1

Sensitivity Analysis

Observational Parm

IT: Integration Time (sec) 100.00
 SU: Sensitivity Units W/cm**2

Zody Parm

EZ: Emissivity 2.30E-07
 TZ: Temperature (K) 246.00

Telescope One

R1: Resolving Power 1000.00
 D1: Diameter (m) 0.85
 B1: Beamsize (arcsec) 1.00
 E1: Emissivity 0.10
 T1: Temperature (K) 7.00
 C1: Chopper freq. (Hz) 0.00
 N1: Read Noise 200.00

Telescope Two

R2: Resolving Power 3000.00
 D2: Diameter (m) 0.85
 B2: Beamsize (arcsec) 1.00
 E2: Emissivity 0.10
 T2: Temperature (K) 7.00
 C2: Chopper freq. (Hz) 0.00
 N2: Read Noise 200.00

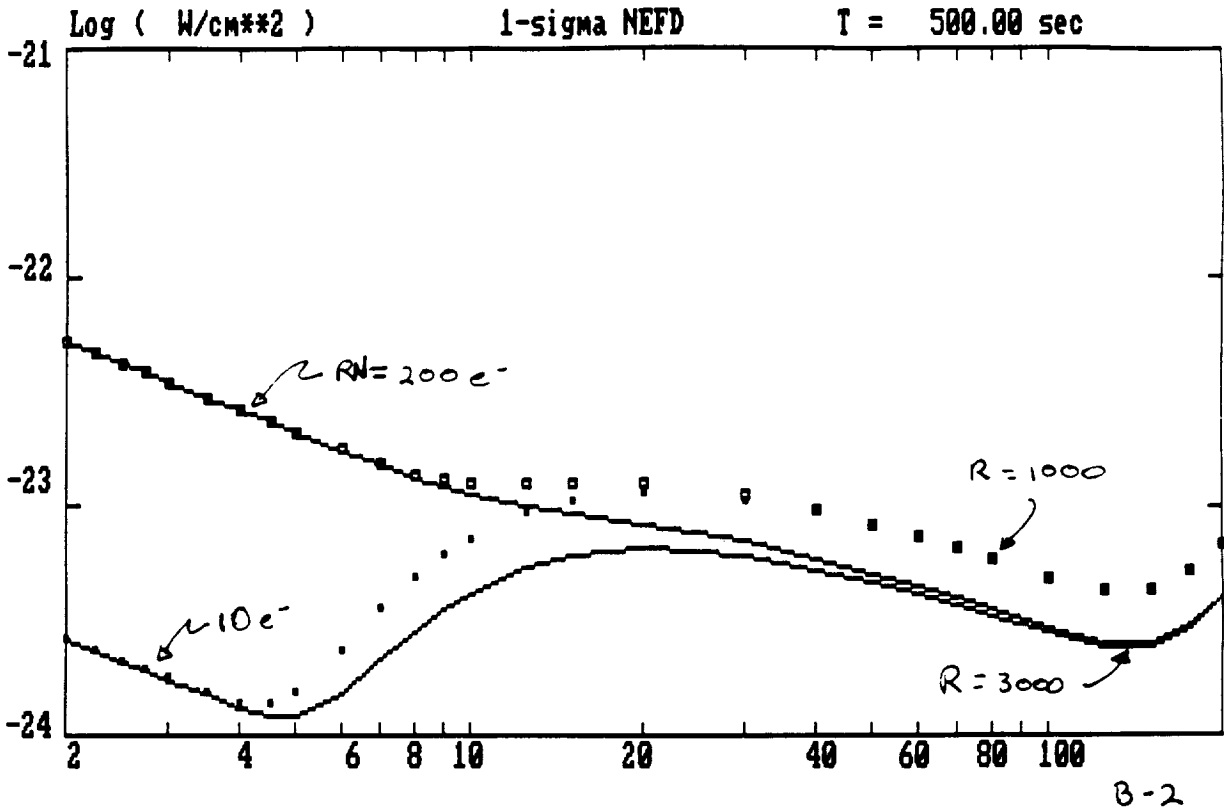
Miscellaneous

CO: Compute Sensitivity
 PR: Printer Output (Y/N) No
 NC: Number of Log Cycles 0.00
 PL: Plot LI: List EX: Exit

Instrument Parm

TR: Transmission 0.30
 QE: Quantum Efficiency 0.50
 WR: Wavelength Range all
 PG: Photo-cond. Gain 1.00
 PH: Photovoltaic/cond. PV

Select :



Sensitivity Analysis

Observational Parm's

IT: Integration Time (sec) 500.00
 SU: Sensitivity Units W/cm**2

Zody Parm's

EZ: Emissivity 2.30E-07
 TZ: Temperature (K) 246.00

Telescope One

R1: Resolving Power 1000.00
 D1: Diameter (m) 0.85
 B1: Beamsize (arcsec) 1.00
 E1: Emissivity 0.10
 T1: Temperature (K) 7.00
 C1: Chopper freq. (Hz) 0.00
 N1: Read Noise 200.00

Telescope Two

R2: Resolving Power 3000.00
 D2: Diameter (m) 0.85
 B2: Beamsize (arcsec) 1.00
 E2: Emissivity 0.10
 T2: Temperature (K) 7.00
 C2: Chopper freq. (Hz) 0.00
 N2: Read Noise 200.00

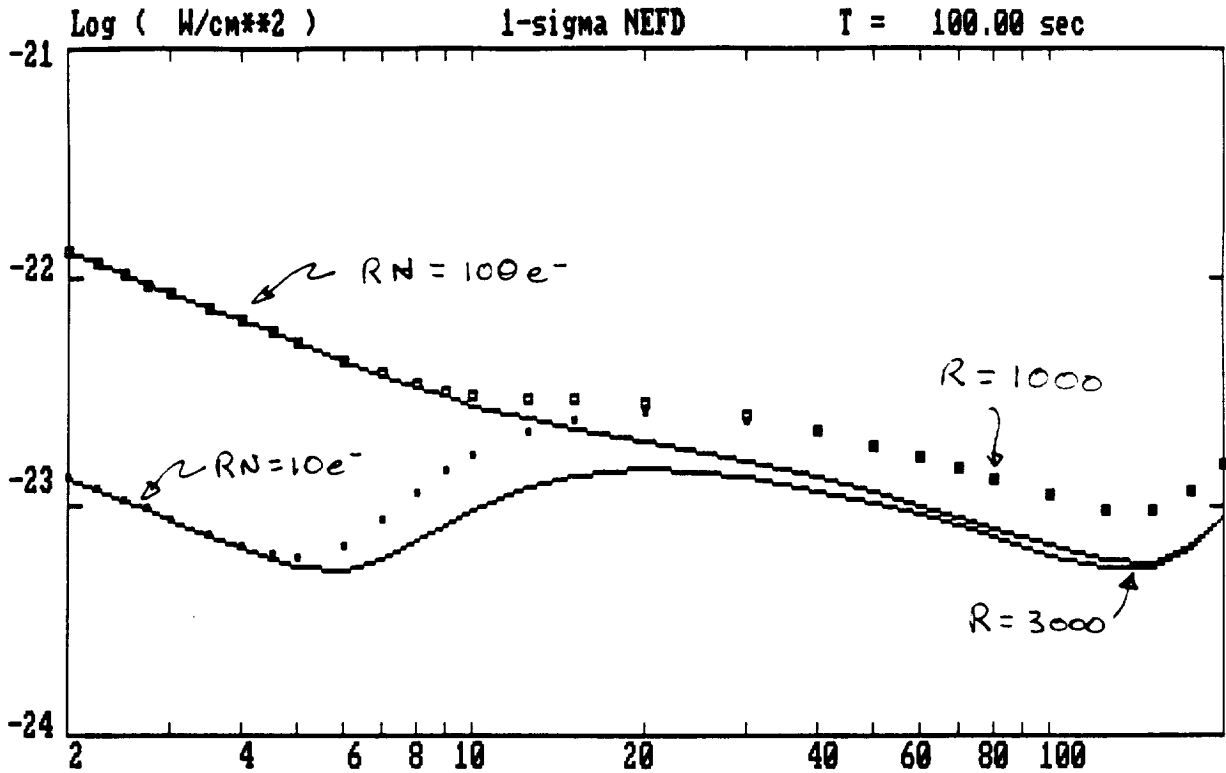
Miscellaneous

CO: Compute Sensitivity
 PR: Printer Output (Y/N) No
 NC: Number of Log Cycles 3.00
 PL: Plot LI: List EX: Exit

Instrument Parm's

TR: Transmission 0.30
 QE: Quantum Efficiency 0.50
 WR: Wavelength Range all
 PG: Photo-cond. Gain 1.00
 PH: Photovoltaic/cond. PV

Select :



B-3

Sensitivity Analysis

Observational Parm's

IT: Integration Time (sec) 100.00
 SU: Sensitivity Units W/cm**2

Zody Parm's

EZ: Emissivity 2.30E-07
 TZ: Temperature (K) 246.00

Telescope One

R1: Resolving Power 1000.00
 D1: Diameter (m) 0.85
 B1: Beamsize (arcsec) 1.00
 E1: Emissivity 0.10
 T1: Temperature (K) 7.00
 C1: Chopper freq. (Hz) 0.00
 N1: Read Noise 100.00

Telescope Two

R2: Resolving Power 3000.00
 D2: Diameter (m) 0.85
 B2: Beamsize (arcsec) 1.00
 E2: Emissivity 0.10
 T2: Temperature (K) 7.00
 C2: Chopper freq. (Hz) 0.00
 N2: Read Noise 100.00

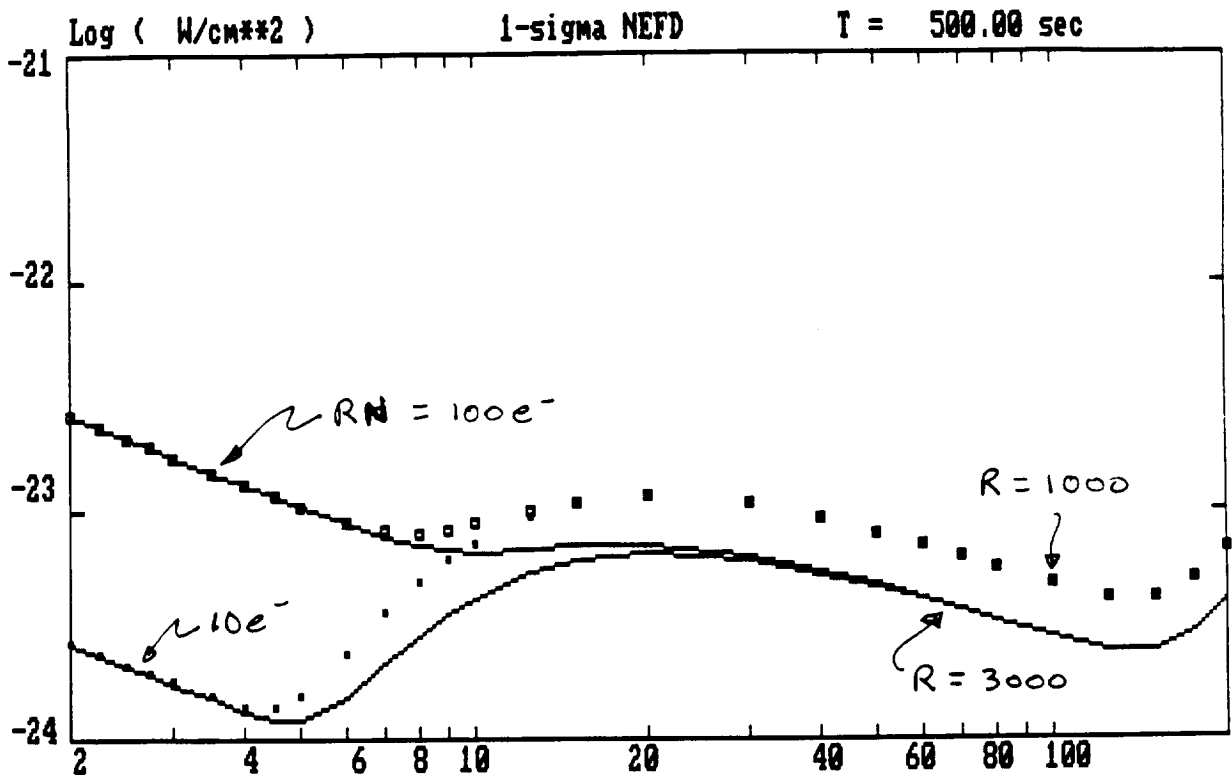
Miscellaneous

CO: Compute Sensitivity
 PR: Printer Output (Y/N) No
 NC: Number of Log Cycles 3.00
 PL: Plot LI: List EX: Exit

Instrument Parm's

TR: Transmission 0.30
 QE: Quantum Efficiency 0.50
 WR: Wavelength Range all
 PG: Photo-cond. Gain 1.00
 PH: Photovoltaic/cond. PV

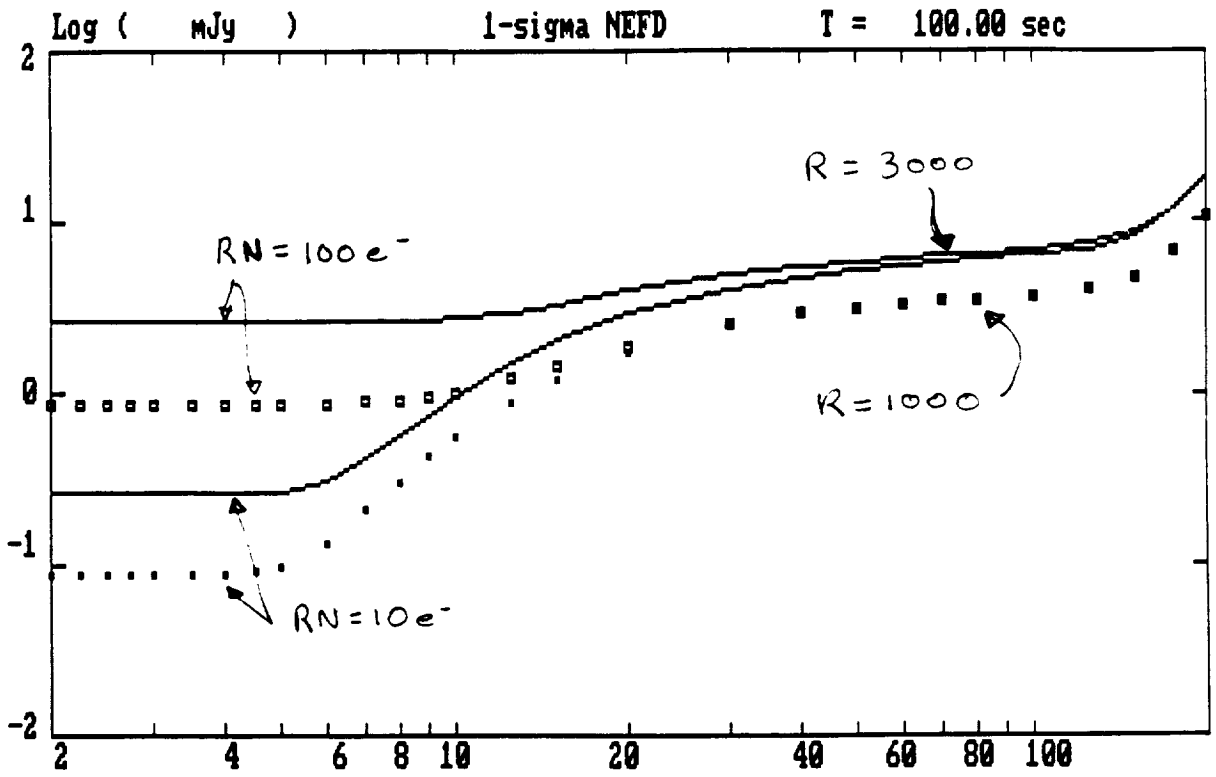
Select :



Sensitivity Analysis

----- Observational Parm's -----		----- Zody Parm's -----	
IT: Integration Time (sec)	500.00	EZ: Emissivity	2.30E-07
SU: Sensitivity Units	W/cm**2	TZ: Temperature (K)	246.00
----- Telescope One -----		----- Telescope Two -----	
R1: Resolving Power	1000.00	R2: Resolving Power	3000.00
D1: Diameter (m)	0.85	D2: Diameter (m)	0.85
B1: Beamsize (arcsec)	1.00	B2: Beamsize (arcsec)	1.00
E1: Emissivity	0.10	E2: Emissivity	0.10
T1: Temperature (K)	7.00	T2: Temperature (K)	7.00
C1: Chopper freq. (Hz)	0.00	C2: Chopper freq. (Hz)	0.00
N1: Read Noise	100.00	N2: Read Noise	100.00
----- Miscellaneous -----		----- Instrument Parm's -----	
CO: Compute Sensitivity		TR: Transmission	0.30
PR: Printer Output (Y/N)	No	QE: Quantum Efficiency	0.50
NC: Number of Log Cycles	3.00	WR: Wavelength Range	all
PL: Plot	LI: List	PG: Photo-cond. Gain	1.00
	EX: Exit	PH: Photovoltaic/cond.	PV

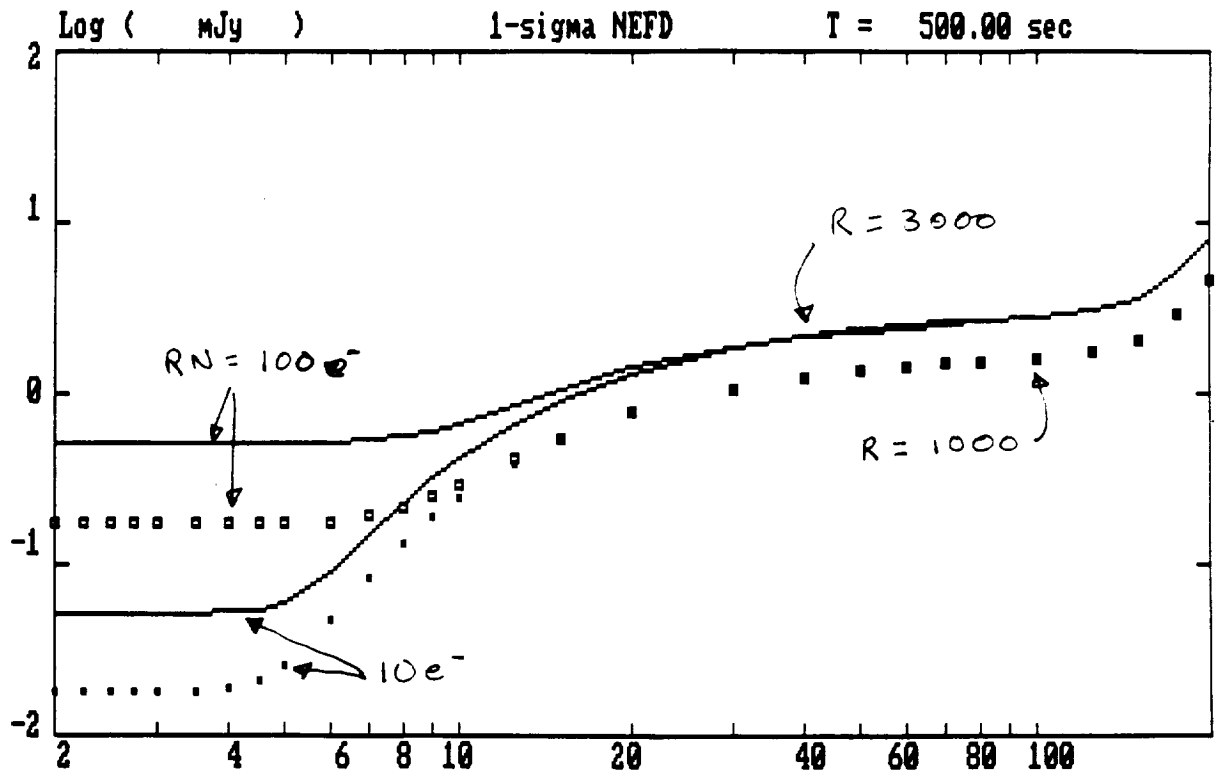
Select :



Sensitivity Analysis

<u>Observational Parm's</u>		<u>Zody Parm's</u>	
IT: Integration Time (sec)	100.00	EZ: Emissivity	2.30E-07
SU: Sensitivity Units	mJy	TZ: Temperature (K)	246.00
<u>Telescope One</u>		<u>Telescope Two</u>	
R1: Resolving Power	1000.00	R2: Resolving Power	3000.00
D1: Diameter (m)	0.85	D2: Diameter (m)	0.85
B1: Beamsize (arcsec)	1.00	B2: Beamsize (arcsec)	1.00
E1: Emissivity	0.10	E2: Emissivity	0.10
T1: Temperature (K)	7.00	T2: Temperature (K)	7.00
C1: Chopper freq. (Hz)	0.00	C2: Chopper freq. (Hz)	0.00
N1: Read Noise	100.00	N2: Read Noise	100.00
<u>Miscellaneous</u>		<u>Instrument Parm's</u>	
CO: Compute Sensitivity		TR: Transmission	0.30
PR: Printer Output (Y/N)	No	QE: Quantum Efficiency	0.50
NC: Number of Log Cycles	0.00	WR: Wavelength Range	all
PL: Plot		PG: Photo-cond. Gain	1.00
LI: List		PH: Photovoltaic/cond.	PV
EX: Exit			

Select :



B-6

Sensitivity Analysis

Observational Parm's

IT: Integration Time (sec) 500.00
 SU: Sensitivity Units mJy

Zody Parm's

EZ: Emissivity 2.30E-07
 TZ: Temperature (K) 246.00

Telescope One

R1: Resolving Power 1000.00
 D1: Diameter (m) 0.85
 B1: Beamsize (arcsec) 1.00
 E1: Emissivity 0.10
 T1: Temperature (K) 7.00
 C1: Chopper freq. (Hz) 0.00
 N1: Read Noise 100.00

Telescope Two

R2: Resolving Power 3000.00
 D2: Diameter (m) 0.85
 B2: Beamsize (arcsec) 1.00
 E2: Emissivity 0.10
 T2: Temperature (K) 7.00
 C2: Chopper freq. (Hz) 0.00
 N2: Read Noise 100.00

Miscellaneous

CO: Compute Sensitivity
 PR: Printer Output (Y/N) No
 NC: Number of Log Cycles 4.00
 PL: Plot LI: List EX: Exit

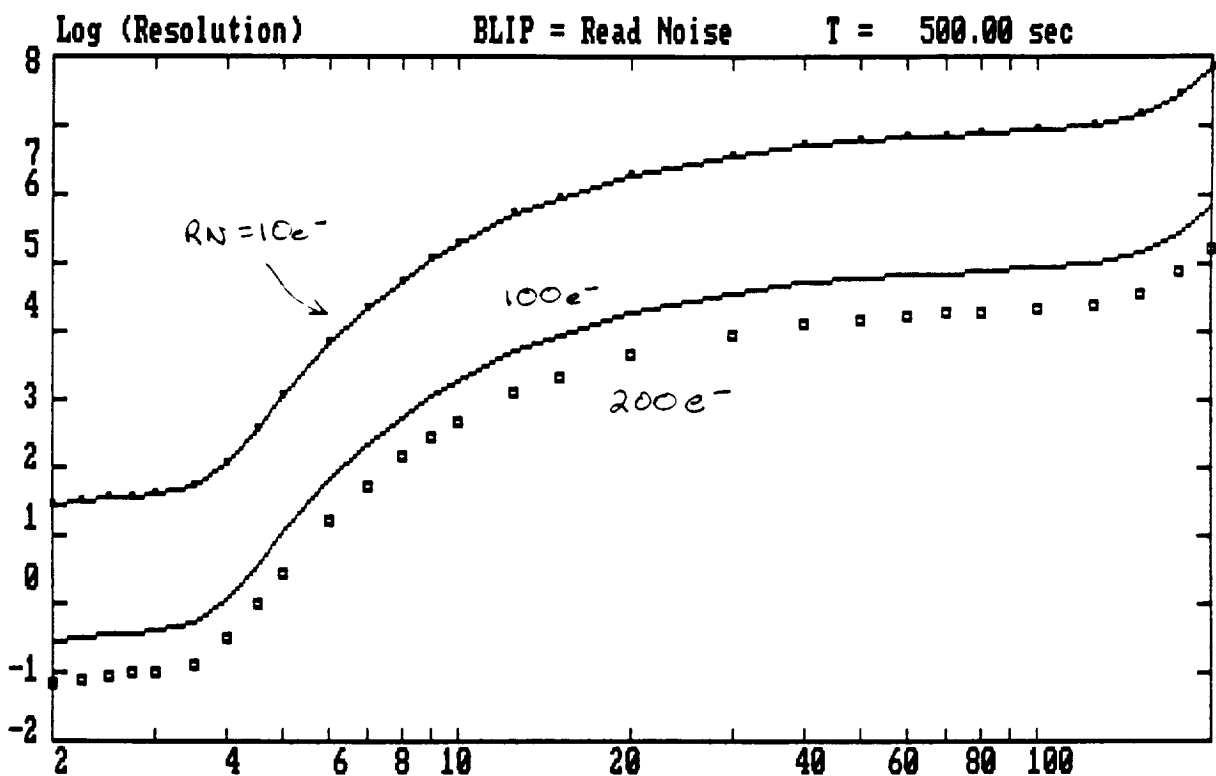
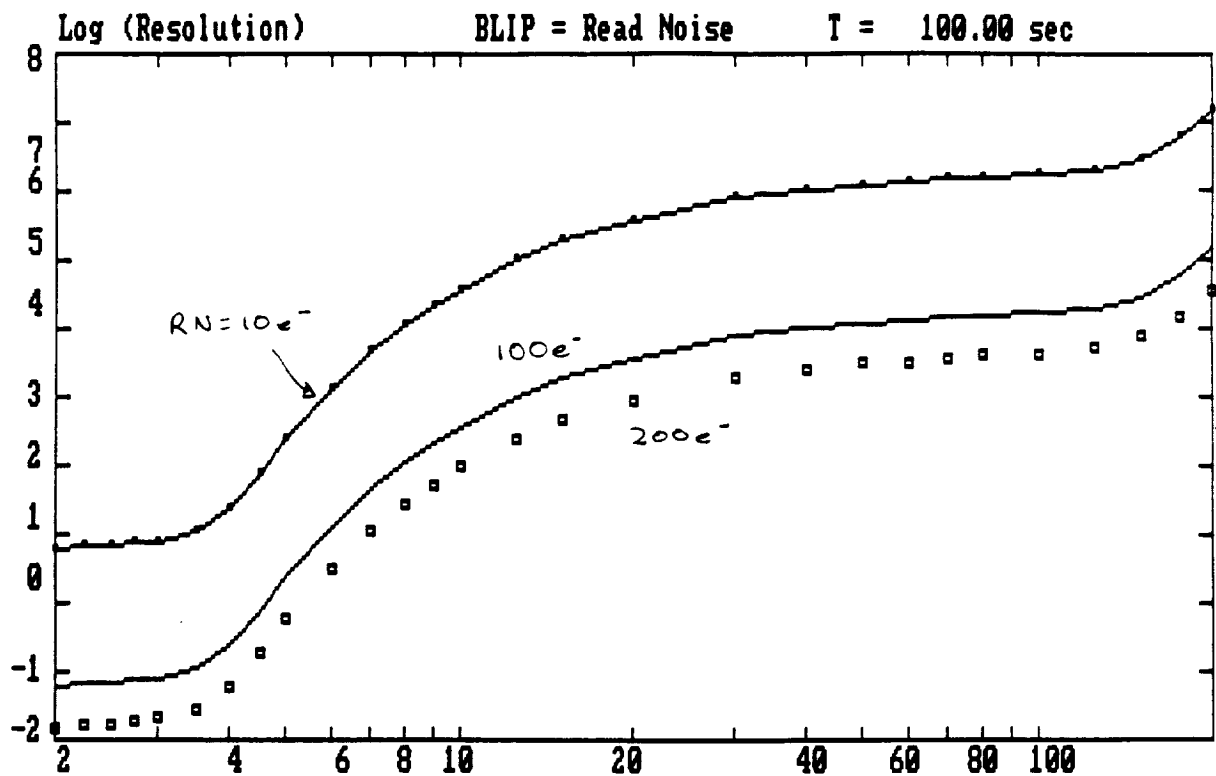
Instrument Parm's

TR: Transmission 0.30
 QE: Quantum Efficiency 0.50
 WR: Wavelength Range all
 PG: Photo-cond. Gain 1.00
 PH: Photovoltaic/cond. PV

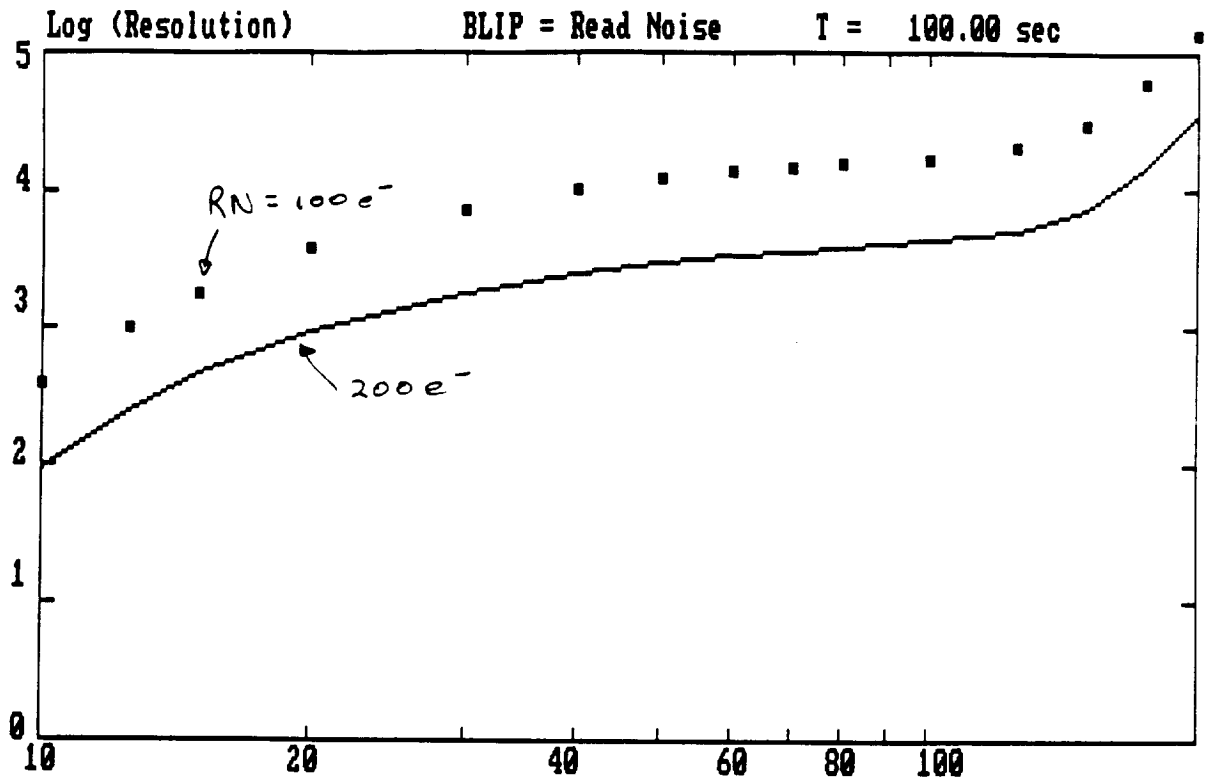
Select :

The resolution necessary for the read noise to equal the photon (background) noise is computed for several different read noises and integration times. The backgrounds are the same as those used previously. Figures B-7 through B-9 give the results. Figures B-8 and B-9 reproduce the results of Figure B-7, but slightly enlarged and with a listing of the computed resolution at selected wavelengths.

These figures show that for wavelengths greater than $20\mu\text{m}$, the IRS is likely to be background-limited.

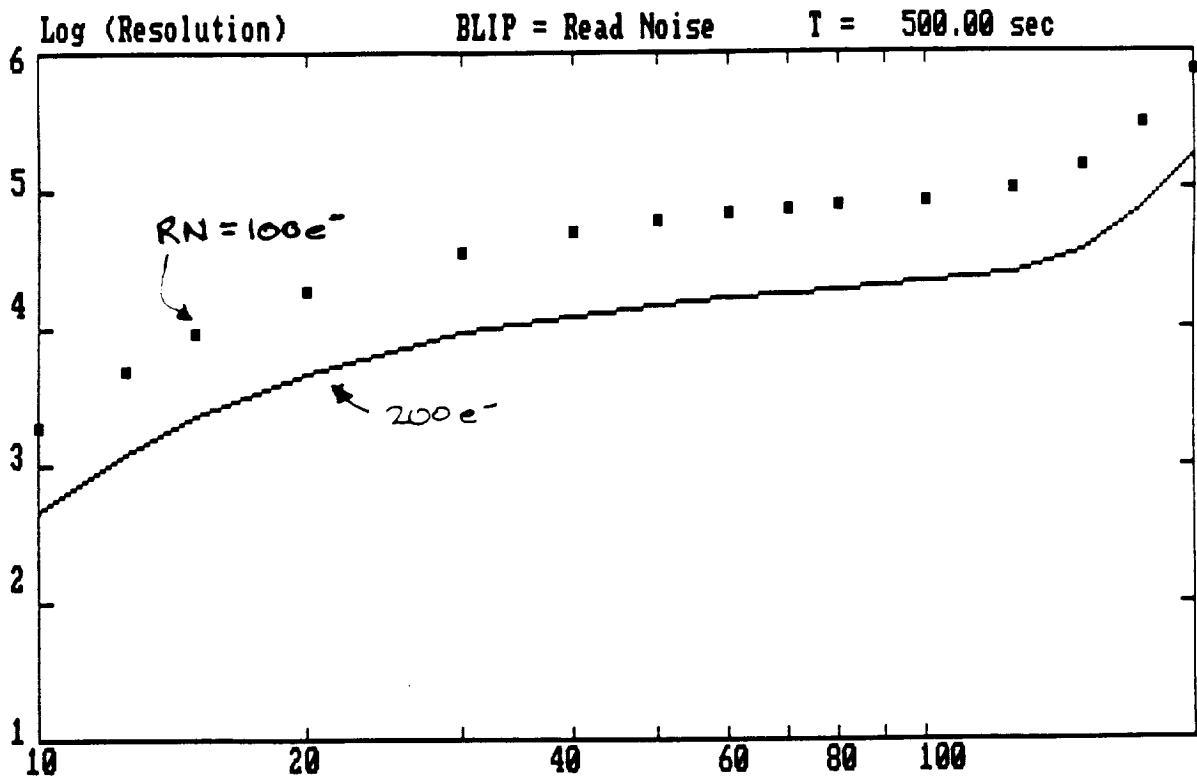


B-7



B-8

	Resolution-1	Resolution-2
La ia	100 e ⁻	200 e ⁻
10.00	3.820E+02	9.550E+01
12.50	9.906E+02	2.477E+02
15.00	1.821E+03	4.551E+02
20.00	3.747E+03	9.368E+02
30.00	7.305E+03	1.826E+03
40.00	9.958E+03	2.490E+03
50.00	1.189E+04	2.973E+03
60.00	1.334E+04	3.334E+03
70.00	1.445E+04	3.614E+03
80.00	1.537E+04	3.842E+03
100.00	1.702E+04	4.254E+03
125.00	2.018E+04	5.044E+03
150.00	2.915E+04	7.288E+03
175.00	5.874E+04	1.469E+04
200.00	1.422E+05	3.554E+04



B-9

	Resolution-1	Resolution-2
La _α	100 e ⁻	200 e ⁻
10.00	1.910E+03	4.775E+02
12.50	4.953E+03	1.238E+03
15.00	9.103E+03	2.276E+03
20.00	1.874E+04	4.684E+03
30.00	3.653E+04	9.132E+03
40.00	4.979E+04	1.245E+04
50.00	5.946E+04	1.486E+04
60.00	6.668E+04	1.667E+04
70.00	7.227E+04	1.807E+04
80.00	7.684E+04	1.921E+04
100.00	8.508E+04	2.127E+04
125.00	1.009E+05	2.522E+04
150.00	1.458E+05	3.644E+04
175.00	2.937E+05	7.343E+04
200.00	7.108E+05	1.777E+05

APPENDIX C

Sampling Interval

Resolution of the spectrometer is defined as the apparent width (FWHM) of an infinitely narrow line measured with the spectrometer. The sampling interval, points-per-resolution element (PPRE), defines the coverage of the dispersed light relative to the FWHM. This is the number of pixels per projected aperture size.

Let p be the PPRE, then for BLIP conditions

$$N_{\text{sig}} \propto \frac{1}{p} \quad \text{signal}$$

$$N_{\text{noise}} \propto \frac{1}{p^{1/2}} \quad \text{noise}$$

$$\Rightarrow \frac{S}{N} \propto p^{-1/2}$$

Co-adding back to one PPRE improves signal to noise by $p^{1/2}$. Thus

$$\left(\frac{S}{N}\right)_{\text{co-add}} \propto \text{constant.}$$

For read-noise-limited performance (RNLIP)

$$N_{\text{sig}} \propto \frac{1}{p}$$

$$N_{\text{noise}} \propto \text{constant}$$

$$\Rightarrow \frac{S}{N} \propto p^{-1}$$

Co-adding then yield

$$\left(\frac{S}{N}\right)_{\text{co-add}} \propto p^{-1/2}$$

so that sensitivity is lost and cannot be "gained back" by co-adding for the case of oversampling in the RNLIP limit.

The above analysis is true for lines or continuum. In the case of lines, co-adding is effectively achieved by fitting the line profile. Appendix B discusses the conditions under which BLIP is achieved.

Calculations in Appendix B assume one PPRE sampling. The above analysis can be used to determine how the results in Appendix B scale with more than one PPRE sampling. The resolution at which BLIP equals RNLIP scales with the number of PPRE as

$$R \propto \frac{1}{P},$$

so that if the PPRE increases from 1 to 2, the resolution must decrease by a factor of 2.

APPENDIX D

The Flat Fielding and Line Contrast Problem

The problem of line contrast relative to the continuum is of direct interest since flat-fielding may pose a limit to line detectability above that expected for background-limited performance (BLIP) alone. The effect of resolution on line contrast is investigated for continua originating from

- (1) the source, and
- (2) the zodiacal background.

I. Source Line-to-Continuum Contrast

Line fluxes and continua near [SIII] 18.7 and 33.5 μ m, [SiII] 34.8 μ m and [OI] 63 μ m for three types of sources that are likely to be observed with the IRS are given in Table 1. These are 1) an HII region (the Trapezium region in Orion), 2) the central region of a galaxy (the galactic center), and 3) a starburst galaxy (M82). Two weak line fluxes, [ArIII] 21.8 μ m and [NeIII] 36.0 μ m], are estimated from the SIII data.

TABLE 1

FLUX

Line	Trapezium-Orion		Gal. Cen.-IRS 16		M82		Beam Size (arc sec)
	line $10^{18} \text{ W cm}^{-2}$	cont $10^{-16} \text{ W cm}^{-2} \mu\text{m}$	line 10^{-18}	cont 10^{-16}	line 10^{-18}	cont 10^{-16}	
SIII 18.7 μm	60	21	18	15	4.3	0.3	~25
SIII 33.5	18	11	26	9	12	1.2	~25
SiII 34.8	24	38	23	9	7	1.1	48/25/25
OI 63	80	8.6	100	4.5	19	0.92	30/44/44
ArIII 21.8	(1.4)	20	(0.17)	14	(0.079)	0.4	~25
NeIII 36.0	(6.9)	11	(0.82)	9	(0.38)	1.2	~25

() ==> estimated from SIII 33.5 μm line

Line-to-Continuum Ratio (R = 1000)

Line	Gal. Cen.		M82
	Trap.	Gal.	
SIII 18.7 μm	1.5	0.64	7.7
SIII 33.5	0.49	0.86	3.0
SiII 34.8	0.18	0.73	1.8
OI 63	1.5	3.5	3.3
ArIII 21.8	0.032	0.0056	0.091
NeIII 36.0	0.17	0.025	0.088

Line-to-Continuum Ratio

defined by

$$\frac{\text{Line}}{\text{Cont}} = \frac{F_{\ell}}{F_{\lambda} \Delta_{\lambda}}$$

II. Line-to-Background Continuum Contrast

The flux limit for BLIP is computed and compared to natural background emission.

o Definition of Terms:

F_{BLIP}	:	Background-limited spectrometer flux limit	($W\ cm^{-2}$)
N_{ph}	:	Number of background photons detected	(photons)
θ	:	Beam diameter	(arc sec)
D	:	Telescope diameter	(meters)
R	:	Spectral resolution	
f	:	$G\eta\tau$ (Gain \times Q.E. \times transmission)	
t	:	Integration time	(seconds)
ϵ	:	Background emissivity	
T	:	Background temperature	($^{\circ}K$)
B_{λ}	:	Planck function	($W\ cm^{-3}s^{-1}sr^{-1}$)

$$B_{\lambda}(T) = \frac{1.19 \times 10^4}{\lambda^5 (\mu m)} \frac{1}{e^{\frac{14388}{\lambda T}} - 1}$$

$$\text{Diff. Limit} : \theta = \frac{2.4\lambda}{D}$$

$$\text{o } \underline{\text{BLIP Limit:}} \quad \text{Noise} = 2h\nu\sqrt{N_{ph}}$$

$$\text{Signal} = F_{BLIP} (W/cm^2) \frac{\pi}{4} D^2 ft$$

for $S/N = 1$ one has

$$F_{BLIP} = \frac{2h\nu}{\pi D^2 ft} \sqrt{N_{ph}}$$

Thus the flux limit is given by

$$F_{\text{BLIP}} = \frac{5.06 \times 10^{-23}}{\lambda(\mu\text{m}) D^2(\text{m}) \text{ft}} \sqrt{N_{\text{ph}}} \text{ W cm}^{-2}$$

N_{ph} is given by:

a) Diffraction-Limited Performance:

$$\begin{aligned} N_{\text{ph}} &= \frac{\epsilon_{\lambda} B_{\lambda}(T)}{h\nu} \text{tf} \frac{\pi}{4} D^2 \frac{\pi}{4} \left(\frac{2.4\lambda}{D}\right)^2 \frac{\lambda}{R} \\ &= 1.79 \times 10^{11} \frac{\lambda^4(\mu\text{m}) \text{ft} \epsilon_{\lambda} B_{\lambda}}{R} \end{aligned}$$

b) Fixed Beam Size

$$\begin{aligned} N_{\text{ph}} &= \frac{\epsilon_{\lambda} B_{\lambda}(T)}{h\nu} \text{tf} \frac{\pi}{4} D^2 \frac{\pi}{4} \theta^2 \frac{\lambda}{R} \\ &= 7.29 \times 10^{11} \frac{(\lambda\theta D)^2 \text{ft} \epsilon_{\lambda} B_{\lambda}}{R} \end{aligned}$$

c) Constraint on fixed beam size is:

$$\theta \geq \frac{2.4\lambda}{D} = \frac{0.50 \lambda(\mu\text{m})}{D(\text{m})} \text{ (arc sec)}$$

which for SIRTf becomes

$$\theta \geq 5.8 \left(\frac{\lambda}{10\mu\text{m}}\right) \text{ arc sec}$$

Assuming diffraction-limited

$$F_{\text{BLIP}} = \frac{2.14 \times 10^{17}}{D^2(\text{m})} \lambda(\mu\text{m}) \sqrt{\frac{\epsilon_{\lambda} B_{\lambda}}{\text{ft}R}} \text{ W cm}^{-2}$$

and for fixed beam size:

$$F_{\text{BLIP}} = 4.32 \times 10^{-17} \frac{\theta(\text{''})}{D(\text{m})} \sqrt{\frac{\epsilon_{\lambda} B_{\lambda}}{\text{ft}R}} \text{ W cm}^{-2}$$

o Zodiacal Background:

For diffraction-limited operation

$$F_z = \frac{\lambda}{R} \epsilon \frac{\pi}{4} \left(\frac{2.4\lambda}{D}\right)^2 B_\lambda(T)$$

$$= 4.51 \times 10^{12} \frac{\lambda^3(\mu\text{m})}{RD^2(\text{m})} \epsilon B_\lambda(T)$$

and for fixed beam size

$$F_z = 1.85 \times 10^{-11} \frac{\lambda(\mu) \theta^2(\text{''})}{R} \epsilon B_\lambda(T) \text{ W cm}^{-2}$$

In ecliptic: $\epsilon = 2.3 \times 10^{-7}$

$T = 246 \text{ }^\circ\text{K}$

o Comparison of BLIP Limit and Zody Background:

Let f_z be the amount of zodiacal emission relative to the BLIP limit, i.e.,

$$F_z = f_z F_{\text{BLIP}}$$

Using the derived expressions for F_z and F_{BLIP} , and solving for R yields

diffraction-limited:

$$R = \frac{4.5 \times 10^{10} \lambda^4(\mu\text{m}) \text{ ft } \epsilon B_\lambda(T)}{f_z^2}$$

fixed beamsize:

$$R = \frac{1.8 \times 10^{11} [\lambda(\mu\text{m}) \theta(\text{''}) D(\text{m})]^2 \text{ ft } \epsilon B_\lambda(T)}{f_z^2}$$

Choosing:

$\epsilon = 10^{-7}$

$F = 0.2$

$f_z = 100$

, $T = 246^\circ\text{K}$

, $t = 100 \text{ sec}$

Diffraction-limited case

$\lambda (\mu)$	$B_\lambda (T)$	Resolution	
		$t = 100s$	$t = 500s$
10	3.44×10^{-4}	31	155
20	2.11×10^{-4}	300	1500
50	1.71×10^{-5}	960	4800
100	1.50×10^{-6}	1350	6700
150	3.29×10^{-7}	1500	7500

This demonstrates that for the longest integration times the resolution of the spectrometer will have to be quite high (>5000) at wavelengths greater than $50\mu m$ for the background to be only 100 times the expected noise limit imposed by the background fluctuations. Note that even at the zodiacal pole the required resolution is less than a factor of 2 smaller ($\epsilon \sim 7 \times 10^{-8}$), while in the zodiacal plane the required resolution is a factor of 3 larger than given in the table.

It is worth noting that if flat fielding is a problem, then the camera teams are in much worse shape. The same equation derived above applies to continuum detection. Solving now for f_z yields:

$$f_z = 2.1 \times 10^5 \lambda^2 (\mu m) \sqrt{\frac{ft \epsilon B_\lambda (T)}{R}}$$

Choosing $R = 4$ and using the same numbers as before yields:

$\lambda (\mu m)$	f_z		
	$t = 10$	$t = 100$	$t = 500 \text{ sec}$
10		275	620
20		860	1900
50		1500	3400
100	580	1800	-
150	600	1900	-

Rieke's group calculated that the confusion limit will be reached in ~20 seconds at 100 μ m with their instrument at a resolution of 2, employing super resolution. Also, please note that the long integration times require a large bucket size (for R = 4 in 100 sec about $2 - 5 \times 10^7$ electrons are expected).

APPENDIX E

Correspondence from Co-Investigators

Posted: Fri Apr 4, 1986 12:00 AM EST

Msg: GGIG-2227-2376

From: TSOIFER
To: jhouck
CC: tsoifer
Subj: thoughts on spectrometer

Jim,

I thought of another constraint that should limit the high end of the resolution. It seems to me that we should be planning on being able to determine and verify redshifts purely with the spectrometer. I would propose the following scenario. A source is located with the infrared imager, then a low resolution spectrum is taken. A tentative redshift is determined, but it must be verified. This requires a redshift determined by a high resolution spectrum to detect at least two lines. The requirement that should then be placed on the high resolution spectrometer is that the wavelength spanned by the spectrometer in a single setting must be enough to span the likely redshift range in a line chosen for the confirming redshift. I can well imagine that the [OIII] 88um line or [OI] 63um line will be a prime candidate for confirming redshifts in objects with redshift $z \geq 1$. With a low resolution spectrum of resolution 75-100 and a weak feature as the candidate redshift the uncertainty is likely to be $d\lambda/\lambda = 0.005$ so to cover a two sigma range says we'd want the high resolution instrument to span a total range of at least $d\lambda/\lambda$ of 0.02. If we have only 10 pixels this implies $r=500$, or $r=1000$ would require 20 detectors. It seems clear to me from this consideration that we can clearly rule out resolutions greater than 3000 at almost all wavelengths, and I suspect this will push us close to the $R=1000$ domain in the germanium world.

Hope this is of some use.

Cheers,
Tom

April 8, 1986

Dear Terry,

Following our assignment during the telecon, here are my opinions concerning the revised spectrograph design as it impacts extragalactic astronomy.

Mechanically, this design is a major improvement because of the simplification, which I feel will be an essential challenge to keep in mind at all stages. Another major advantage of an echelle is the flexibility gained in terms of usable detector formats. If square arrays are available for some reason related to the needs of the imaging teams, then we will be in a position to consider maximum utilization of them via cross dispersion.

Details of the detector format will be important for combining high and low resolution on the same detector. The reason is that long slit observations including substantial spectrum from the natural background will be necessary for low resolution observations looking for broad absorption or continuum features. The flux limit for such observations will probably depend on our ability to take out this background, and, as I discussed earlier with JH, may be optimistically set at 10% of background. This question of just how to determine detection limit in the face of a given natural background is a challenging one that we haven't really thought out completely. I don't think it is enough just to speak of the time required to reach a signal equivalent to the background. We need to combine accurately a. photon noise per detector element (pixel) from the background continuum, b. integrated thermal noise per pixel, c. read noise per pixel, d. calibration uncertainty per pixel, e. photon noise per pixel from the source. It is the items a, d, and e which dominate in optical spectroscopy that is "background limited" by the night sky continuum and which make no one ever expect to do spectroscopy on objects fainter than 10% of the night sky no matter how big their telescope or how long their integration time..

SIRTF extragalactic observations at high resolution will most often be in search of particular emission features. If the features are weak relative to the source continuum, then that continuum is the "background" of relevance and all observations that reach source continuum are "background limited". It is for this reason that I feel the resolution issue is complex but critical for extragalactic observations. This does mean, however, that having "sky" channels for subtracting the natural background is not as important for high resolution, because one will be subtracting the source background continuum. If pressed,

therefore, an array only one pixel wide might be useful for high resolution observations, but not low resolution.

I think that choosing the appropriate high resolution for extragalactic observations means picking that optimum resolution at which the intrinsic line profile just fills the resolution element but is not resolved. If the line is resolved so that a profile is seen, the line is spread over more pixels than necessary and contrast diminishes between line and continuum. If the detector is noiseless, this makes no difference, but the detector and its calibration will not be noiseless. The optimum resolution to profile match will probably occur at about 300 km s^{-1} , or resolution of 1000. The intrinsic FWHM of optical emission lines in spatially unresolved starburst nuclei averages 200 km s^{-1} . The rotation curves of galactic disks rise to this value within a few kpc of the nucleus. Given our large beam size, it is unlikely that, except in the very nearest systems such as M82, the velocity dispersion of the gas in the beam will be less than 200 km s^{-1} . For Seyfert and active nuclei, the FWHM are more like 500 km s^{-1} . All in all, I think that we will be observing line profiles rather than unresolved lines if resolution much exceeds 1000.

The counterpoint is that it is very desirable to reach a resolution close to the intrinsic line width, so the modified design is an improvement over the initial resolution of a few hundred. If the line is too narrow compared to a pixel, then the line signal also gets blended with overmuch continuum.

How should we define resolution in terms of pixel match? My suggestion, based on experience with CCD spectrographs, is to match two pixels to the projected aperture size. Our "aperture" size is wavelength dependent so this should be considered the minimum match, accepting more pixels per projected aperture at the longer wavelengths. Within this definition, the "resolution" is defined by the projected aperture on the array illuminating two pixels at the shortest wavelength, and this is optimized to the numerical value given above. Why not match to only one pixel? Accurate radial velocity information is lost that way, because it is not possible to centroid on one pixel, and we risk the dilution effect mentioned before where the intrinsic line is substantially within a single pixel.

I will be out of town April 15-18; call me any other time if we need to discuss this further.

Regards,

Dan Ueda

Progress Report 3

for

NASA-Ames Grant NAG 2-317

The Infrared Spectrograph During the SIRTf Pre-Definition Phase

through March 1, 1987

March 10, 1987

TABLE OF CONTENTS

CORNELL ACTIVITIES REVIEW

Technology Development Page 1
Management Activities Page 2

APPENDIX A

Cornell Technology Development (Hardware and Software)

APPENDIX B

- Rockwell Bi-Monthly Progress Report No. 4
- Rockwell Bi-Monthly Progress Report No. 5
- Rockwell Bi-Monthly Progress Report No. 6

APPENDIX C

- BASD SER: Study Plan and Relay Optics
- BASD SER: Reflective Relay Optics
- BASD SER: IRS Concept with Czerny-Turner-Type High-Resolution Sections

APPENDIX D

California Institute of Technology Update

APPENDIX E

University of Rochester Update

APPENDIX F

Penn State University Update

Technology Development: Cornell

We describe below progress in the Cornell Technology Development effort over the past nine months. This aim of this work is to evaluate Rockwell International SiBIBIB array detector technology under low background conditions to determine its suitability for use on SIRTF. Highlights of this period include:

- 1) Delivery of two 10x50 multiplexers from Rockwell.
- 2) Delivery of two "untested" 10x50 SiBIBIB (silicon back-illuminated blocked-impurity-band) hybrid detector arrays from Rockwell.
- 3) Testing of a SiBIBIB hybrid array at Rockwell for SIRTF.
- 4) Running and debugging of detector evaluation facility at Cornell.
- 5) Preliminary evaluation of one SiBIBIB array at Cornell.

This period has seen the completion of most of the components of the Cornell University Detector Evaluation Facility (CUDEF). The dewar, clocking electronics, preamplifier, and data acquisition and analysis software have been completed. We received delivery of two multiplexers from Rockwell and used these multiplexers to ensure proper operation of the CUDEF before actual testing of hybrid arrays. Subsequent to this checkout period we began evaluation of a SiBIBIB hybrid array that was delivered by Rockwell. Our initial testing has been oriented toward determining read noise (as a function of integration time and read rate) and dark current.

Initial testing was begun in mid-December and appeared to confirm Rockwell results of 70 electrons per read at high frame rates for double correlated sampling. Subsequent analysis and diagnostic work on the array, however, demonstrated that the drain voltage (suggested by Rockwell) on the output FET amplifier was too low to provide linear operation. Because of this difference between expected and actual operating parameters for the driving voltages of the hybrid, we spent considerable time exploring array operation as a function driving levels. The results of these tests indicate that array performance can be seriously degraded if the driving voltages are not adjusted properly.

We summarize now some of our results on the Rockwell SiBIBIB hybrid array. Operating at a frame rate of 20Hz, the read noise is 150 electron/read and 90 electrons/read for double correlated sampling (DCS) and triple correlated sampling (TCS) respectively. TCS is implemented to reduce kTC noise, however the reduction in noise we see can not be due to the elimination of kTC noise. The kTC noise should be 50 electrons/read for the 0.42 pf nodal capacitance of the detector. Since the kTC noise and read noise will add in quadrature, removing the kTC component from the DCS result yields an expected read noise of 141 electrons/read for TCS. We take the much larger reduction actually seen for TCS as indicative of system noise. We are working now to reduce this noise.

Because of the non-destructive read capabilities of the array (allowing TCS to be implemented) the multiplexer can be read out in many ways. This flexibility can be used to reduce read noise on long integrations and reduce overall power consumption. Our modes of operation include standard clocking where longer integration times are achieved by reducing the overall clocking rate and burst mode in which the read is done quickly after a long integration. The burst mode is further subdivided into three categories; burst silent in which all clocking is turned off while integrating, burst quiet in which BITIN (the access bit which is clocked through a shift register) is not provided, and burst monitor in which all clocks and BITIN are provided but the integrated signal is not reset. This latter burst mode allows the array to be monitored while integrating. The burst modes are clearly preferred to reduce 1/f noise on long integrations; however, we have found problems with these modes which need further exploration. For instance, we find that the output level of the signal changes depending on the rates at which monitoring is done, that is, how long no "signal" is present at the output of the detector.

Burst mode effects show up in measurements of the dark current. To measure detector dark current, the detector is placed in a cold dark enclosure. The detector is readout in burst monitor mode to lower read noise. A short integration is performed to establish the baseline (a reference frame to remove offsets) then a longer integration is performed. The dark current is computed by subtracting these frames and dividing by the integration time difference. We have performed integrations up to 1000 seconds with the upper limit determined by operator patience. The dark current is found to vary from approximately 220 electrons/second for integration times of one second to less than 50 electrons/second for integration times of 1000 seconds. This difference is not due to residual electrons which are to first order corrected by our subtraction technique and neither are they due to a constant injection of charge due to our monitoring. The change in dark current with integration time is probably due to the baseline drift mentioned above that appears for the monitor modes. This drift seems to decay exponentially as an equilibrium is established in the monitoring, possibly accounting for the effects seen.

Rockwell has finished their first round of tests for SIRTf on a SiBIBIB hybrid array. Rockwell results are contained in Rockwell Progress Report No. 5 (Appendix B). The changeover from operating under a grant to a contract at Cornell has interrupted our funding to Rockwell preventing them from writing a report on further test results. We expected this situation to be corrected shortly.

A discussion of hardware and software development in the CUDEF is presented in Appendix A. Near terms goals for the CUDEF will be to reduce system noise, characterize and possibly eliminate the burst drift problem, measure read noise versus integration time, measure detector quantum efficiencies, and measure pixel-to-pixel crosstalk. We will provide feedback to Rockwell so that an improved SiBIBIB array with better short wavelength response can be constructed.

Management Activities under NASA grant NAG2-317

Grant Administration

In June 1986, a Leading Edge Model D personal computer was purchased the SIRTf Project Office to aid in the administrative tasks being performed.

Two grant extensions were applied for and received. The first, made in August 1986, extended the grant termination date to March 31, 1987. The second extension, granted in March 1987, forwarded the grant termination date to September 30, 1987.

A personal copier for the use of the SIRTf team at Cornell was purchased in January. It was paid for with outside funds, but will be maintained by this office.

A new subcontractor, Wallace Instruments, was signed on to help with the design and construction of the test dewar. Wallace began work in December, 1986.

On May 13, 1986, we received a request from Gerry Lamb of GSFC to purchase for him a Rockwell detector. On May 16, we submitted to ARC a grant augmentation request for authorization to purchase the detector for Lamb which was subsequently rejected.

In late September Cornell contacted Giovanni Fazio, the IRAC PI at the SAO. Fazio requested we not provide Lamb with a detector as it would take him away from the testing he was to do for the IRAC. On Fazio's recommendation we elected not to purchase a detector for Gerry Lamb.

Contract Preparation

The contract preparation process began on June 4, when the RFP finally arrived from ARC. In actuality, the process began long before this date, with Cornell having submitted drafts of its study plan to ARC for NASA review since April. However, on July 22, the finished proposal was sent out to ARC for their evaluation.

In the following months, nearly every facet of the proposal was revised, expanded upon, or detailed more fully. In early August, the budgets were edited to reflect a change in BASD labor rates, travel breakdowns for each institution were prepared, and copies of existing subcontracts were added to the proposal. On August 7, ARC informed Cornell the SIRTf Phase I was being stretched to 36 months, although this done unofficially.

During mid-August a request for additional supporting financial documentation Cornell's negotiated rate agreements, made by ARC's contracting office, was met. A set of worksheets, detailing the formulae used to determine salaries, benefit expenses, and indirect costs for each of the four academic institutions involved with the IRS, were prepared and mailed to NASA at the request of ARC auditor Paul Char.

On August 26, another budget revision was sent to ARC, this one incorporating the revised overhead figures agreed on the previous week by Cornell and the Office of Naval Research. It was at this time Cornell began planning for its contract negotiations with ARC, and set a preliminary date of September 8.

In the meantime another supporting document, a breakdown of proposed administrative expenses during the contract, was prepared for Paul Char. On September 16, ARC informed us our contracting officer, Lena London, had quit. The contract negotiations were postponed until her replacement was ready to take her place.

Two weeks later Connie Dove, the replacement for Lena London, called looking for the derivation of the benefits figures in the budget. A three-page worksheet was prepared for her and Federal Expressed it to ARC that afternoon. Preparations also began for the next set of budgets, which would reflect the new contract start date of November 1.

The contract negotiations were rescheduled for October 21. During the preceeding week estimates of our expected November expenses and a breakdown of Rockwell's remaining expenses on our BIB contract were prepared for the negotiations. On October 20 a two-hour meeting was held at ARC and the level six reporting requirements of the SIRTf Project Office were discussed.

The negotiations were held on October 21. A week later a follow-up letter arrived from requesting additional revisions in the study plan and budgets to reflect changes in the proposed contract. In mid-November, a budget revision incorporating these changes was submitted to ARC. Two weeks later, another budget revision was submitted to ARC. At that time, on December 8, Cornell's letter of confirmation was sent to the ARC contracting office.

On Monday, December 15, the Kickoff Meetings/SWG began at ARC. The following day Cornell presented an overview of its study plan. The management portion of the meetings were completed by Thursday.

On January 8, Cornell submitted its last budget revision and second confirmation letter to ARC. An acceptable solution to the SF-295 problem was proposed in this letter. The contract arrived January 26. Cornell signed the contract, calling out errors that were contained within it, and asked for a corrected version to be sent at a later date. It arrived February 12, but still contained typographical and factual errors. A letter correcting the errors arrived from ARC in early March. The re-revised, corrected contract had not arrived as of this report.

APPENDIX A

Cornell Technology Development

(Hardware and Software)

Cornell Technology Development

We outline our hardware and software development over the past nine months. A schematic displaying the Cornell Detector Evaluation Facility is shown in Figure 1.

I. Software Development

We have developed software to allow us control the array, and acquire and analyze data. Features include:

- 1) Programmable clocking modes driven by a dedicated VME single-board computer.
- 2) Computer controlled preamp gain and bandwidth.
- 3) Dynamical Offset Clocking System (DOCS) which adjusts the DC level of each pixel of the array as it is read out to flatten the array output. This allows maximum preamp gain to be applied by removing slopes and curvature. An automatic adjustment capability is incorporated.
- 4) Double correlated sampling (DCS) or triple correlated sampling (TCS). Frame rates as fast as 40Hz can be accommodated. Statistics are computed as the frame is acquired.
- 5) Burst read modes, with monitoring or non-monitoring during integration period to reduce 1/f noise on long integrations.
- 6) Continuous monitoring mode with grayscale display (updates approximately once a second) to examine changes in array output over time. The last six frames taken are displayed. A single pixel is also tracked and displayed on a voltage vs. time plot.
- 7) Numerous display and analysis capabilities for interpreting data, including a FORTH like command processor for manipulating frames (subtracting, adding, scaling, etc.).
- 8) Automatic routines for finding and marking "bad" pixels for convenient display scaling. Permanent marking for bad pixels. Automatic monitoring of input data for saturation and flagging.
- 9) Frame storage and retrieval capability for later analysis.

Highlights of some of these areas is given below:

- Generalized code-development utilities and support libraries for system, screen, I/O, graphic/hardcopy, and user interaction have been developed and used/debugged thoroughly. System hardware dependencies have been isolated in kernel and terminal driver libraries, and in graphic device drivers.

- Complete 2D data manipulation and plotting capabilities, including general linefitting, vector operations and editing, and extensive user control over plot (and multi-plot) format and content on multiple graphic devices.
- Focal Plane Array Controller (FPAC) software for clocking and triggering resides on a single-board VME bus computer. Soft tables are clocked out to a parallel port providing the active multiplexer signals in a variety of arrangements. Variable clocking rate and several clocking modes (regular, burst,...) are available to a Data Acquisition System (DAS) host sampling routine running on the main system processor, with interprocessor communication by way of a handshake scheme utilizing dedicated shared global memory locations.

FPAC also provides clocking out of dynamic offsets during each pixel access period, allowing the output signal to be shifted into an acceptable A/D input range so that maximum gain may be applied. This can compensate for ramped array output, for example. Offset tables are passed from the host through RAM. The host is responsible for table maintenance and editing.

- Frame-oriented routines for manipulation, dissection, and display of frame data. In the display category we have developed:
 - 3D wire frames, animate under user control, with scaling;
 - Gray-scale/color maps with noise and S/N, various scalings including auto (relative), absolute, and logarithmic;
 - Contour maps, user-selectable contour levels;
 - Histograms of signal and noise;
 - Frame auto-characterization to detect various pixel qualities (such as noisy, saturated, exceed Hi/Lo user limits, etc.);
 - Use of characterization mask to ignore pixels and gain greater dynamic range, in auto-scaled output;
 - Slices (by row or column) and frame reconstruction from slices, and;
 - "Snooping" of the frame pixel by pixel, using cursors, with readout of signal, noise, and S/N in user selectable units of Volts, mV, uV, e-, ke-, etc.

In the realm of manipulation and data management, there are utilities for managing frames on disk, with multiple (arbitrary) frames/file and a RAM-resident table for keeping up to 72 frames for quick display and manipulation. The primary method of actually performing computation with frames is provided by a forth-like interpreter that maintains both scalar and frame-oriented stacks, allowing standard operations like +, -, *, /, SQR, SQRT, LOG, ALOG, etc. Also, control facilities such as loops, variables, user prompts for input, and partial access to system plotting and output utilities exists. This finite set of atomic capabilities is augmented by a complete macro definition and maintenance ability, including disk storage and recall of one or multiple macro files.

Current plans call for extending the atomic abilities of command processor to accept directives to set acquisition parameters and take data. This would allow automated testing of various sorts, and when coupled with the macro capability, will provide a DAS of considerable power and performance.

- A data acquisition host incorporating all of the above exists and provides the user interface for these capabilities. Several methods of sampling the array are provided:
 - One row at a time : vector output
 - Frame built up of multiple single row acquisition; i.e., vary frame rate and take the same row ten times, producing a frame of Signal vs. Frame Rate vs. Column
 - Full Frame acquisition in either
 - regular mode
 - burst with no clocks during integration
 - burst with clocks, but no BITIN
 - burst with clocks and BITIN (to monitor buckets filling)
 - FFT analysis of any given pixel, or a long analysis of the entire entire array
 - Real time continuous acquisition with output of frames as they are taken, with a temporal trace of a selected pixel to reveal long-term drifts or variations
 - Temporal method of reading one pixel (as in FFT) but dumping the results into a frame to bring frame analysis abilities to bear

The more general DAS abilities provided here are:

- Complete display abilities
- File management, Frame table management/perusal
- Command processor w/macros
- Dynamic offset table maintenance and editing, download to FPAC
- Automated gain/bandwidth setting from computer console
- Frame marking characterization constraint system

II. Hardware Development

We have designed and constructed a liquid-nitrogen-shielded, liquid-helium-cooled dewar for testing Rockwell BIBIB 10 x 50 nondestructive arrays. The dewar has a 2-liter LN₂ and 2-liter LH_e capacity and a hold time of one and one-half days. The work volume is approximately 6 inches in diameter by 5 1/2 inches long. The system turn-around time is 24 hours, i.e., the system can be cooled in the morning, tested during the afternoon and evening, dumped and warmed up by the following morning.

The work volume contains two chambers. One chamber encloses the detector array, socket, and PC board along with the shielded input and output wires for operating the array. A PC board was developed which enables us to simply install an array into a 68-pin socket and install the socket onto the work surface. The various signals are then accessed by plugging three headers into the PC board. Several of these PC boards were manufactured enabling us to have the arrays all mounted and ready to install when changing out an array in the dewar. The other chamber contains two filter/aperture slides, reimaging optics, and the ability to steer a point source around on the detector. These chambers are both cooled to LH_e temperatures and are enclosed within a LN₂ shield (Fig. 1).

We have also designed and constructed two electronic boxes for running the array. The first box, a clock box, is used to condition the clocking signals coming from the computer and to set the D.C. levels required by the array. The other box is the system preamp. It contains 10 low noise channels with gains from 25 to 2500, and bandpasses from 100 Hz to 360 kHz (Fig.

1). We have designed and produced PC boards in-house for the various functions required in these boxes. This has enabled us to produce a system that is very neat and compact. As these two boxes are relatively small, they are attached to the side of the dewar. The dewar and electronics boxes weigh approximately 40 lbs. when assembled and cooled.

CORNELL DETECTOR EVALUATION FACILITY

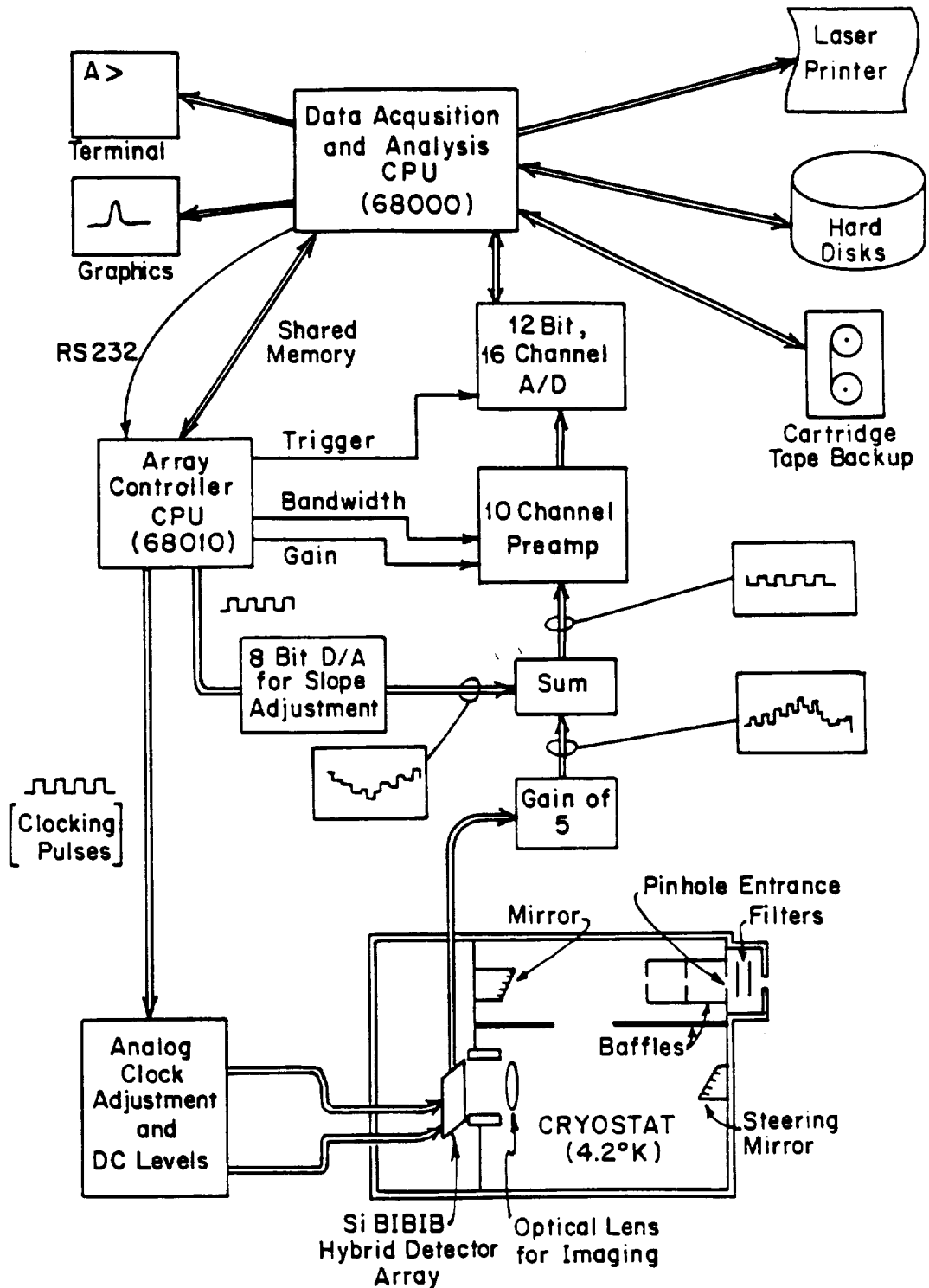


Figure 1 - Schematic diagram of the Cornell University Detector Evaluation Facility (CUDEF).

APPENDIX B

Rockwell Bi-Monthly Progress Reports Nos. 4, 5 and 6

Company Security

Science Center
Rockwell International Corporation
3370 Miraloma Avenue
P.O. Box 3105
Anaheim, California 92803-3105



Rockwell
International

July 29, 1986

In reply refer to SC86-712

Cornell University
Attn: Dr. James Houck, CRSR
220 Space Science Building
Ithaca, New York 14853-2801

Re: Bi-Monthly Progress Report No. 4
For Period 04/21/86 through 06/20/86
Sub-Contract No. OSP 3867
Document No. SC5452.BMR

In accordance with the above referenced contract, enclosed please find subject report.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

D. H. Seib

D. H. Seib
Manager
Focal Plane Technology

IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRTf

1.0 GENERAL

Indium columns were grown on the BIBIB detector wafers fabricated for the program and die were prepared for screening tests. Multiplexer wafers fabricated for the program, which are designed with a non-destructive readout option, were functionally tested at room temperature and found to be operative. Multiplexer wafers were returned to processing in order to have indium columns deposited. A delay in the first deliverables for the program (a tested multiplexer and two untested hybrids) was requested and approved by the contract monitor (T.Herter).

2.0 DETECTOR DEVELOPMENT

Indium columns were grown on all thirteen wafers of the first BIBIB detector lot. These columns will serve as interconnects to the SWIFET multiplexers in the hybrid mating process. Two of the wafers were diced. Selected die will be packaged for cryogenic testing. A test dewar was prepared to accommodate the devices during measurement of dark current and photoresponse vs. voltage. The results from these tests will be used as the selection criteria for detectors to be mated to multiplexers.

3.0 MULTIPLEXER DEVELOPMENT

Two wafers from the lot of SWIFET multiplexers fabricated for the program were given a room temperature functional screening test. These wafers were tested before the aluminum sinter step; the intent of the measurements is to assure that devices are operative prior to commitment to indium bump processing and to validate the design and performance of the modifications made for non-destructive readout. The non-destructive readout design incorporates two clocks, θ_{rst} and θ_{rst} , which control the timing of the reset pulse, rather than the reset pulse being automatically generated on chip. The functional screen test did demonstrate that the non-destructive read implementation functioned properly. In the test, the output of pixel 50 was monitored, as well as the access and reset pulses for pixel 50. In the presence of strong visible light, which discharges the floating node on the device (which would normally be connected to the detector), the integrated light signal could be seen when the access pulse came on. When the reset pulse was turned on, the pixel output was properly reset. Then when the reset pulse went off, but with the access pulse still on, the node voltage could be seen to start to decrease due to discharge by the

light. This was the expected behavior.

On the two wafers tested, the percentage yield of devices which functioned properly was 50% and 47% respectively. Based on these results, eight wafers from the lot were returned to processing for deposition of indium columns.

4.0 PLANS FOR NEXT PERIOD

Detector die screening tests, i.e. measurement of selected, un-multiplexed detectors, will be conducted to evaluate the detector material. Detector die will be chosen for hybridization on the basis of these results and visual inspection. Multiplexer wafers will be processed with indium bumps and then fully screen tested at room temperature. A small number of multiplexers will be chosen for bonding and test without detectors. Additional multiplexers will be chosen for hybridization with the detector arrays and the hybrids fabricated and packaged.

Science Center
Rockwell International Corporation
3370 Miraloma Avenue
P.O. Box 3105
Anaheim, California 92803-3105



Rockwell
International

November 5, 1986

In reply refer to SC86-713

Cornell University
Attn: Dr. James Houck, CRSR
220 Space Science Building
Ithaca, New York 14853-2801

Re: Bi-Monthly Progress Report No. 5
For Period 06/21/86 through 08/20/86
Sub-Contract No. OSP 3867
Document No. SC5452.BMR

In accordance with the above referenced contract,
enclosed please find subject report.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

D. H. Seib
Manager
Focal Plane Technology

IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRTF

1.0 GENERAL

Detector die from two wafers developed for the program were packaged and cryogenically tested. Dark current and responsivity measurements were made and showed the detectors to be of good quality; die were therefore selected for hybrid mating. Indium columns were grown on SWIFET multiplexer wafers and the wafers screened to select the best multiplexers for hybridization. A multiplexer device was evaluated at cryogenic temperature for read noise and other parameters. Extensive testing of one hybrid array has also been initiated. A multiplexer device with data package and one untested hybrid device were delivered to Dr. T. Herter of Cornell University on August 13.

2.0 DETECTOR DEVELOPMENT

Thirteen wafers of a Back Illuminated Blocked Impurity Band (BIBIB) detector lot had completed processing in earlier periods. For this lot, the key parameters, active layer thickness and doping concentration, were kept within a narrow range. Thicknesses range from 15.0 to 16.0 microns while concentrations range from 4.0×10^{17} to $5.6 \times 10^{17} \text{ cm}^{-3}$. On the basis of the processing parameters, two of these wafers were selected as being representative of the lot. Properties of these wafers are shown in Table 1.

Table 1. Summary of BIBIB Wafer Properties

<u>Wafer#</u>	<u>Active Layer Thickness (microns)</u>	<u>Arsenic Concentration (cm^{-3})</u>
01	15.0	5.60×10^{17}
38	15.2	4.90×10^{17}

Indium column interconnects were grown on these two wafers and one die from each was packaged for cryogenic tests. Dark current and photoresponse vs. voltage were measured at 10 K and 12 K on several detectors from each die. These temperatures were selected so that a comparison could be made to data previously taken on BIBIB detectors of other programs. Dark current was measured with $Q_B < 10^8 \text{ ph}/(\text{cm}^2\text{-s})$ and photocurrent was measured with $Q_B = 1.5 \times 10^{12} \text{ ph}/(\text{cm}^2\text{-s})$ at 15 microns. There was almost no variation of currents among the measured

detectors of a particular die. Plots of typical dark current and photocurrent are shown in Figure 1(a)-(d) for the two different temperatures. Average currents and responsivities at the nominal bias point of 2.0 V are given in Table 2.

Table 2

Average Currents (pA) at 2.0 Volts Bias

	<u>Wafer#</u>	$Q_B < 10^8$	$Q_B = 1.5 \times 10^{12}$	<u>Photocurrent (difference)</u>	<u>Responsivity (amps/watt)</u>
T=10K	01	.405	34.82	34.42	11.24
	38	.431	34.65	34.22	11.17
T=12K:	01	28.15	61.65	33.5	10.94
	38	23.11	56.30	33.19	10.84

The results indicate slightly higher dark current than was measured on the best of previously fabricated BIBIB detectors. A probable cause is unwanted impurities in the source gas used for growth of the epitaxial layers.

Six arrays were selected and hybrid mated to SWIFET multiplexers. Cryogenic tests of the hybrids provides further, more extensive characterization of the existing BIBIB detectors.

3.0 MULTIPLEXER AND HYBRID DEVELOPMENT

Indium column growth was completed on selected multiplexer wafers from the lot processed for this program. Room temperature screen testing after this step revealed that the

functional yield was essentially the same as before column growth. From these tests die were chosen to be hybridized to detector arrays and to be packaged for detailed multiplexer characterization.

One multiplexer was characterized for noise performance at cryogenic temperature (4.2 K). For these characterization tests, the device integration time was varied by a factor of 20 and the read noise (noise of the multiplexer part only) was measured as a function of electronics bandwidth. As integration time increases, the pixel frequency and the measurement electronics bandwidth can be decreased, resulting in a reduction

in noise. Table 3 shows the measurement results. When 300 kHz bandwidth is used the read noise at the output is approximately 32 μV rms; under conditions such that the bandwidth can be reduced to 10 KHz the noise is reduced to 19 μV rms. These results indicate that reducing the pixel frequency and electronics bandwidth can be effective in reducing read noise to near the kTC noise limit of the present method of device measurement. This multiplexer device, part number 14546-8-1, was delivered with data package to Dr. T. Herter of Cornell University on August 13.

Six hybrid devices were assembled and packaged. Two of these devices functioned properly at room temperature. One (SIRTF hybrid #1) was tested for proper functionality at 4.2 to 10 K, with the result that 499 of the 500 pixels in the array were found to have uniformly low dark current. This device was also sent to Cornell University as an untested hybrid deliverable.

The second functional hybrid (SIRTF hybrid #2) has been tested and evaluated for various operating characteristics and figures of merit. There are no pixels with excess dark current on this hybrid. Tests conducted include detector dark current vs. temperature, multiplexer read noise, linearity of output with integration time, responsivity, detectivity (D^*) and noise equivalent input (NEI).

The read noise histogram for the device is shown in Figure 2 for the conditions temperature = 4.2 K, integration time = 1.24 ms, and electronics bandwidth 100 kHz. For a hybrid, the read noise is defined as the noise measured when the detector bias is zero. The mean value for all 500 pixels is 19.8 μV rms. Using the source follower gain of 0.74 measured for this device and a node capacitance value of 0.42 pF (measured previously for similar hybrids), this corresponds to 70 electrons rms at the input.

Dark current measurements were performed as a function of temperature for all elements of the array with 2.0 volt bias on the detectors. Dark current measurements are made with the dewar apertures blocked off; it is believed that the background flux under these conditions is $<10^7$ ph/cm²-s. Measurements were made for temperatures of 12, 10, 9, 8, 7 and 6 K. Increased integration times (up to 1 second) were used for the lower temperatures to allow an appreciable integrated charge signal to be accumulated. Output signal voltages were converted to currents using the gain and capacitance values given above. Figure 3 gives a plot of the measured mean dark current vs $1/T$. The straight line indicated results in an activation energy of 15.5 mV; this is in reasonable agreement with the expected value for the arsenic dopant. The dark current values shown on Fig. 3 for 10 and 12 K differ by a factor of approximately 2 from the values quoted in Table 2; this is believed to be due to the

different devices used or slight temperature differences in the two test setups. The uncertainty bars on the data for 8 and 9 K result because the response of the device divided into two separate histograms; this effect will be discussed further below.

Tests were conducted to determine the device input-to-output transfer characteristic. Constant background (1.2×10^{12} ph/cm²-s) was maintained on the device and the integration time was varied to map out the transfer curve, which is shown in Fig. 4. The data plotted is referenced to the output after an integration time of 2 ms, which is the first data reading after reset. Initial bias across the detector is 2.0 V. The total output voltage dynamic range is approximately 550 mV but the response is not linear over this range because of debiasing of the detector. That is, as the bias across the detector is changed due to charge integration, the detector responsivity changes. This characteristic is expected to be repeatable and calibratable.

Figures of merit (responsivity, D^* and NEI) were measured under two sets of conditions: 10^{12} ph/cm²-s at T=10 K; and 9×10^9 ph/cm²-s at T=4.2 K. The center wavelength in both cases is 10.6 μ m. Histograms for the higher background case are shown in Figures 5-7; the results for all three quantities are comparable to results previously achieved under the same conditions. Additional measurement parameters are an integration time of 1.24 msec and a detector bias of 2.0 volts. Assuming background limited operation, The mean D^* implies a detective quantum efficiency of 16% at 10.6 μ . Note that the non-uniformity across the array is very small - 2.7% (standard deviation/mean) - for the three histograms.

For the lower background, low temperature case, the response histograms (responsivity, D^* , and NEI) are shown in Figures 8-10. Additional measurement conditions for these histograms are an integration time of 62 ms and a detector bias of 2.0 V. Again assuming that the D^* is background limited (because of the relatively long integration time used), the detective quantum efficiency is found to be 20.6%. The difference between this value and the value inferred from the higher background data is believed to be due to uncertainties in measuring flux values or possibly some dark current induced noise in the 10 K measurements. The responsivity data for these test conditions (Fig. 8) consists of two distinct histograms, each containing 250 elements. This is a result of the fact that rows 1-5 of the multiplexer have a different unit cell design than do rows 6-10. When small amounts of charge are integrated, the outputs of these two groups are different. This is graphically illustrated in figure 11 where the responsivity array map is shown for the same conditions as for Fig. 8. The same non-uniform response

effect was observed in dark current measurements when small charges were integrated, leading to uncertainty in some of the dark current data (Fig.3). The detailed explanation of this behavior is not yet understood and further measurements are planned to select the input cell design with the best performance. Future multiplexer designs will not have the problem of two different responses because a single unit cell design will be used. Note that the mean responsivity is nearly the same in the two measurements conducted (Figs. 5 and 8).

The hybrid data obtained to date indicate that the hybrids developed for the program have excellent performance in terms of read noise, background limited D and other parameters.

4.0 PLANS FOR NEXT PERIOD

Testing of SIRTF hybrid #2 will be continued, with emphasis placed upon characterizing the operation at lower backgrounds and longer integration times. The response difference between the two types of input cell layouts will be studied in more detail in order to identify which of the layouts has the best performance. Additional hybrids will be fabricated to provide more devices for test and delivery.

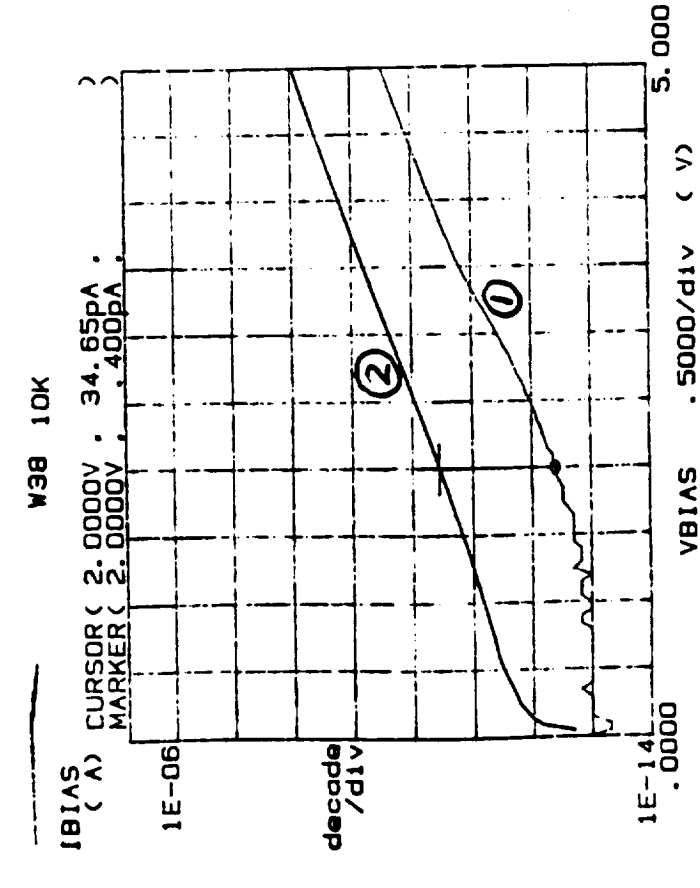
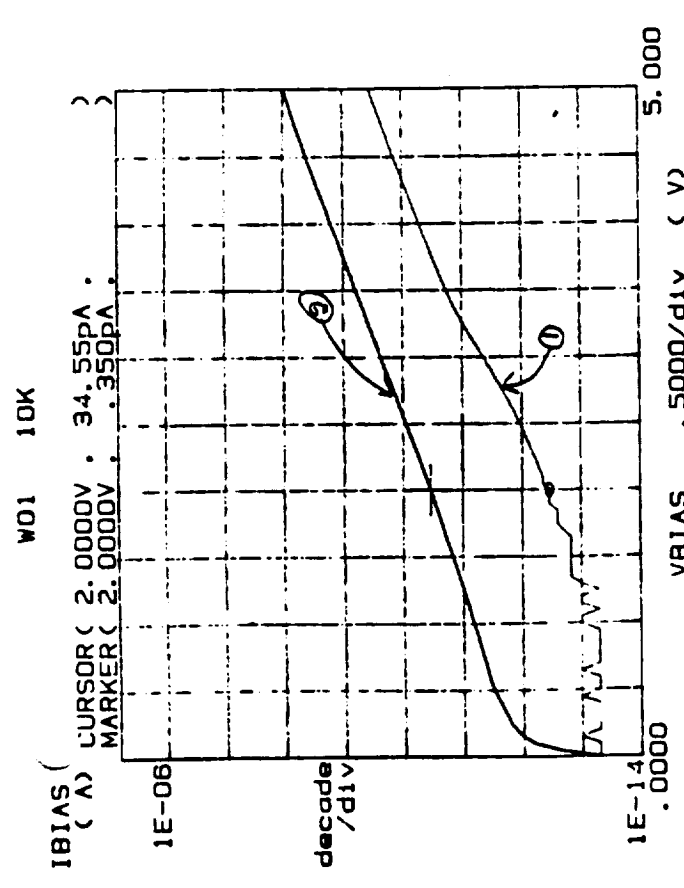
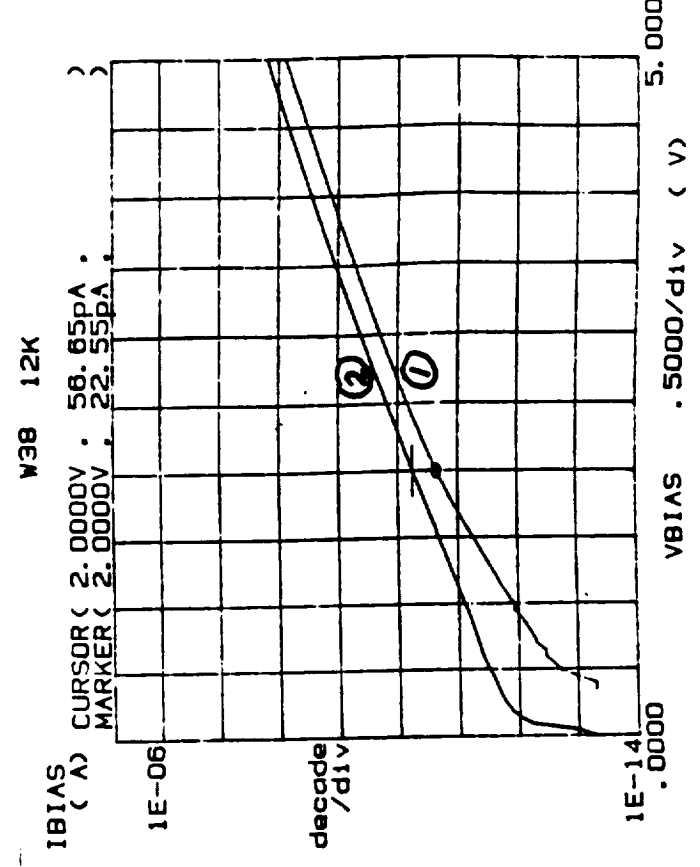
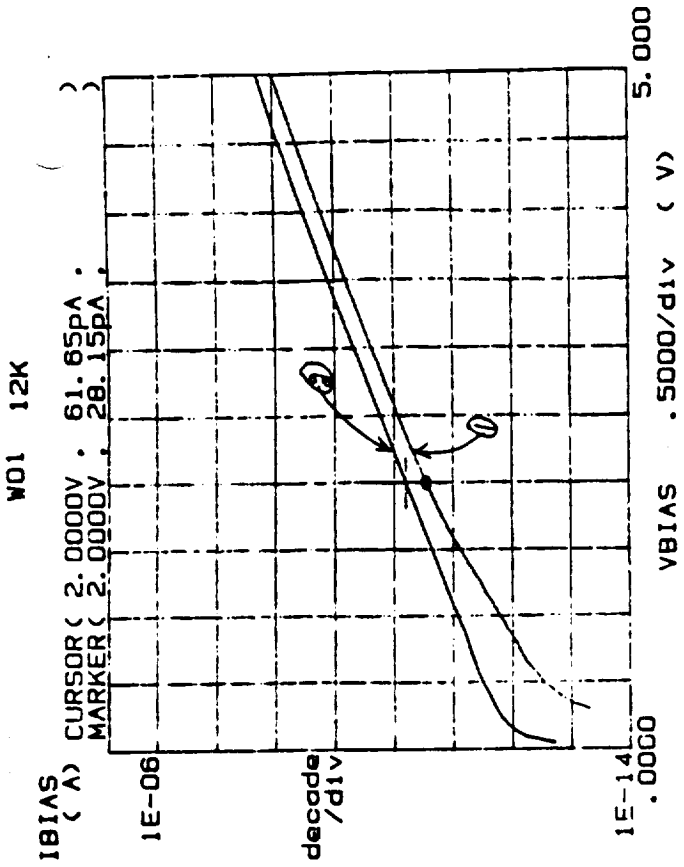
TABLE 3

MULTIPLEXER NOISE VS PRE-AMP BANDWIDTH
FOR VARIOUS CLOCK RATES

o Multiplexer ID#14546-8-1, Die D1

o T = 4.2 °K, Data from BUS 3 (S3)

<u>Integration Time (ms)</u>	<u>Pixel Frequency (KHz)</u>	<u>Pre-Amp Bandwidth (KHz)</u>	<u>Mux Noise (µV @ Output)</u>
0.310	167	300	34
1.24	41.7	300	31
"	"	100	26
2.49	20.8	300	32
"	"	100	28
"	"	30	21
3.72	13.9	300	32
"	"	100	28
"	"	30	24
4.96	10.4	300	32
"	"	100	28
"	"	30	26
6.20	8.33	300	32
"	"	100	28
"	"	30	25
"	"	10	19



②: $Q_B = 1.5 \times 10^{12}$ oh/($cm^2 \cdot sec$) ϕ 15 μm

①: $Q_B < 108$ ph/($cm^2 \cdot sec$)

FIGURE 1: I-V Characteristics for die from two wafers at 10 and 12K

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.00001577
.00000207
465

NOISE LEVEL IS EQUAL TO

1-4 2K tint=1.235 msec frame time=1.248msec READ NOISE

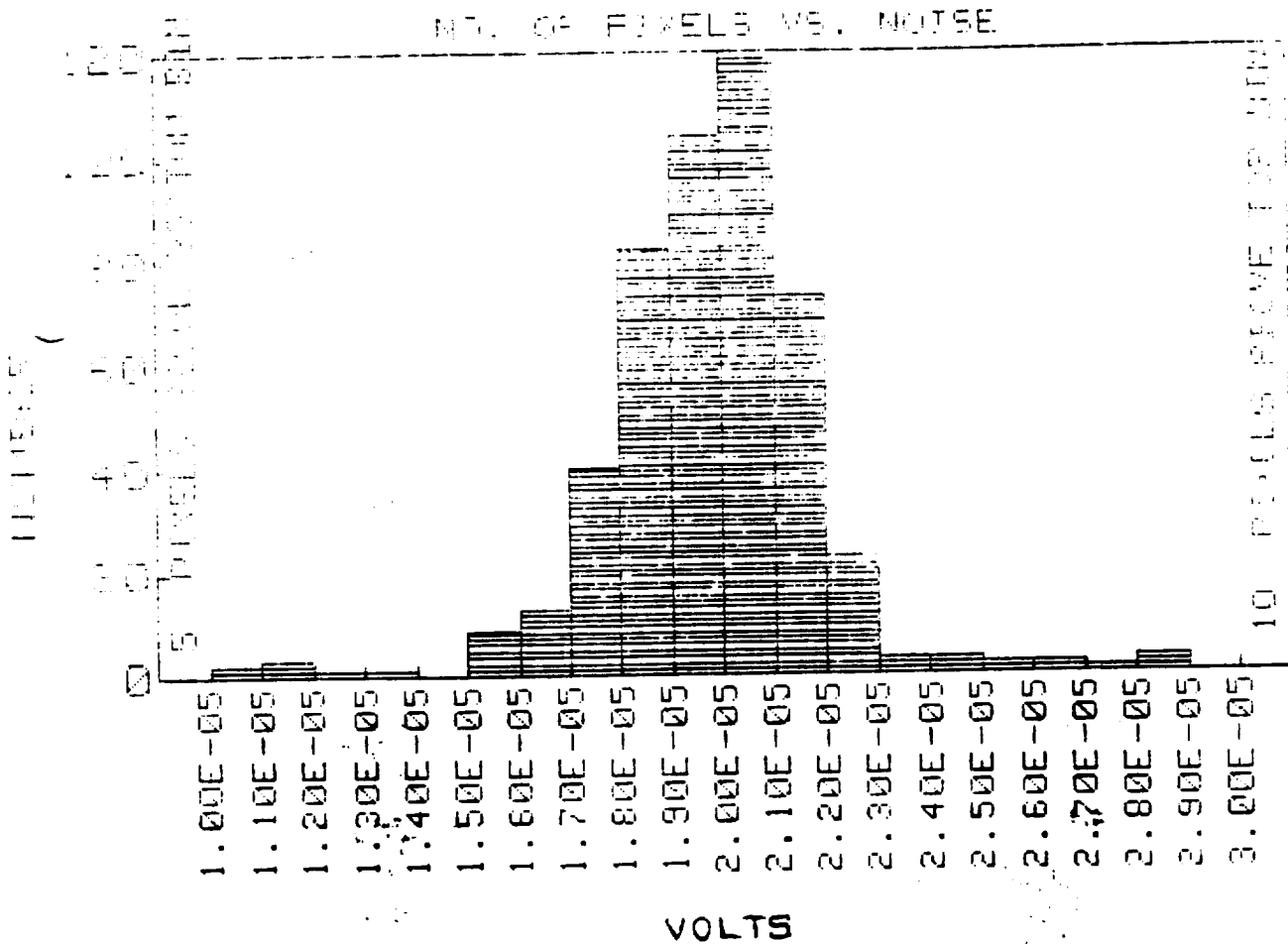


FIGURE 2

Noise Histogram for SIRT Hybrid #2

MODEL

DATE

1000000

100000

10000

1000

100

10

1

SIRTF HYBRID #2

DETECTOR BIAS = 2V

46 6460

K&E SEMI-LOGARITHMIC 7 CYCLES X 60 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

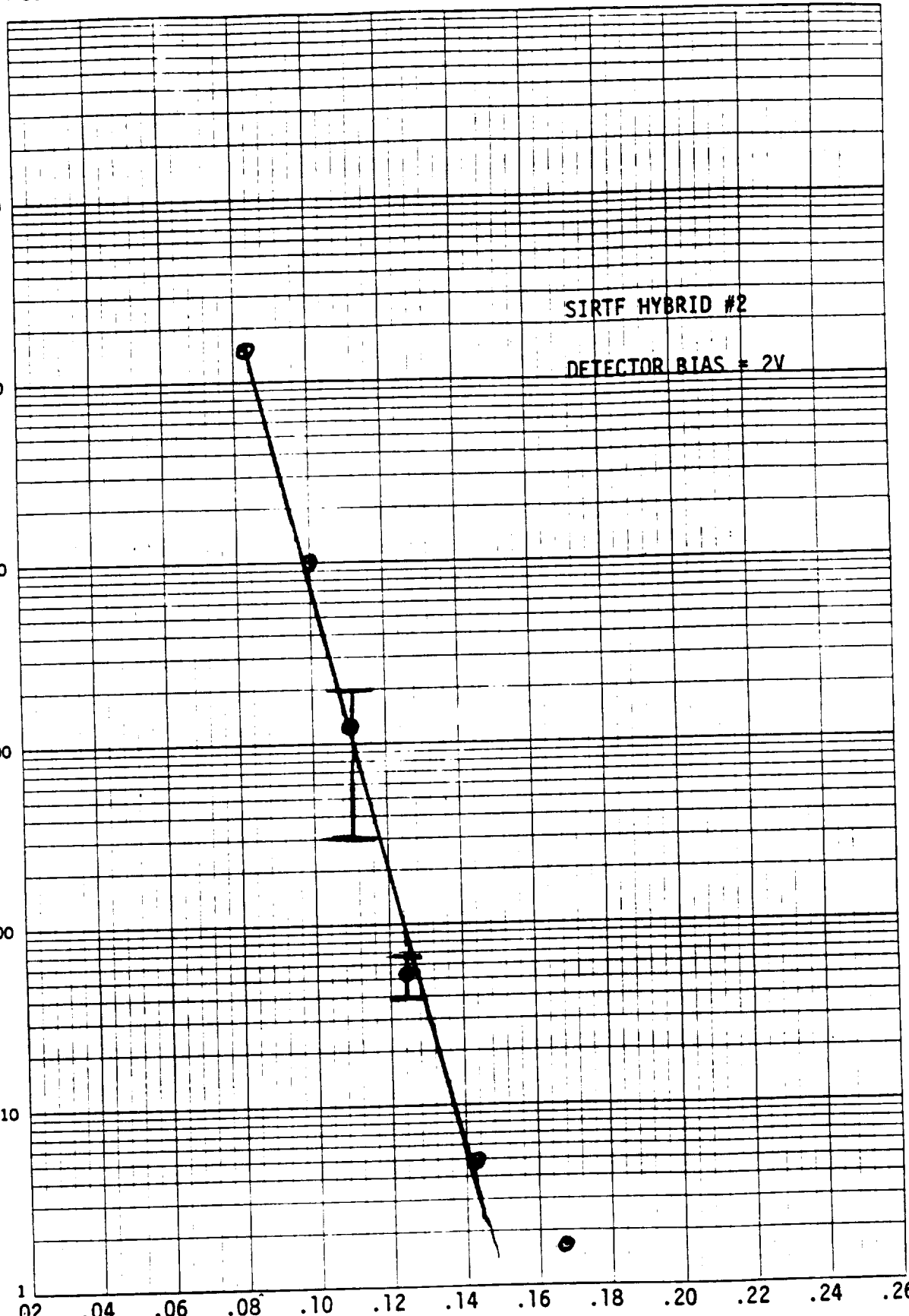
DARK CURRENT ($\times 10^{-16}$ A)
("ZILCH" BACKGROUND)

.02 .04 .06 .08 .10 .12 .14 .16 .18 .20 .22 .24 .26

FIGURE 3

Dark Current vs. 1/T for SIRTF Hybrid #2

1/T ($1/^\circ\text{K}$)



46 1320

K·E 10 X 10 TO 1/4 INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

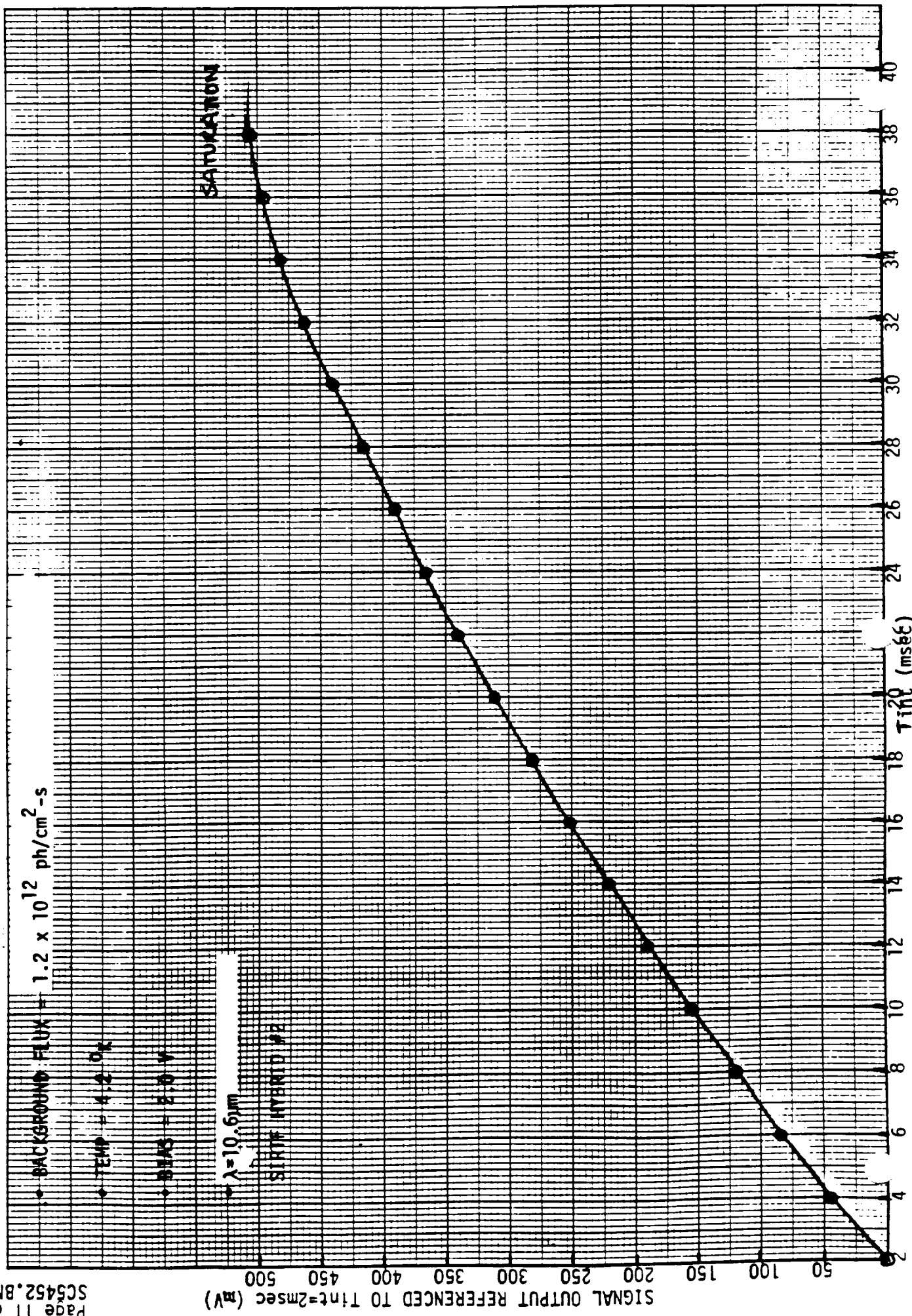


Figure 4 Output vs Integration Time for Constant Background

MEAN VALUE OF MAIN GROUP OF PIXELS IS 4.15228092
STD OF MAIN GROUP OF PIXELS IS .08855933
THE NUMBER OF GOOD PIXELS IS EQUAL TO 500

14548/008/4/C1 SIRTf HYBRID BIAS-2.0V T-10K HIGH BACKGROUND 08/25/86

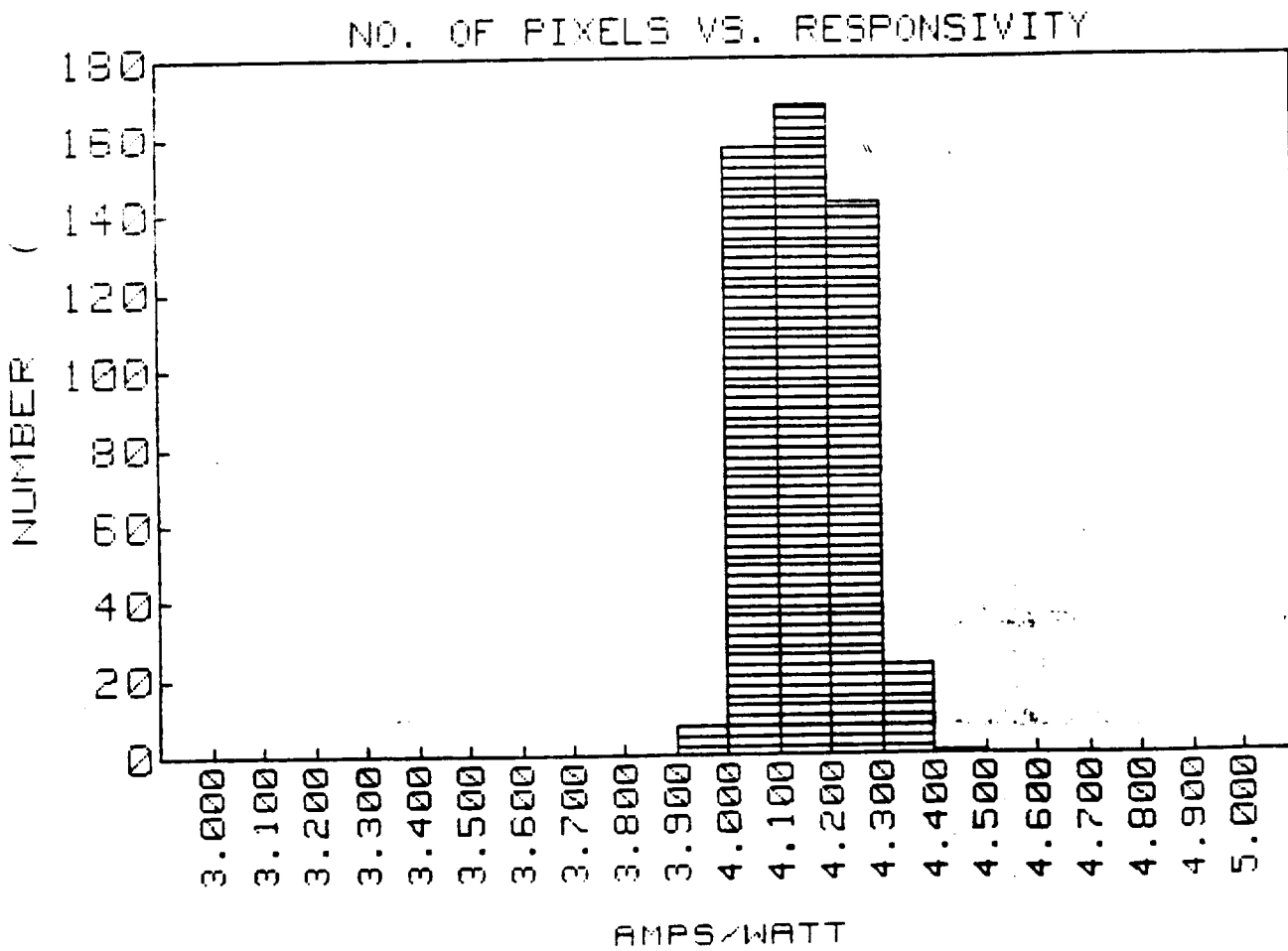


FIGURE 5
Responsivity Histogram-BKND Flux = 10^{12} ph/cm²-sec

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MEAN VALUE OF MAIN GROUP OF PIXELS IS 1.464E+13
STD OF MAIN GROUP OF PIXELS IS 4.112E+11
THE NUMBER OF GOOD PIXELS IS EQUAL TO 500

14548/008/4/C1 BIAS-2.0V T-10M BKND-1E12 @ 10.6 microns 08/29/88

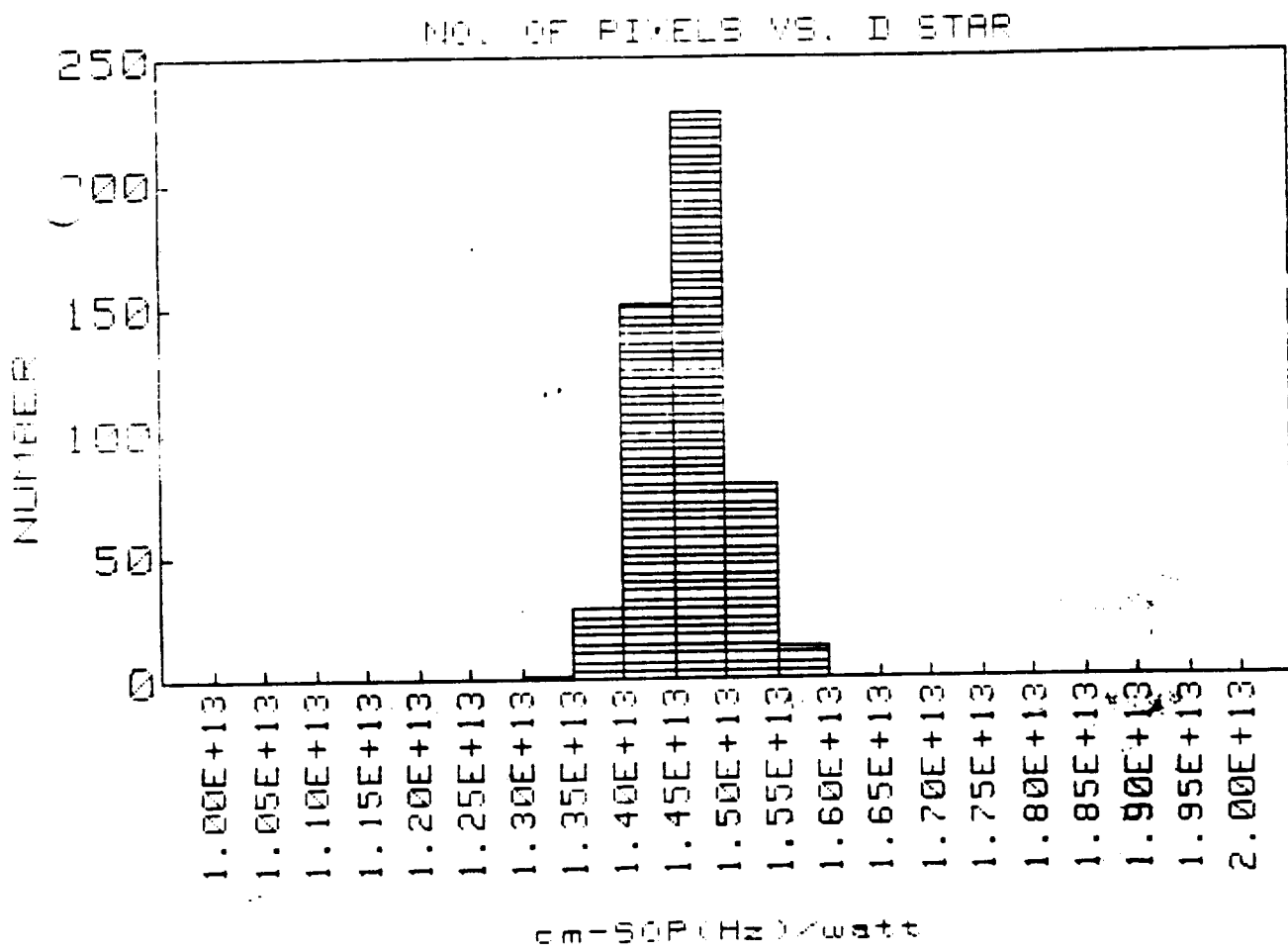


FIGURE 6
D* Histogram-BKND Flux=10¹² ph/cm²-sec

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MEAN VALUE OF MAIN GROUP OF PIXELS IS 1089.27198615
 STD OF MAIN GROUP OF PIXELS IS 30.59572760
 THE NUMBER OF GOOD PIXELS IS EQUAL TO 500

14548/008/4/C1 BIRS-2.0V T=10K Tint=1.24msec BKND=JE12 @ 10.6 microns

NO. OF PIXELS VS. NEI

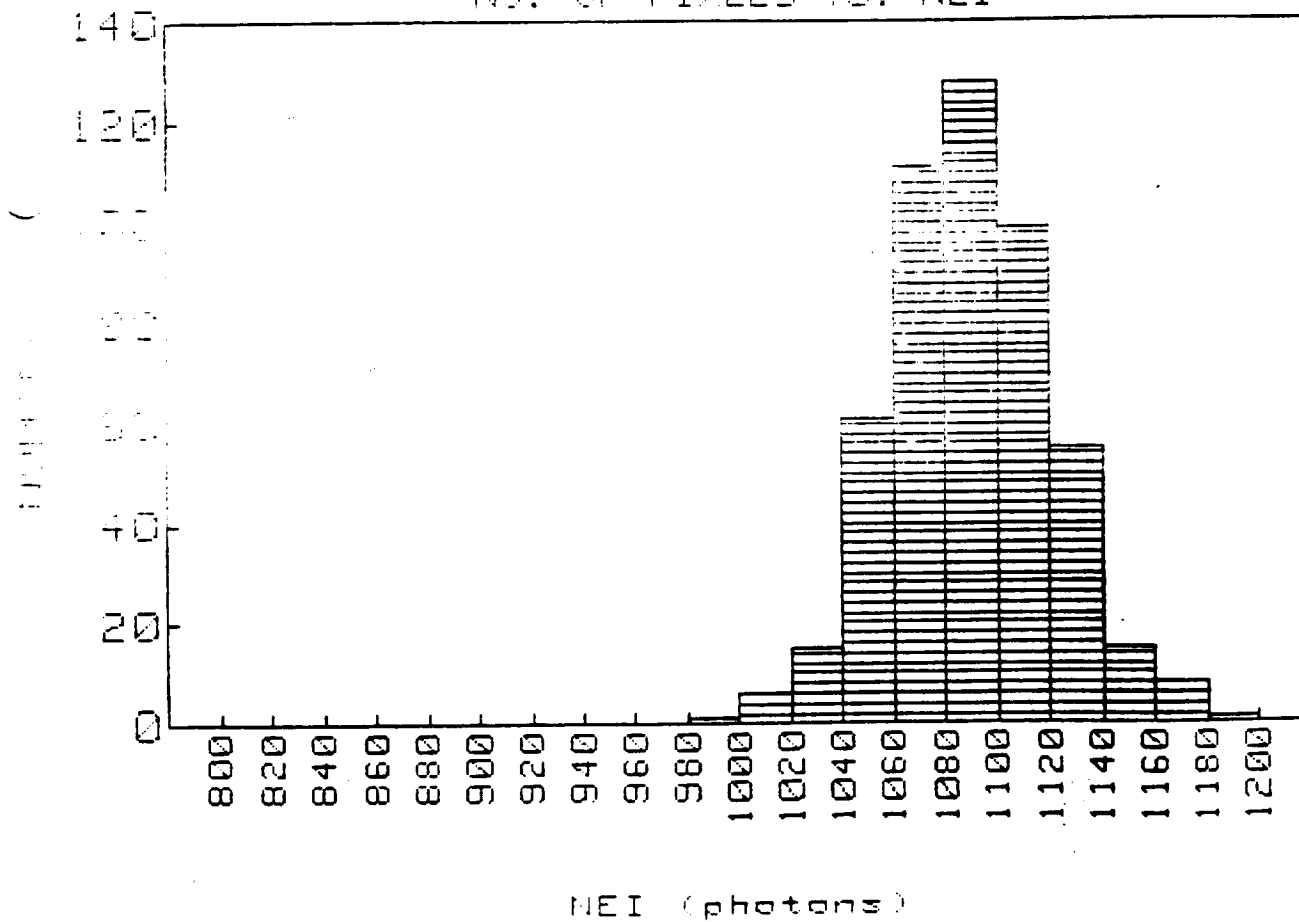


FIGURE 7
 NEI Histogram-BKND Flux= 10^{12} ph/cm²-sec

MEAN VALUE OF MAIN GROUP OF PIXELS IS 4.01509996
STD OF MAIN GROUP OF PIXELS IS .26491680
THE NUMBER OF GOOD PIXELS IS EQUAL TO 500

14548/008/4/C1 SIRTf HYBRID BIAS-2.0V T-4.2K LOW BACKGROUND 08/29/86

NO. OF PIXELS VS. RESPONSIVITY

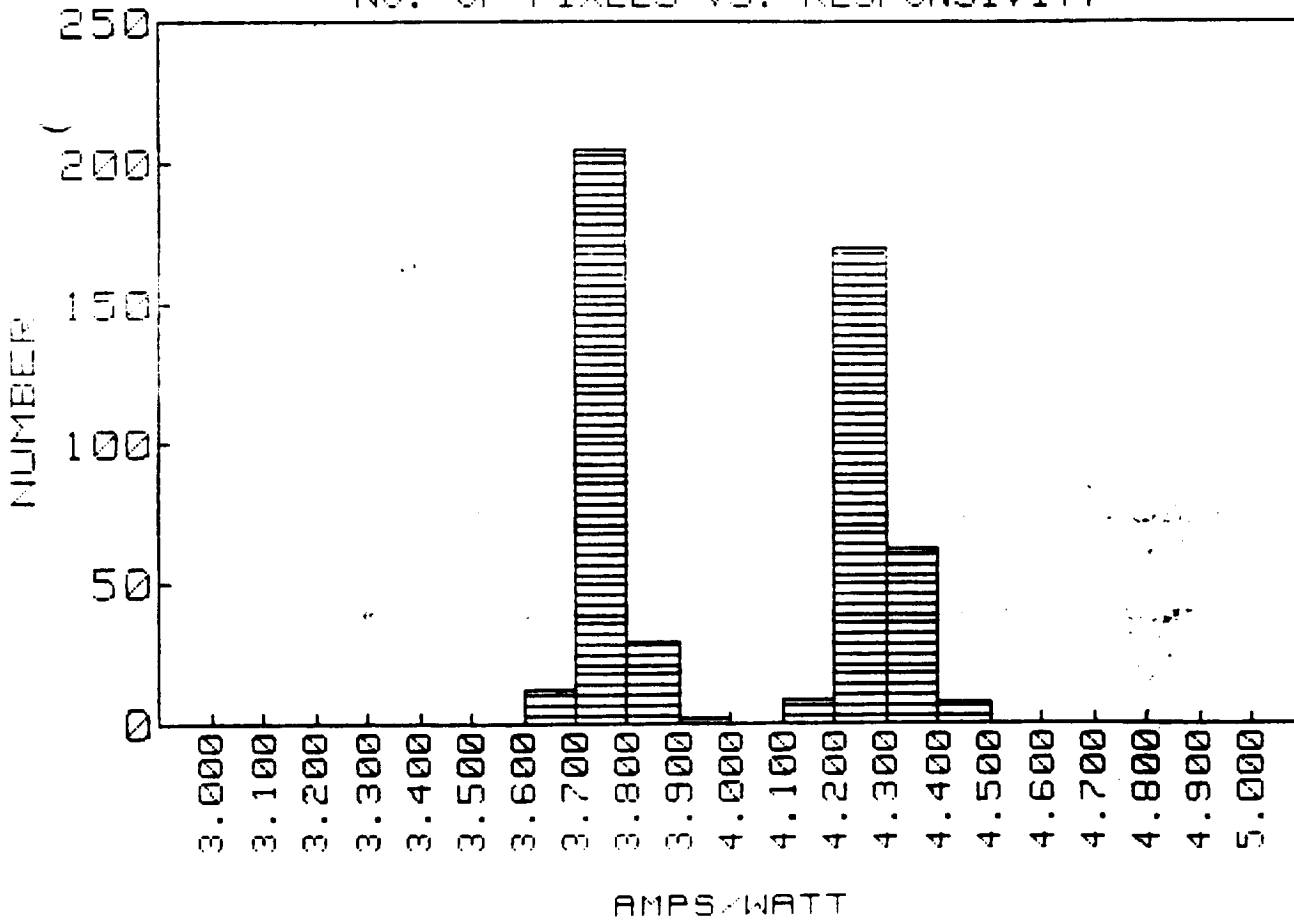


FIGURE 8

Responsivity Histogram-BKND Flux= 9×10^9 ph/cm²-sec

MEAN VALUE OF MAIN GROUP OF PIXELS IS 1.835E+14
STD OF MAIN GROUP OF PIXELS IS 9.978E+12
THE NUMBER OF GOOD PIXELS IS EQUAL TO 500

14548/008/4/C1 BIAS=2.0v T=4.2K BKND=9E9 @ 10.6 microns 08/29/86

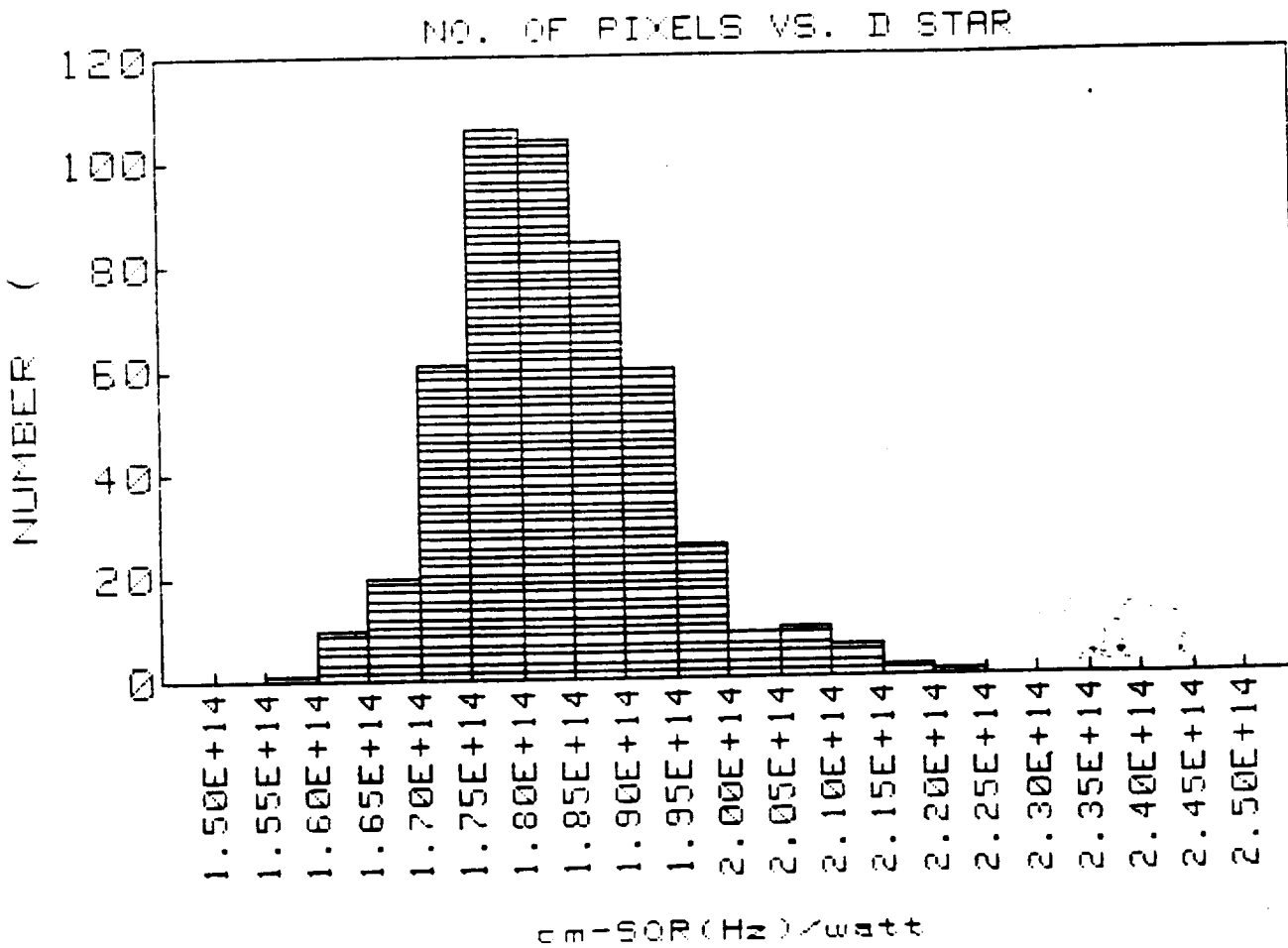


FIGURE 9
D* Histogram-BKND Flux=9x10⁹ ph/cm²-sec

MEAN VALUE OF MAIN GROUP OF PIXELS IS 639.50887097
 STD OF MAIN GROUP OF PIXELS IS 33.89566178
 THE NUMBER OF GOOD PIXELS IS EQUAL TO 500

14546/008/4/C1 BIRS=2.0v T=4.2K Tint=62msec BKND=9E9 @ 10.6 microns

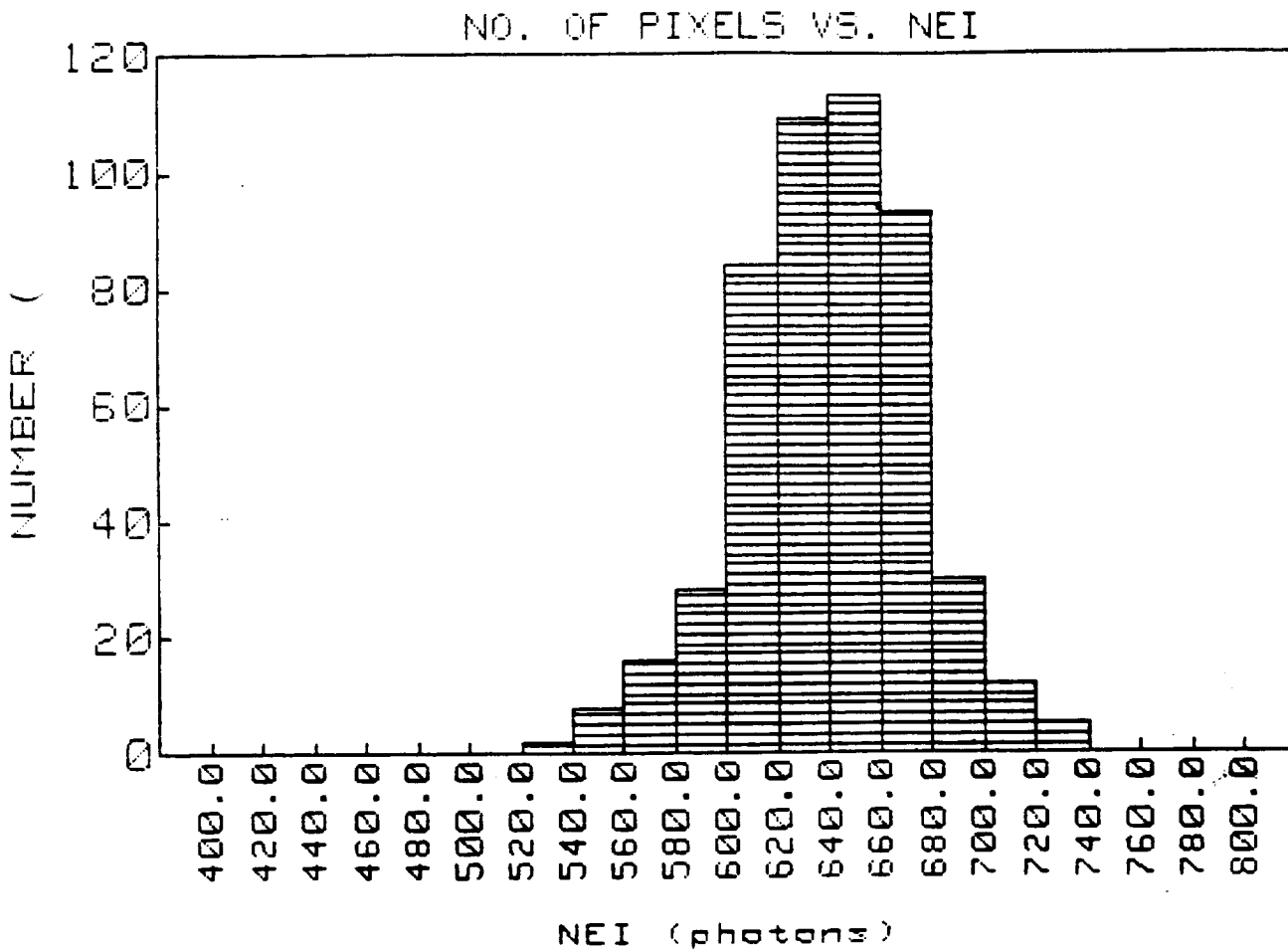


FIGURE 10
 NEI Histogram-BKND Flux= 9×10^9 ph/cm²-sec

LOW BKND
VRST-DETSUB=2.0v

T=4 degK
08/29/86

14521/BB53/01/C8 (BIBIB DETECTOR)
14546/008/4/C1 (SWIFET MUX)

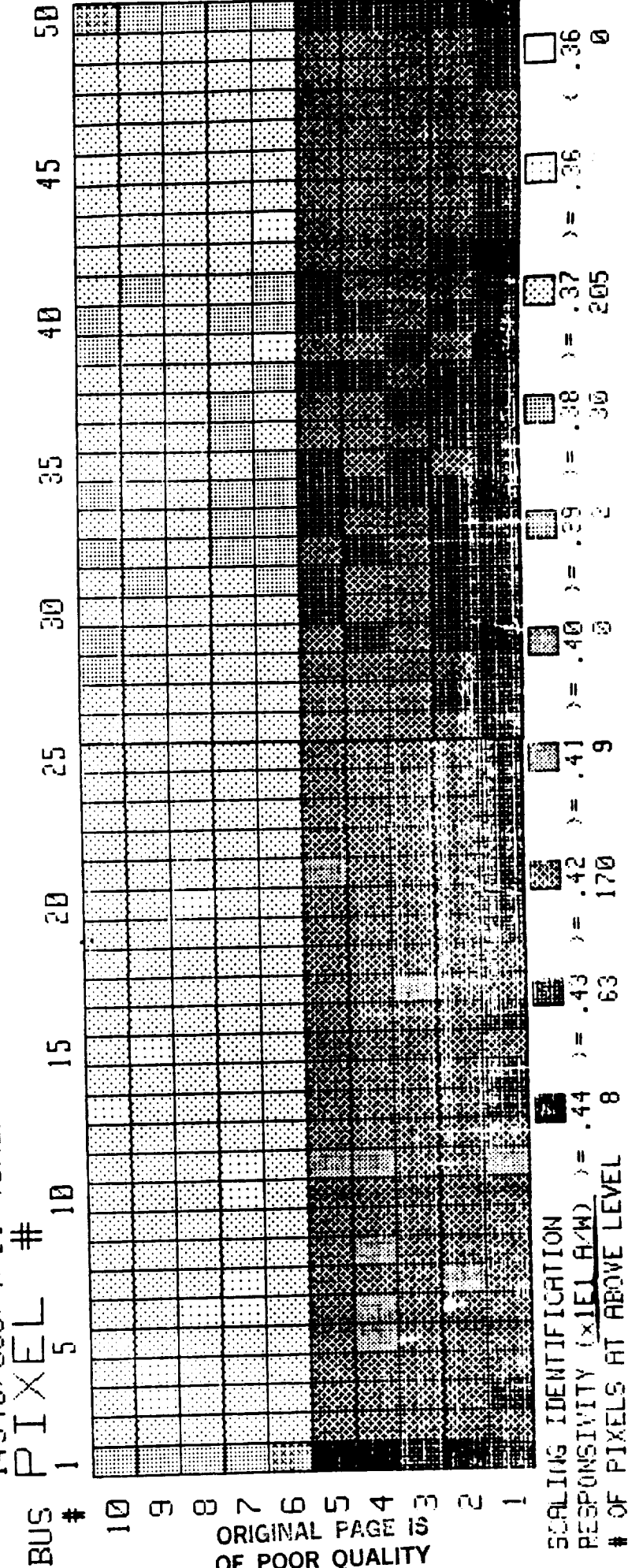


FIGURE 11
Responsivity Array Map-BKND Flux= 9×10^9 ph/cm²-sec

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SCALING IDENTIFICATION
RESPONSIVITY (x1E1 A/W) = .44
OF PIXELS AT ABOVE LEVEL

2 1440
712 031-3214

Science Center
Rockwell International Corporation
3370 Miraloma Avenue
P.O. Box 3105
Anaheim, California 92803-3105



Rockwell
International

December 6, 1986

In reply refer to SC86-714

Cornell University
Attn: Dr. James Houck, CRSR
220 Space Science Building
Ithaca, New York 14853-2801

Re: Bi-Monthly Progress Report No. 6
For Period 08/21/86 through 10/20/86
Sub-Contract No. OSP 3867
Document No. SC5452.BMR

In accordance with the above referenced contract, enclosed
please find subject report.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

D. H. Seib
Manager
Focal Plane Technology

IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRTFF

1.0 GENERAL

Six additional BIBIB/SWIFET hybrids were assembled, however none of these hybrids functioned properly. Failure analysis was conducted to attempt to identify and rectify the failure mechanism. Additional multiplexer and detector die were chosen for hybridization.

2.0 HYBRID EVALUATION

Six new BIBIB/SWIFET hybrid arrays were fabricated for the program, using a multiplexer wafer (wafer #5) different than the wafer originally used for the first set of hybrids. Four of these devices did not function properly at room temperature. The other two were functional, but at cryogenic operating temperature a large signal offset with no detector bias was observed for the pixels of certain columns. Testing of these latter two devices was not pursued further.

Because of the low hybridization/bonding yield experienced, failure analysis of the parts, including non-functional devices from the first batch assembled, was conducted. Room temperature functional testing and checking of various leads with a curve tracer were conducted. Table 1 presents a summary of the analysis results on the non-functional hybrids. No failure mode common to all die was identified; however improper behavior of a non-static protected reset pulse input and the detector substrate connection was observed on a number of die. Following these tests, the remaining (unused) die from the two multiplexer wafers were checked visually and electrically to see if any obvious damage or degradation during the wafer dicing step had occurred. No difference was observed in electrical performance when compared to the original electrical screening results. Visually, it was observed that the diameter of the indium columns on one wafer was much larger than for the other; however the diameter did not appear to be large enough to cause any problem.

Six additional multiplexer and detector die were chosen for hybridization. These hybrids will be assembled with special attention to static precautions to result in additional devices for the program.

3.0 PLANS FOR NEXT PERIOD

Testing of SIRTf hybrid #2 (previously extensively tested) will be continued, with emphasis placed upon characterizing the operation at lower backgrounds and longer integration times. The additional hybrids now in fabrication will be evaluated for room temperature functionality and cryogenic evaluation will also begin.

TABLE 1

Non-Functional Hybrid Test and Analysis Summary

<u>Hybrid S/N</u>	<u>Result</u>
3	Shift register failure. PHRST gate (not gate protected) conducts to sub for negative bias only.
4	Same as S/N 3.
5	Same as S/N 3. Also, DET SUB-MUX SUB leakage at room temp. (should be diode at room temp.).
6	Shift register OK. Device output bad. DET SUB problem same as S/N 5.
7	Signal offset at 0v detector bias.
8	Device doesn't respond to DET SUB changes. DET SUB-MUX SUB open (room temp).
9	Reset problem on mux. No diode or gate problems observed.
10	Same as S/N 7
11	Same as S/N 9.

APPENDIX C

BASD SER: Study Plan and Relay Optics

BASD SER: Reflective Relay Optics

BASD SER: IRS Concept with Czerny-Turner-Type High Resolution Sections



**System
Engineering
Report**

REPORT NO. 2470.001

DATE 10/22/86

PROJECT

IRS Optical System Study

TITLE

Study Plan and Relay Optics

PREPARED BY

M. Bottema

DATE

10/22/86

APPROVED BY

DATE

SCOPE/TEXT: (ATTACH ADDITIONAL SHEETS AS REQUIRED)

In the course of this year, the Cornell University has developed an alternative concept for the Infrared Spectrometer (IRS) on the Shuttle Infrared Telescope Facility (SIRTF), as originally baselined for their proposal to NASA of December 1983. The Cornell University intends to present this alternative concept (here called the New High Resolution Spectrograph, NHRS) in a SIRTF review at the Ames Research Center (ARC), December 15-17, 1986 and has requested BASD to evaluate and critique this concept prior to that meeting. This SER presents an outline of BASD's approach to this evaluation.

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NHRS Study Plan and Relay Optics

M. Bottena

The NHRS consists of two basically identical tandem spectrographs. One covers the 4 to 32 micron wavelength range, the other the 30 to 200 micron range. Each tandem spectrograph consists of a low-resolution Czerny-Turner spectrograph, followed by a Littrow high-resolution spectrograph. The Littrow optics consist of an off-axis section of a cassegrainian telescope. The Cornell University layout is shown in Figure 1.

The Czerny-Turner collimator matches the output beam of the SIRTf telescope, which, at present, is defined as a 85 cm diameter, f/24 Ritchey-Chretien system. In the Cornell University concept the Littrow spectrograph is defined as an f/10 system. This is convenient for matching the two spectrographs, but makes it necessary to add relay optics for effective coupling to the detectors. Cornell University considers an f/3 beam optimal. Optical analysis by the Cornell University showed that good image quality could be obtained at the Littrow image plane. However, no satisfactory solution was found for the relay optics. Consequently, we propose to address this problem first. We intend to compare various relay-optics options and will consider modification of the Littrow spectrograph, if found necessary. After this is completed we will construct a model of the entire optical system, including the telescope. This will then be used to study packaging in the Multiple Instrument Chamber (MIC) and updates will be made as found necessary. For the present we will restrict ourselves to the short-wavelength NHRS, since the detectors for the long-wavelength NHRS have not yet been defined. A preliminary assessment is attached.

NHRS Study Plan and Relay Optics

M. Bottema

1. Relay-optic options

The purpose of the relay optics is to convert the f/10 Littrow beam into an f/3 beam at the detector. In the short-wavelength NHRS the detector will be an array of 50 elements on 0.15 mm centers in the direction of dispersion and 10 elements across. We assume here that the array must be flat. The detector area is $7.5 \times 1.5 \text{ mm}^2$, which corresponds to $25 \times 5 \text{ mm}^2$ at the Littrow image plane.

In principle, the relay optics can be placed either in front or behind the Littrow image plane. We prefer the latter because it allows an intermediate field stop to be placed at this location. In its simplest form, the reimaging element is either a concave mirror or a positive lens. The former has the advantage of perfect achromatism. The only refractive material available for the $4 \mu\text{m}$ to $32 \mu\text{m}$ wavelength range is KRS-5. Its use is not a priori excluded, because its dispersion is relatively small. However, in either case the focal length must be fairly large to assure good image quality over the field required. The main aberration of concern is field curvature. It originates from both the Littrow spectrograph and the relay optics. Use of a field flattening lens is therefore almost unavoidable. Furthermore, a field lens near the Littrow image plane may be desirable to reduce the aperture of the reimaging element and allow better control of aberrations. Considering that three elements are now needed, a two-element reflective system would seem more attractive. However, before abandoning the single-element approach we decided to evaluate its performance and establish its limitations. An example is given on the following pages.

2. Relay mirror with KRS-5 field flattener and KRS-5 field lens.

As a starting point for investigation of the relay system we constructed a model of the Littrow spectrograph and simulated the preceding optics by assuming perfectly stigmatic sources in the entrance slit. The nominal spectrograph parameters are listed in Table 1. The actual parameters, used for the model, are listed in Table 2. The object distance (TH,0) and the image distance (TH,7) are slightly smaller than in Table 1 to allow for the curvature of the field. The entrance pupil is represented by surface 3 and simulates the image of the Czerny-Turner spectrograph grating. It is placed orthogonal to the optical axis at the center of the grating (Surface 4).

The relay mirror is an off-axis ellipsoid with magnification $M = 0.4$ (Surface 13). We selected an object distance $p = 140 \text{ mm}$ (TH,12). The image distance is then $g = Mp = 56 \text{ mm}$ (TH,13). These distances are related to the major axis a and minor axis b of the ellipsoid by

$$p = a + (a^2 - b^2)^{1/2} \quad (1)$$

$$g = a - (a^2 - b^2)^{1/2} \quad (2)$$

The radius of curvature at the vertex (RD, 13) is given by

$$r = -b^2/a. \quad (3)$$

The conic constant (CC,13) is

$$CC = (b/a)^2 - 1 \quad (4)$$

In the case at hand $a = 98$ mm and $(b/a)^2 = 40/49$. The axis of the ellipsoid is tilted at 3.18 degrees in the YZ plane (ALPHA, 9), to follow the direction of the chief ray, and at 10 degrees in the XZ plane (BETA, 12) to clear the detector from the incident beam (Figure 2).

The field flattener is represented by surfaces 15 and 16. It is tilted at 24.7 degree in the XZ plane (BETA, 14) to place it orthogonal to the chief ray. Together with the $M = 0.4$ ellipsoid it creates an $f/3.3$ beam at the detector. The field flattener is tentatively placed at a distance of 1 mm from the detector (TH, 17). The image quality was optimized by focussing in the direction of dispersion (Y) at wavelengths 15.965 microns and 16.035 microns, i.e., at the 0.7 zones of the detector. The curvature of the field lens was then varied to find a balance between the focus at 16 microns (center of detector) and the ends (15.95 microns and 16.05 microns). We found little variation for radii of curvature between 7 mm and 12 mm. For the present we selected the latter value (RD, 15). The effect is not fully understood and needs further attention.

The field lens is represented by surface 10 and 11. The power is adjusted to image the entrance pupil at the relay mirror.

Preliminary image-quality data are shown in Table 3. Of main interest is the image blur in the direction of dispersion. It varies from less than 120 microns at the center of the detector to just over 225 microns (1.5 pixel) at the ends, but is almost independent of the wavelength setting. The image blur in the imaging direction (X) varies less across the detector and stays under 185 microns. Also shown are the rms aberration values. Roughly speaking, more than 70 percent of the energy falls within one pixel, if these values are less than 75 microns. For comparison we also show an example of the image quality without the field lens. At the end of the detector it is noticeably worse, but some improvement might be expected with a stronger field flattener.

Within the 10-pixel width of the detector, the aberrations vary little with field angle. No data are presented here.

3. Conclusions

Our preliminary results indicate that a single-mirror relay mirror, combined with a KRS-5 field flattener and a KRS-5 field lens should produce adequate image quality. However, it remains desirable to reduce systematic aberrations as much as is practical, in order to leave the largest possible margins for component-figure errors and focus and alignment errors. This is especially true for cryogenically cooled instruments of great complexity.

Possible means to reduce the systematic aberrations are:

- Relay mirror
 - increase focal length
 - reduce tilt angle
 - use different profile (e.g. toroidal ellipsoid)

- Field flattener
 - change shape
 - use two components
 - aspherize

- Field lens
 - use different pupil-imaging criterion

However, at the present time it would seem more useful to explore an all-reflective relay system next and compare performances, especially since an all-reflective system will be needed anyway for the long-wavelength NHRS.

Table 1. Littrow spectrograph parameters

Collimator and camera

focal length	1143 mm (45 in)
aperture diameter	114.3 mm (4.5 in)
decenter distance	101.6 mm (4.0 in)

Primary mirror

focal length	-381 mm (-15.0 in)
conic constant	- 1
distance from aperture stop	228.6 mm (9.0 in)

Secondary mirror

focal length	-123.825 mm (- 4.875 in)
conic constant	- 4
distance primary	-298.45 mm (-11.75 in)
image distance	247.65 mm (9.75 in)
magnification	3

Grating

grating constant	18.47625 microns
blaze angle	60 degrees

Slit and field

slit distance	- 12.065 mm (0.475 in)
field size	25 mm x 5 mm

Table 2

>PG-1

NHRS, ELLIPT. RELAY, FIELD LENS

BASIC LENS DATA

SURF	RD	TH	MEDIUM	RN	DF	
0	0.00000000	246.84000000	AIR			
1	247.65000000	-298.45000000	REFL			
2	762.00000000	228.60000000	REFL			
3	0.00000000	0.00000000	AIR			
4	0.00000000	0.00000000	REFL			
5	0.00000000	-228.60000000	AIR			
6	762.00000000	298.45000000	REFL			
7	247.65000000	-246.85631764	REFL			
8	0.00000000	0.00000000	AIR			
9	0.00000000	-3.00000000	AIR			
10	0.00000000	-3.00000000	MATL	KRS-5	2.355029	-0.002
11	134.32683783	4.93923903	AIR			
12	0.00000000	-140.00000000	AIR			
13	80.00000000	56.00000000	REFL			
14	0.00000000	-3.72130041	AIR			
15	12.00000000	3.00000000	MATL	KRS-5	2.355029	-0.002
16	0.00000000	1.00000000	AIR			
17	0.00000000	0.00000000	AIR			

REFRACTIVE INDICES

SURF	N1	N2	N3	N4	N5
10	2.355029	2.355141	2.354917	2.355188	2.354869
15	2.355029	2.355141	2.354917	2.355188	2.354869

Table 2 Continued

>PG-2

SPECIAL CONDITIONS

SURF 4 CONDITION GRATY GRSP = 18.476 ORDER NBRS = -2 -2 -2 -2 -2

CC AND ASPHERIC DATA

SURF	CC	AD	AE	AF	AG
1	-4.00000E+00				
2	-1.00000E+00				
6	-1.00000E+00				
7	-4.00000E+00				
13	-1.86374E-01				

TILT AND DEC DATA

SURF	TYPE	YD	XD	ALPHA	BETA	GAMMA
3	DEC	-101.60000	0.00000			
4	TILT	0.00000	0.00000	-59.99797	0.00000	90.00000
5	RTILT	0.00000	0.00000	-59.99797	0.00000	90.00000
6	DEC	101.60000	0.00000			
9	TILT	-12.11096	0.00000	-3.17939	0.00000	0.00000
12	TILT	0.00000	0.00000	0.00000	10.00000	0.00000
14	TILT	0.00000	0.00000	0.00000	-24.73121	0.00000
7	TILT	0.00000	0.00000	1.35468	7.26374	0.00000

CLEAR APERTURES AND OBSTRUCTIONS (CA ON)

SURF	TYPE	CAY	CAX
3	CIRCLE	57.1500	

PICKUPS

SURF	TYPE	J	A	B
5	ALPHA	4	1.0000	0.000000
5	TH	2	-1.0000	0.000000
6	YD	3	-1.0000	0.000000

REF OBJ HT	REF AP HT	OBJ SURF	REF SURF	IMG SURF
0.120650E+02 (-2.7983 DG)	57.15000	0	3	17

EFL	BF	F/NBR	LENGTH	OID	T-MAG
37.5288	1.0000	-0.62	387.9171	-84.7984	0.289028

WAVL NBR	1	2	3	4	5
WAVELENGTH	16.00000	15.96500	16.03500	15.95000	16.05000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

APERTURE STOP AT SURF 3

JS UNITS ARE MM

Table 3. Image sizes (dimensions in microns)

With field lens

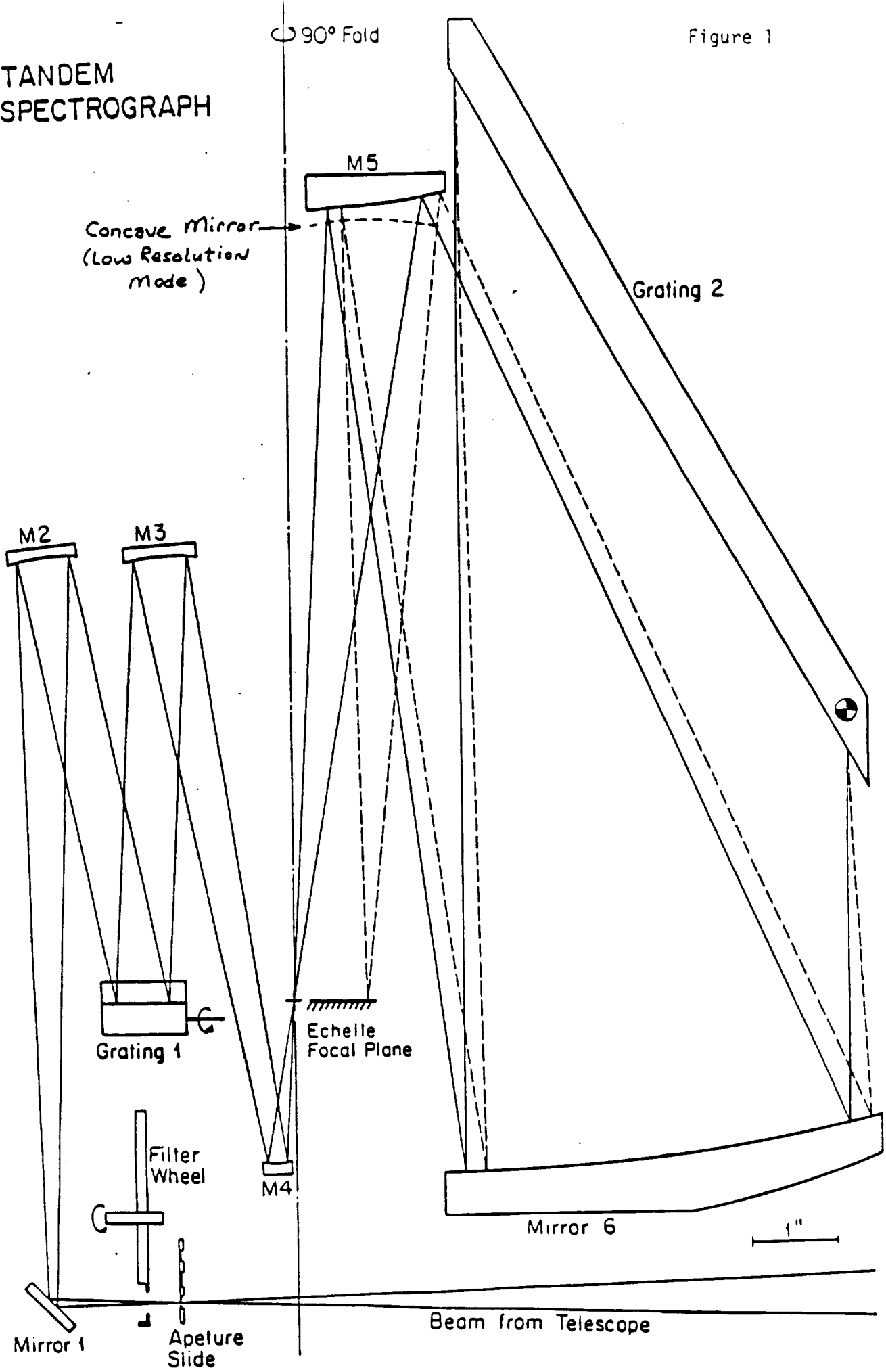
Wavelength (microns)	Image location Y (mm)	Total image width		Rms aberration	
		Δy	Δx	dy	dx
3.987	-4.0	228	181	64	42
3.99125	-2.8	132	134	31	36
4	0	117	154	27	36
4.00875	2.9	138	128	32	35
4.0125	4.2	227	182	65	43
15.95	-4.1	210	182	62	42
15.965	-2.8	134	135	31	36
16	0	117	154	27	36
16.035	2.9	139	129	32	34
16.05	4.2	227	184	64	44
31.90	-4.1	214	185	59	43
31.93	-2.8	134	137	32	37
32	0	115	152	27	35
32.07	2.9	140	131	33	35
32.1	4.3	227	187	63	44

Without field lens

15.95	-4.0	287	189	78	45
15.965	-2.6	136	134	32	38
16	0	156	192	36	45
16.035	2.7	144	139	34	39
16.05	4.1	329	120	90	48

TANDEM SPECTROGRAPH

Figure 1



ORIGINAL PAGE IS
OF POOR QUALITY

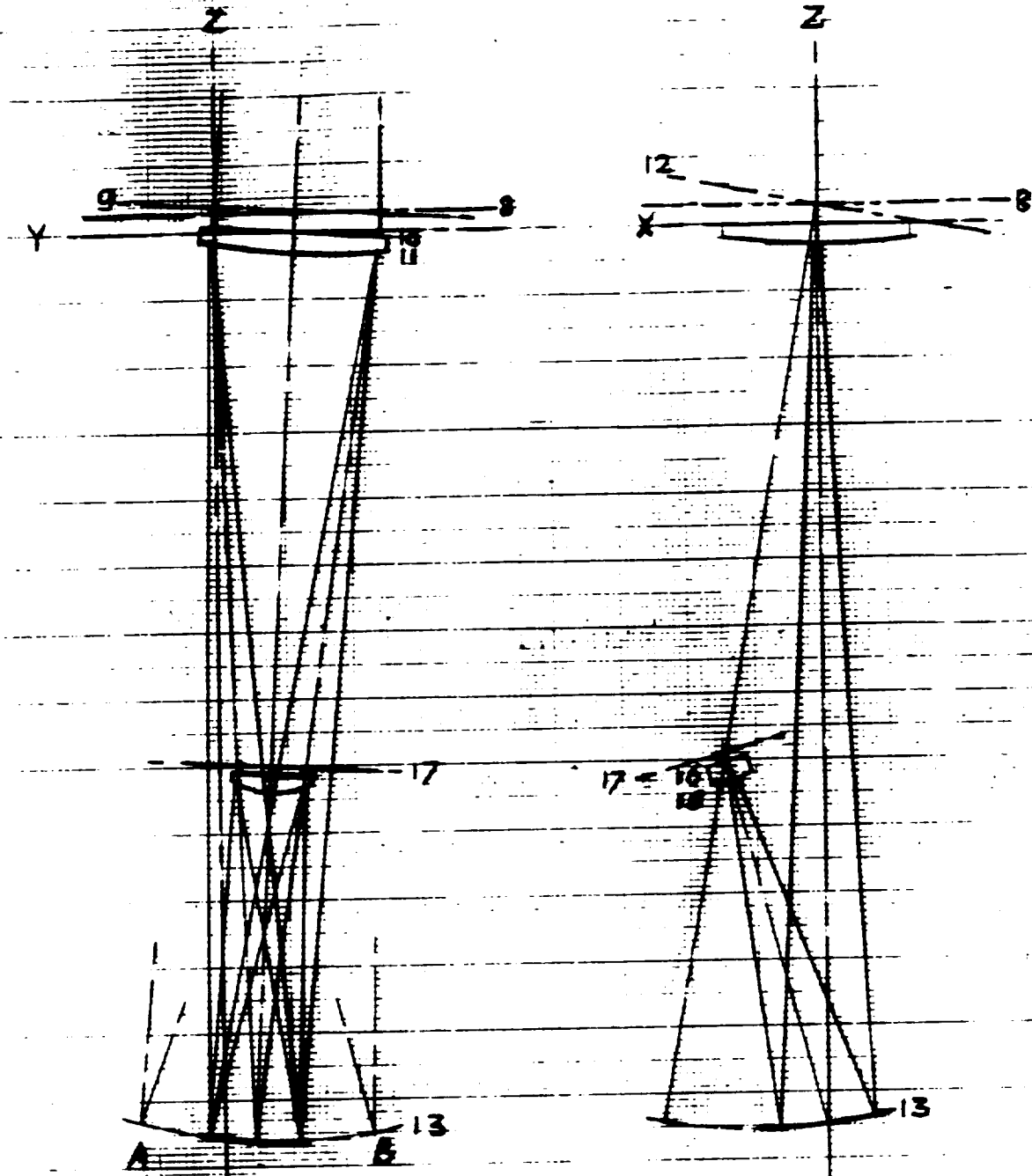


Figure 2. - Relay mirror with field flattener and field lens. AB = beam width without field lens. (Scale 1:1).



System
Engineering
Report

REPORT NO 2470-002 DATE 11-26-86

PROJECT			
IRS Optical System Study			
TITLE			
Reflective relay optics			
PREPARED BY	DATE	APPROVED BY	DATE
M. Bottema	11-26-86		

SCOPE/TEXT: (ATTACH ADDITIONAL SHEETS AS REQUIRED)

Please refer to the attached pages .

DISTRIBUTION

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Reflective relay optics

M. Bottema

An effort has been made to design a two-mirror relay system to convert the $f/10$ output beam of the Littrow spectrograph to an $f/3$ beam at the detector. To simplify the analysis, the spectrograph camera was simulated by a two-mirror telescope with the same parameters (including aperture stop distance and decentering) as in SER 2470.001, 10/22/86. However, for ease of coma control, the telescope was made aplanatic. The relay system was initially also made aplanatic, so as to null third-order spherical aberration and coma. The relay parameters were then chosen to compensate field curvature and astigmatism in the telescope. Together with the condition for aplanatism, this defines the relay parameters uniquely. The telescope and relay optics were then modelled on ACCOS V and focus, spherical aberration and coma were adjusted by automatic iteration to balance the third-order aberrations against higher-order aberrations. At $f/3$, the latter are quite large. No effort was made to also adjust field curvature and astigmatism.

The optical configuration is shown in Figure 1. To facilitate accommodation of the 25-mm field, the simulated direction of dispersion was placed in the X direction. The consequence for the Littrow spectrograph is that the grating is used in an "off-plane" mode, rather than in an "in-plane" mode. The simulated distance between the spectrograph entrance and exit slits was reduced from 25 mm to 7.5 mm, which eases control of image quality. The main problem at present is interference of the relay optics with the Czerny-Turner spectrograph. This will need attention.

The ACCOS V model is shown in Table 1. The relay mirrors (surfaces 6 and 7) are both oblate spheroids. The asphericity of the primary mirror (6) is extremely high (The third-order value is 102!), which is a point of concern with regard to fabrication. The secondary mirror (7) could probably be made spherical.

Examples of the image quality are given below. The aberrations were minimized in the direction of dispersion (X). Further reduction seems possible, since several parameters are available for optimization. This may permit a reduction of the size of the relay optics while preserving detector-limited resolution.

Image position	X(mm)	0	1.9	3.8
Rms aberration	dX (microns)	1	19	57
Rms aberration	dY (microns)	3	12	19
Total image width	ΔX (microns)	4	76	221
Total image width	ΔY (microns)	11	41	67

Table 1

LEPRT

NHRS, OPTIMIZED AT FOB,.3 AND FOB,.3 1

BASIC LENS DATA

SURF	RD	TH	MEDIUM	RN	DF
0	0.00000000	1.14300000E+20	AIR		
1	0.00000000	228.60000000	AIR		
2	-762.00000000	-298.45000000	REFL		
3	-247.65000000	247.65000000	REFL		
4	-80.17446000	0.00000000	AIR		
5	0.00000000	133.33050000	AIR		
6	351.83610000	-184.23530000	REFL		
7	179.60240000	137.11052449	REFL		
8	0.00000000	0.00000000	AIR		

CC AND ASPHERIC DATA

SURF	CC	AD	AE	AF	AG
2	-1.06147E+00				
3	-4.95745E+00				
6	4.66340E+01				
7	-3.12570E-02				

TILT AND DEC DATA

SURF	TYPE	YD	XD	ALPHA	BETA	GAMMA
2	DEC	-101.60000	0.00000			
5	DEC	5.00000	0.00000			

CLEAR APERTURES AND OBSTRUCTIONS (CA ON)

SURF	TYPE	CAY	CAX
1	CIRCLE	57.1500	

REF OBJ HT	REF AP HT	OBJ SURF	REF SURF	IMG SURF
-0.125000E+19 (0.6266 DG)	57.15000	0	1	8

EFL	BF	F/NBR	LENGTH	GIH
-342.8999	137.1105	-3.00	380.9805	-3.7336

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.58756	0.48613	0.65627	0.43584	0.70652
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

APERTURE STOP AT SURF 1

LENS UNITS ARE MM

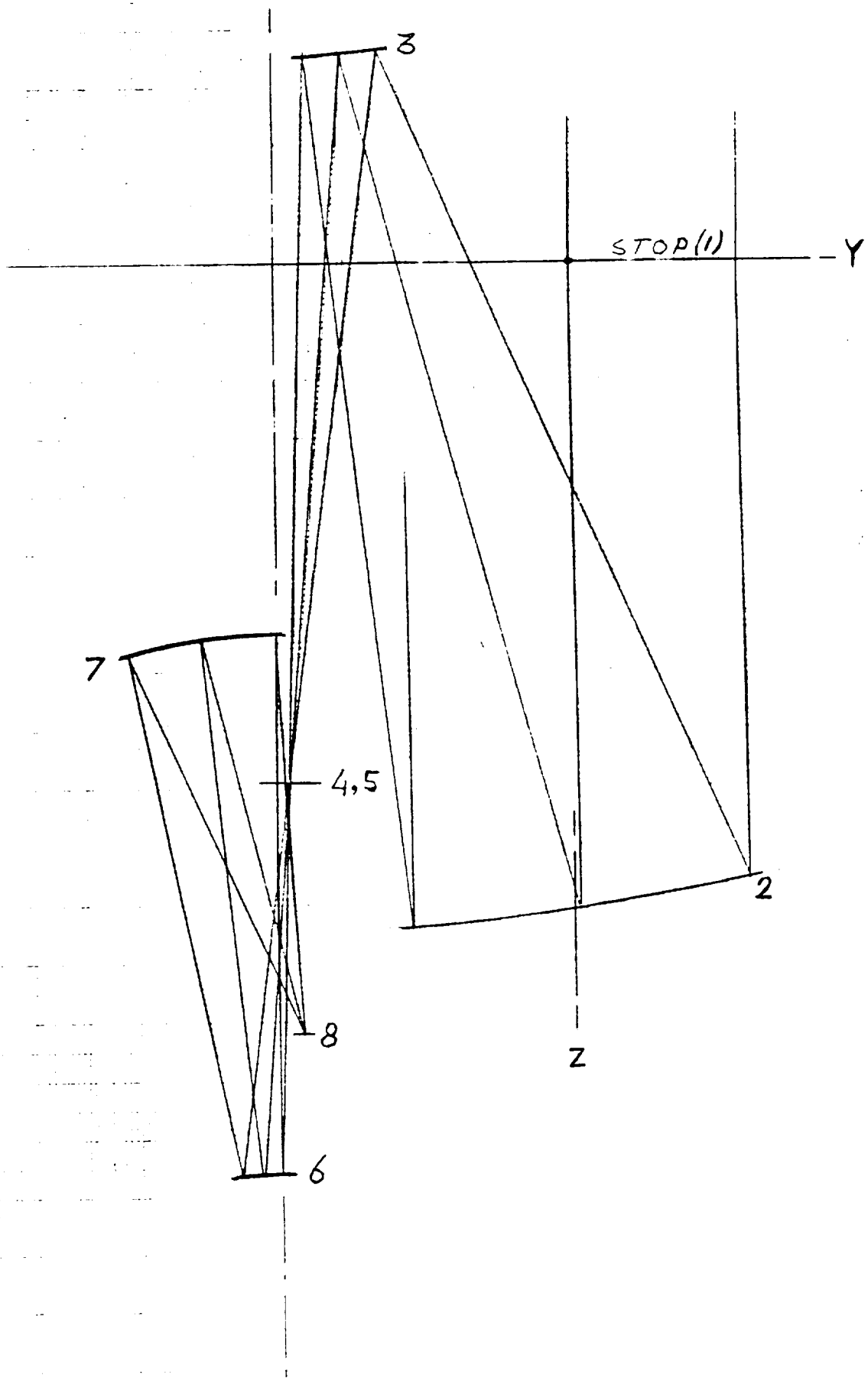


Figure 1



**System
Engineering
Report**

REPORT NO. 2470.003

DATE 1-09-87

PROJECT

IRS Optical System Study

TITLE

IRS concept with Czerny-Turner-type high-resolution sections

PREPARED BY

M. Bottema

DATE

1/09/87

APPROVED BY

DATE

SCOPE/TEXT: (ATTACH ADDITIONAL SHEETS AS REQUIRED)

This report describes a modified IRS concept in which separate camera mirrors create directly an f/3 beam at the detector. Relay optics are then not needed. The camera mirror in the high-resolution mode follows the grating directly. The high-resolution spectrograph thus becomes essentially a Czerny-Turner system. The camera optics for the low-resolution mode consist of a camera mirror, a field mirror and several plane folding mirrors, so as to use the same detector as in the high-resolution mode.

This report addresses only the long-wavelength spectrograph (coverage 30-200 microns). It uses exclusively reflective optics and can be packaged in a 60 cm-long 60-degree MIC segment. A separate segment is needed for the short-wavelength spectrograph (coverage 4-32 microns). This has the advantage that it is not constrained by compatibility with the long-wavelength spectrograph. For instance, the optics could be much smaller and still achieve the same spectral resolution, leaving room for the possible addition of extra detectors. However, the exploration of such options must await further discussion with the science team and is not addressed here.

DISTRIBUTION

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IRS concept with Czerny-Turner-type high-resolution sections

M. Bottema

In the concept, proposed here, the instrument consists of two separate units, one for the short-wavelength range and one for the long-wavelength range. Each is housed in a 60-degree, 60-cm long MIC compartment as described in the SIRTf Newsletter, April 1986, ARC, page 3. We address here only the long-wavelength unit. The optics must be large to attain the described spectral resolution. Hence, packaging is of primary concern. In the short-wavelength unit this is less of a problem.

The predisperser is of the same type as in the Cornell concept of late 1986, described in "A new high-resolution spectrograph design." The output beam can be directed either to the entrance slit of the high-resolution section or directly to the detector. A preliminary concept is shown in Figures 1, 2, 3 and 4. The telescope beam is inserted by means of a steerable folding mirror M1 on the telescope axis and then passes through the following elements:

SW slit wheel

FW filter wheel,

M2 folding mirror, directing the beam to the collimating mirror C1.

C1 600-mm focal length, f/24 off-axis paraboloid,

G grating wheel with four gratings and one mirror, in off-plane configuration, i.e., with grating dispersion in the X direction,

B beam-steering device for selection of high-resolution and low-resolution modes.

For the high-resolution mode, the optical train continues as follows:

C2 300-mm focal length, f/12 camera mirror (off-axis paraboloid),
S entrance slit of high-resolution section,
M3, M4, M5 folding mirrors in high-resolution collimator,
C3 1200-mm focal length, f/12 collimating mirror (off-axis
 paraboloid),
E echelle-type high resolution grating,
C4 300-mm focal length, f/3 camera mirror (off axis paraboloid),
D detector

For the low-resolution mode, the optical train consists of:

C5 field mirror, imaging the grating in G on the low-
 resolution camera mirror C6
M6, M7, M8, M9, plane folding mirrors,
C6 ellipsoidal camera mirror,
D detector.

Mirrors C4 and C5 form an f/3 off axis section of an aplanatic gregorian telescope. C4 is a highly aspherical oblate spheroid, but the small off-axis section, actually used, could possibly be replaced by a toroid. Without the field mirror the beam at C5 would become excessively large. The path length from C4 to C5 is about 750 mm.

The above concept is aimed at a spectral resolution $R = 2000$ in the high-resolution mode. This is the goal set in "System requirements for the IRS", Rev. 2.3, 12/09/86, for the wavelength range 4 to 100 microns. To achieve this we increased the blaze angle of E from $\theta = 60^\circ$ to $\theta = 63.4^\circ$ ($\tan\theta = 2$). This is a standard blaze angle in commercially available echelles. The minimum acceptable camera focal length f_c then follows from the relation

$$R = 2(f_c/s)\tan\theta$$

and becomes $f_c = 300$ mm for $s = 0.6$ mm. The associated beam diameter is then $f_c/3 = 100$ mm. This defines the size of grating E.

The grating sizes in the low-resolution mode are defined by the collimator focal length and the scanning ranges. The diameter of the collimated beam is 28 mm. Four gratings suffice to cover the wavelength range from 30 to 200 microns, with about 10 percent overlap between subranges and a ratio 1.75 between the upper and lower wavelength limits within each subrange.

The division is:

Grating	Subrange (microns)
G1	30.0 - 52.5
G2	46.9 - 82.0
G3	73.2 - 128.1
G4	114.3 - 200

In the present concept no reimaging of the predisperse gratings on E is provided. The beam spread seems sufficiently small to make this unnecessary. However, this remains to be verified in detail.

In the high-resolution mode the center of the spectrum is perfectly stigmatic. The main aberrations along the spectrum are coma and decentering-induced astigmatism. Both increase linearly with the distance from the center. For the choice of parameters in the present concept the total blur diameters in the direction of dispersion at the ends of the spectrum remains under 200 microns. However, this does not include the beam spreading, mentioned above.

The low-resolution camera optics were designed for zero third-order spherical aberration and coma. Third-order astigmatism is then independent of decentering. Higher-order aberrations cause the following image blurs:

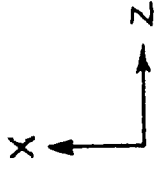
Location	Diameter (microns)	
	Dispersion (x)	Cross dispersion (y)
o	135	56
3.7 (end spectrum)	228	83

Balancing of third-order aberrations against higher-order aberration might improve the image quality but does not seem necessary. Rather, the margin in image quality might be used to relieve the crowding at the mode-selector B by increasing the decentering distance in the optics. As in the high-resolution camera, the direction of dispersion is orthogonal to the direction of decentering.

One concern in the present concept is whether sufficient space is available to accommodate the detector. This needs further attention. Placing mirrors C4 and C6 farther to the left in Figure 3 would help, for instance.

Another concern could possibly be lack of thermal stability in the long optical train of the low-resolution camera. This could be avoided by using a separate low-resolution detector.

TELESCOPE AXIS



600 MM

320 MM

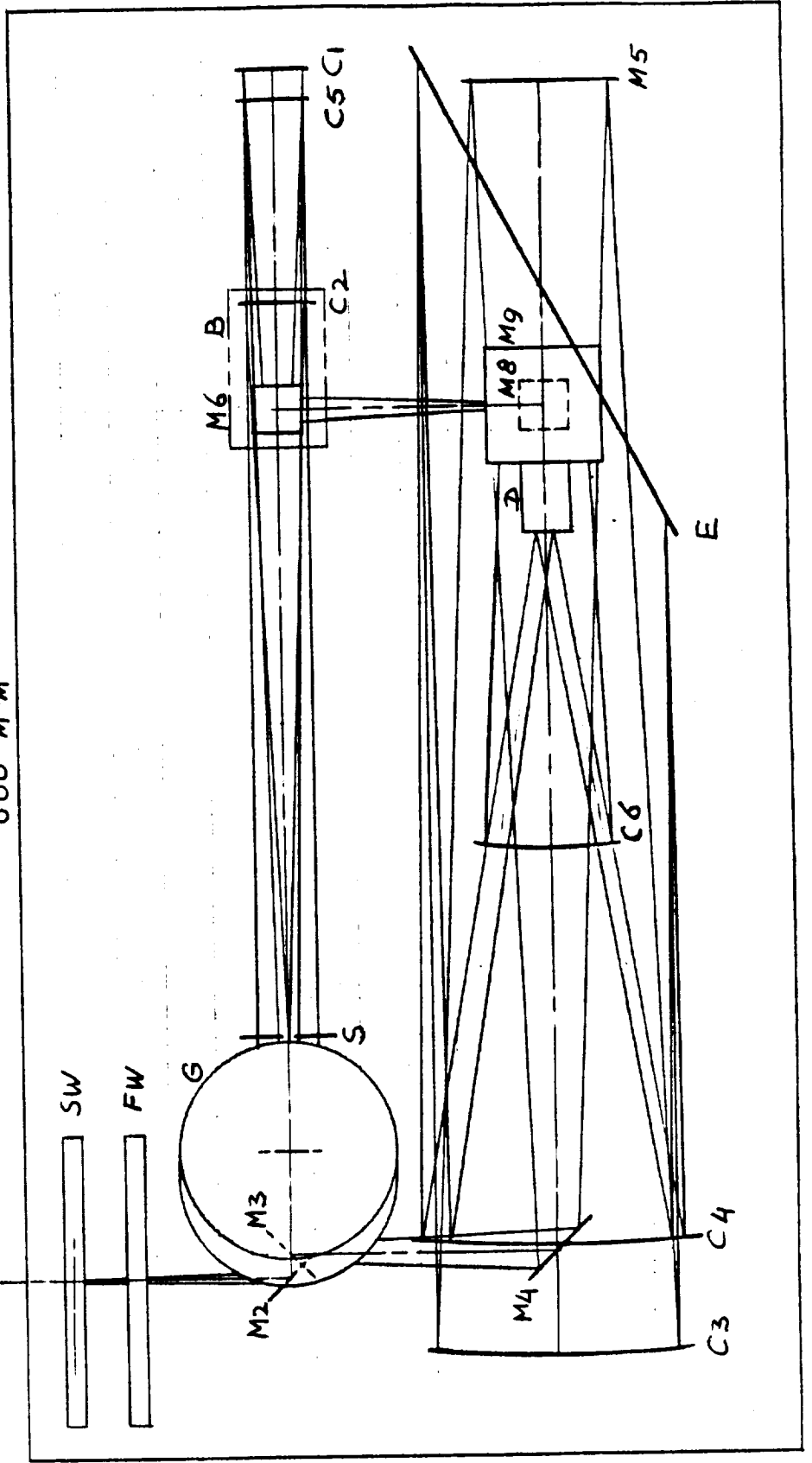


Figure 1. Top view

600 mm

500 mm

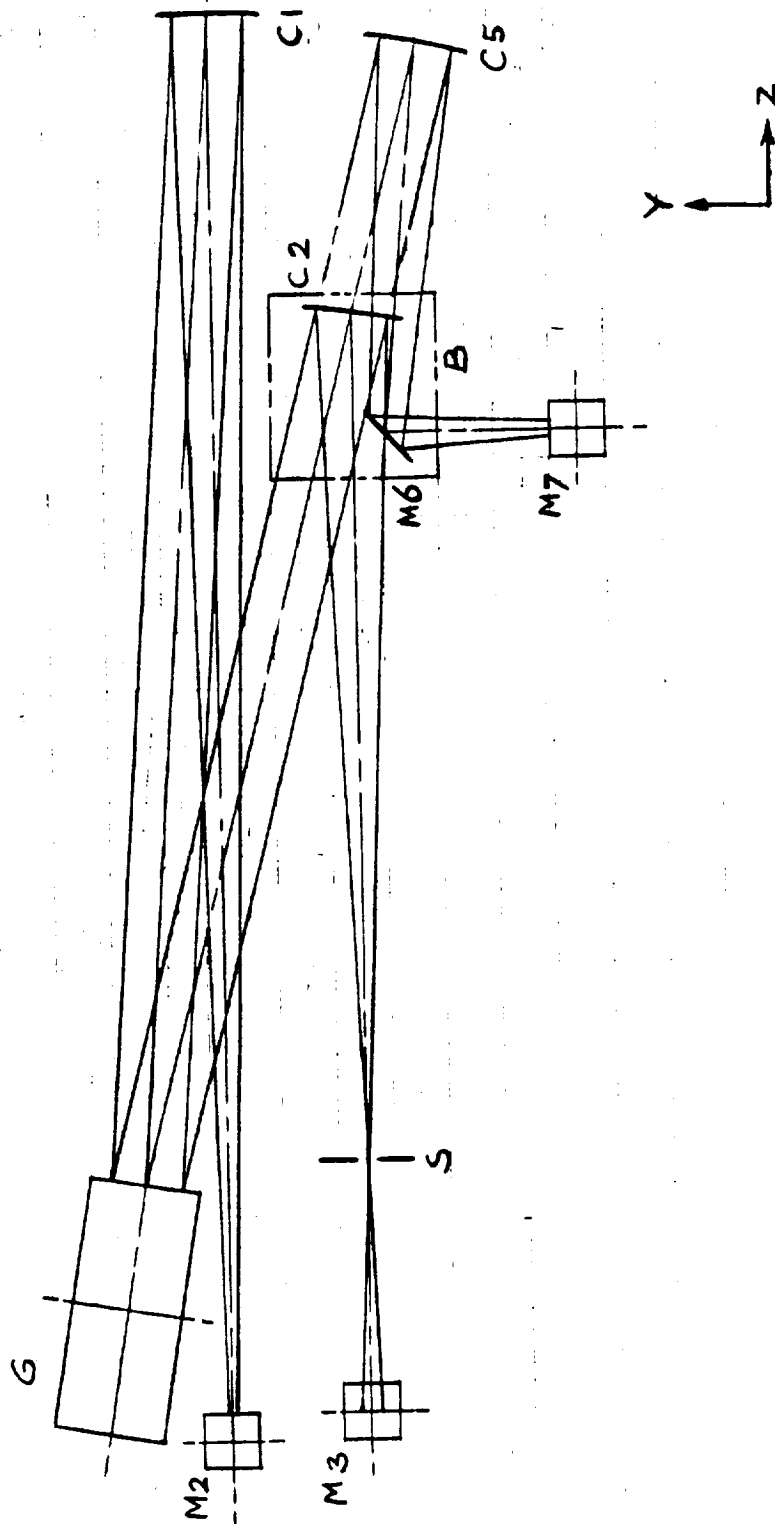


Figure 2. Side view, predisperser and low-resolution section

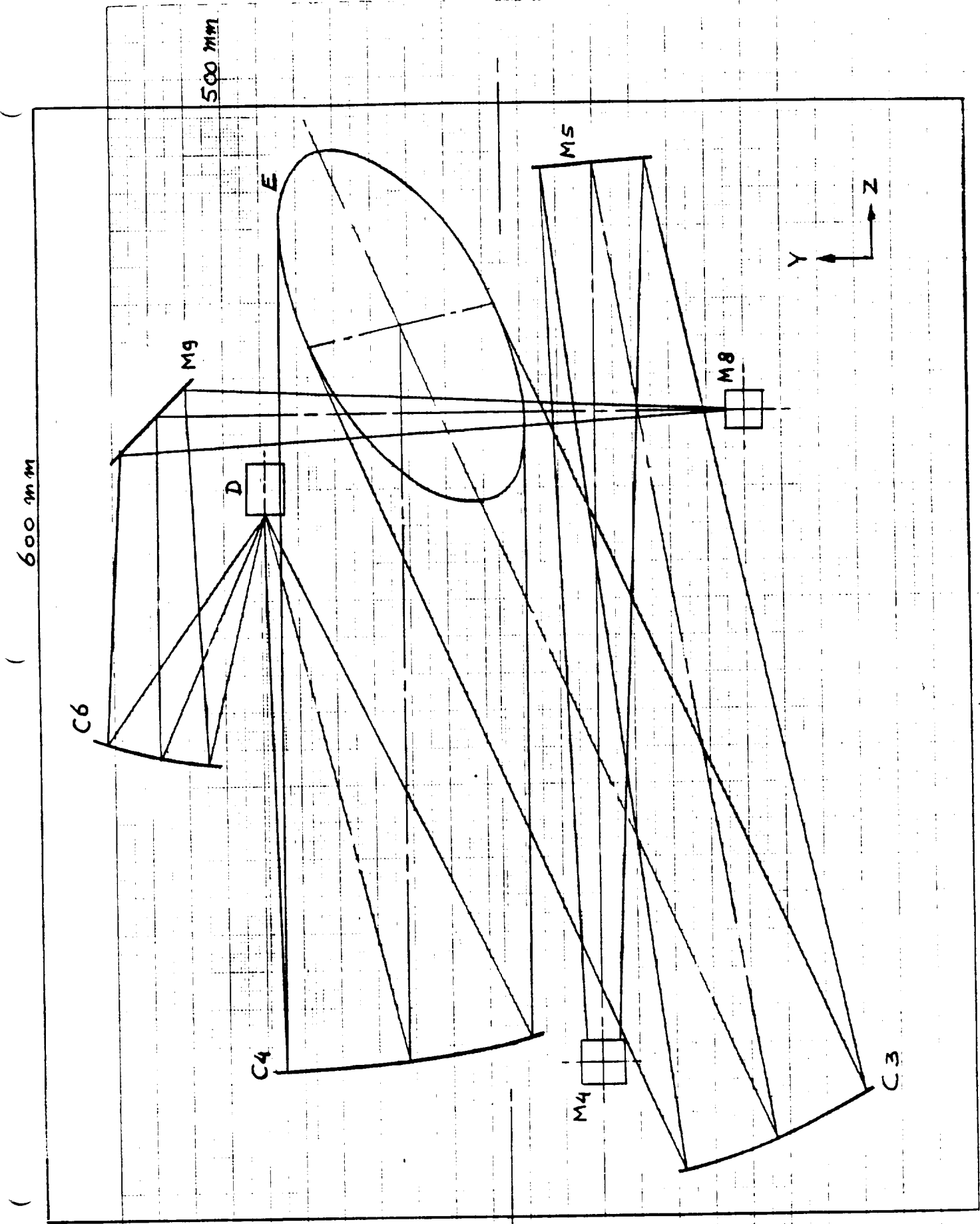


Figure 3. Side view, high-resolution section

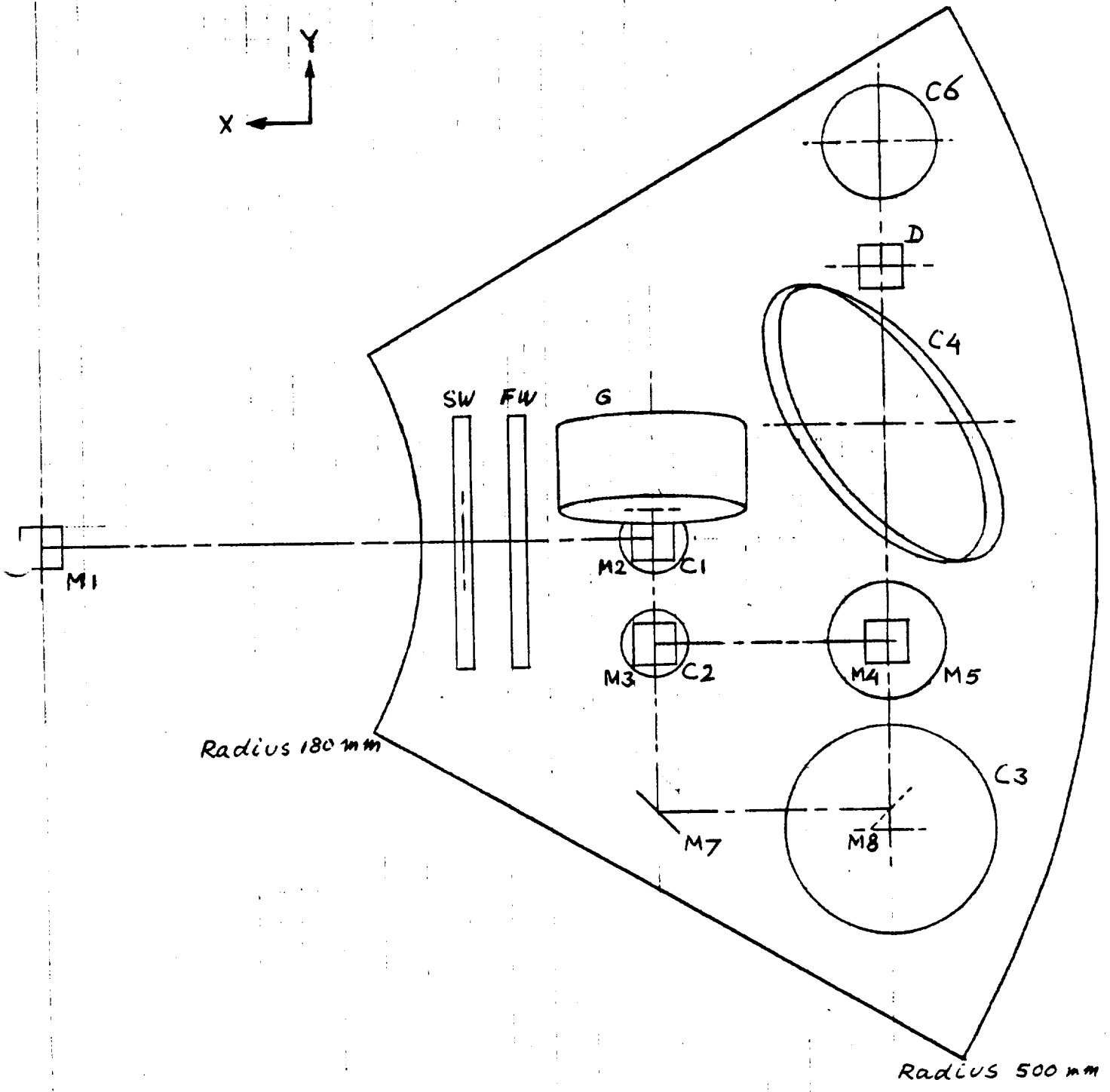


Figure 4. End view

C1 through C6 show beam contours at the mirrors. C4 shows the contours for the two extreme wavelengths, recorded at the detector.

APPENDIX D

California Institute of Technology Update

SIRTF Grant NAG 2-317 Progress Report of B. T. Soifer

Matthews, Soifer, and Watson participated in an IRS team meeting held in Pasadena in June to review the IRS system requirements, and the Phase I activities of the team.

Soifer represented the IRS at the SIRTF Operations Subgroup meeting at Ames in August. The major issues discussed revolved around how to develop an operations plan that was extremely low cost compared with many missions that have been flown to date. Two areas that were thoroughly discussed were the organizational structure of the Science operations center and utilizing the programs developed by the instrument teams as the heart of the Science operations center data processing software. It was felt that the organization was crucial to the effectiveness of the operations center, and that it was crucial to separate the day-to-day pressures of feeding observing plans to the satellite from the scientifically demanding requirements of data reduction and analysis. It was also felt that the design of the SOC must reflect the needs of the general investigator community. The operations subgroup strongly recommended the adoption of common computer systems by all aspects of the project to insure software portability from instrument teams to the Science Operations Center.

In addition Soifer represented the IRS in the Ned Wright Committee, whose charge is to see that the imaging and photometric capabilities are well coordinated. Soifer's summary of the IRS requirements on the focal plane and use as backup capability for imaging are enclosed as Appendix 1. It was clear from this analysis of the requirements that the IRS does require a significant amount of real estate in the SIRTF focal plane. It was also clear that the IRS could act as a backup for photometric observations, but at degraded efficiency. As it is currently designed, the IRS would not be an adequate backup for imaging.

Matthews, Soifer, and Watson participated in the team discussions held on a regular basis over this period. Among the major issues that were discussed, the most significant was the absolute pointing requirements on SIRTF placed by the IRS. It appears from the discussions that the shortest wavelengths of the IRS place the most severe requirements on the absolute pointing of SIRTF.

Watson has been actively working on developing Blocked Impurity Band (BIB) Ge:Ga photoconductors. This work has been carried out both in the infrared lab at Caltech, and through a development contract with Rockwell.

The aim of the Pre-Phase-I part of this program is to develop the techniques required for the fabrication of high-purity, high-crystallinity epitaxial layers of intrinsic germanium. These comprise the blocking layers, the key structure in the BIB device. When grown on bulk impurity-banded Ge:Ga substrates, they should enable us to demonstrate the salient features of GeBIB detectors -- depletion of ionized acceptors and extended wavelength response. In this way we separate the problems of blocking-layer and absorbing-layer growth; the latter task is to be carried out under Phase I. So far, we have succeeded in establishing high-quality intrinsic germanium epitaxy, and the first lot of test detectors is very near completion.

C-3

Bulk impurity-banded Ge:Ga for the substrates was obtained from the Eagle-Pitcher Corp. and made into a large number of 0.5 mm thick, [100]-oriented substrates with flat, polish-etched surfaces suitable for epitaxy. The Ga concentration of the substrate wafers spans the range 1×10^{16} - 1×10^{17} per cc, and therefore have impurity bands ranging in character from two separate Hubbard bands (at the lighter doping levels) up to near-merger with the valence band of germanium.

Using chemical-vapor deposition (CVD), intrinsic germanium blocking layers 3-8 microns thick have now been grown on several of the substrate wafers and on some additional germanium samples, and the purity and crystallinity of the layers have been evaluated. The results have been extremely encouraging. Spreading resistance profiles (SRP) and resistivity measurements at room temperature show that the layers are very abrupt and are otherwise indistinguishable from high-purity intrinsic germanium standard samples, indicating that the residual shallow impurity concentration must be at least as low as the approximately 1×10^{13} thermally-activated carriers per cc which are present in room-temperature intrinsic germanium. This represents an improvement by at least an order of magnitude in purity over any previous germanium CVD epitaxy, and may even be consistent with the goal of 3×10^{12} per cc or less which we obtain by scaling the requirements for SiBIB detectors. X-ray crystallography and electron microscopy yield an average surface defect concentration of 2000 per square cm for the blocking layers, essentially identical to that obtained for the bare substrates. Substrates with better crystal quality are being sought for use in the later stages of this program, which will clearly yield better epitaxial layer crystallinity, but the present defect concentration is quite acceptable for the initial devices.

The resulting wafers with blocking layers have been boron-ion-implanted on each face and annealed to provide Ohmic electrical contacts which are transparent at far-infrared wavelengths. SRP measurements done after the contact fabrication indicate that the structure and properties of the blocking layers were not changed by this processing. After metallization of the back surfaces, most of these wafers will be delivered to Caltech (by 23 March 1987, according to the present schedule), where they will be made into discrete detectors and undergo measurements of responsivity, dark current, wavelength threshold and response bandwidth. Further composition tests, including capacitance vs. voltage measurements to determine the concentration of compensating impurities, will proceed at Rockwell in parallel with the optical tests.

In the meantime, Ge:B BIB devices made at the Jet Propulsion Laboratory have also been obtained and tested at Caltech. So far, none of these has been shown to have a response that can be measured without the use of a high-power far-infrared laser; they have also been found to have a "shelf life" of a few weeks, after which the devices show very low resistance (presumably because of degradation of the blocking layer). We will continue, however, to monitor and evaluate this additional source of GeBIBs.

APPENDIX 1

APPENDIX 1

IRS REQUIREMENTS PRESENTED TO NED WRIGHT COMMITTEE

IRS FOCAL PLANE REQUIREMENTS

SPECTROMETERS OPTIMIZED FOR SPECTRA OF FAINT POINT SOURCES

SLIT WIDTH $W=2.41/D$ (D = diameter)SLIT LENGTH $L = 10 \times W$ TO ALLOW SKY SUBTRACTION ON SAME FRAME
(OR MAXIMUM AVAILABLE FOV)MAX IRS FOV SET BY LONGEST λ DEFINE MAXIMUM SLIT SIZE AT $158 \mu\text{m}$, THEN $2.4 \times \lambda/D=90''$ LENGTH OF 5 SUCH SPOTS $\rightarrow 7 \frac{1}{2}'$ LENGTH = SIRTFOV
THIS LENGTH IS NEEDED TO ACHIEVE SKY SUBTRACTED SPECTRA WITH ONE
EXPOSUREALL OTHER IRS SLITS ARE SMALLER THAN THIS, AND FIT WITHIN THIS
ENVELOPE IN BASELINE DESIGN

IMAGE QUALITY

IMAGE QUALITY SHOULD BE DIFFRACTION LIMITED AT ALL $\lambda > = 4 \mu\text{m}$ FOR $4 \mu\text{m}$ DIAMETER OF SPOT IS $2.3''$, SO IMAGE QUALITY OF IRS FIELD SHOULD
BE BETTER THAN THIS FOR $2.3'' \times 23''$

EQUIVALENT SCALING AT OTHER WAVELENGTHS

IRS AS BACKUP

PHOTOMETRIC

IRS WILL BE BACKGROUND LIMITED IN 100 SEC FOR LOW RES FOR
WAVELENGTHS $\lambda > 9 \mu\text{m}$ TRADEOFF IS EFFICIENCY, SPEED OF OBTAINING OBSERVATIONS, ALLOWABLE
INTEGRATION TO COVER DESIRED RANGE

DEGRADATION IN SENSITIVITY OVER PHOTOMETER

TRANSMISSION

SHORT WAVELENGTHS CLEARLY NOT BACKGROUND LIMITED

EFFICIENCY OF OBSERVATION ?

NOT GOOD IN CONFUSED REGIONS

IMPACTS

OPERATIONALLY COMPLEX SEQUENCES (PERHAPS NO MORE SO THAN SOME SPECTROMETER MODES)

GOOD ONLY FOR POINT SOURCES IN UNCONFUSED REGIONS

IMAGING

COULD REPLACE GRATING WITH MIRROR, OPEN SLIT TO LARGE FOV, GET IMAGING USING ORDER SELECTION FILTERS

DEGRADATIONS

FOV MUCH LESS THAN FOR IMAGER

PIXELS $2.4 \lambda/D$ FOR OPTIMUM SPECTROMETER SENSIVITY

IMPACTS

COMPLICATIONS FOR IRS DESIGN, MORE MODES

RECOMMENDATIONS:

PHASE I STUDY QUESTIONS

STUDY USE OF IRS AS BACKUP WITHOUT COMPROMISING SPECTROSCOPY

SPECIFIC QUESTIONS THAT COULD BE ADDRESSED:

WHAT IS IMAGE QUALITY FOR IMAGING OF OPTIMIZED SPECTROMETER WITH MIRROR IN PLACE OF GRATING?

WHAT IS PHOTOMETRIC SENSITIVITY OF IRS AS BACKUP UNDER GROUNDRULES OF SPANNING 4-200 μm IN 600-SEC POINTING?

WHAT ARE IMPACTS ON OPERATING MODES, OPERATIONAL COMPLEXITY OF IRS TO PROVIDE BOTH PHOTOMETRIC, IMAGING BACKUPS?

APPENDIX E

University of Rochester Update

SIRTF NAG 2-317 Progress Report of W. J. Forrest

A. SBRC-Supplied Equipment Repairs

All of the unreliable Zytrex digital logic chips, about 40, have been replaced in the SBRC electronics. Now we are concentrating on more subtle problems with the SBRC supplied electronics, described below.

1. We found the sample-and-hold circuits in the signal processing section were mistimed. We timed them for proper acquisition of signal-reset and pedestal-reset with their associated A/D "convert" pulses.
2. In our first run to LHe, we found serious problems in the SBRC-clocking scheme. Enormous amounts of heat, much greater than 50 mW, were being generated by the row- and clock- addressing circuits. This only became obvious at the low temperatures because of the reduced heat capacity. We defined a "cold" mode using an external addressing option, which allowed us to reach 10K. However, when we attempted to read out the array, the temperature shot up to about 20K. In the SBRC-supplied-clocking mode, they had left all fets on the addressing circuit on with a 5V voltage drop present. This creates enormous $I \times V$ heating power in the DRO. SBRC has mentioned this problem to us, but hasn't yet specified the recommended changes. Therefore, we cooked up our own changes, and in the process learned a lot more about the DRO operation. This new mode works much better and allows us to run at 8K in continuous mode (36 usec/pixel pair). There is still a fairly large heat load, as the detector reaches 4.2K with the clocks off.

B. New Dewar

After the previously described problems of our original test dewar, we ordered and received in October 1986 our new test dewar. It is a near carbon copy of our current observing dewar and has many nice features. We have a filter wheel with 8 fixed filters, a cold dark slide, and 1% resolution CVF's from 2.5 to 8 microns. The filter wheel is under computer control and integrated into our data taking and analysis software. We have reimaging optics for this dewar which will allow us to assess detector imaging properties. Unfortunately, just as we were starting to use this dewar for testing, it sprung a leak. An arduous repair on the inner can has been performed and we are back on line. The dewar has been run at both pumped nitrogen (47K minimum temperature) and LHe.

Our fixed filters cover the 1.2- to 4.9-micron range. We have also ordered neutral density filters. With a couple of density 3 filters, we can investigate the imaging properties of the detector at low SIRTF-like backgrounds. This system will be tested soon. The 1% CVFs covering the 2.5- to 8-micron range allow us to test the detectors in the lab with our f/14 cold stop over the whole range of wavelength sensitivity without saturating the detectors. Neutral density filters can be added for low-background testing. We have found one company whose neutral density filters work on the principal of absorption and look fairly flat in wavelength.

C. Detector Tests

We have continued testing our "engineering" detector array, made of high-doped InSb and known to have responsivity problems at temperatures below 60K. The detectors show about 1.1 fA of dark current at 47K. Dark current was definitely decreasing rapidly with temperature, but we got no reliable data on our first 10K run because of the previously described clocking problems. The quantum efficiency hasn't been measured yet. We confirmed the loss of quantum efficiency below 56K, and found a pattern with circular symmetry about a point far to the lower left. The noise when subtracting a pair of dark current frames, with 2.3 sec integration time, was about 600-800 e^- rms. This corresponds to 400-600 e^- per read (assuming 1 pF capacitance), which is similar to SBRC values. No optimization of noise has been performed yet. We found quite good imaging properties at 1.65 microns, by observing a soldering iron focussed on the array.

One alarming experience we had was the loss of three entire columns, 10, 26, and 37, from the array during the cool down to 10K. We had just started transferring LHe after dumping the nitrogen when it was noticed that these columns were gone. All three levels: signal, reset, and pedestal, were pinned high, indicating a DRO problem, rather than a detector problem. The temperature was above 30K at that point, and the detector was being clocked out continuously during this cool down. Therefore we can think of no obvious cause for this loss; I have speculated that perhaps the SBRC drive electronics gave out a burst of noise. Our cool down was so gentle, with the fan-out board insulated with nylon washers, that thermal stress doesn't seem likely. We have put 1K resistors in series with the PhiRST and CAEN lines in the hopes of preventing further detector damage. We have observed no glitches of the SBRC electronics while looking at them on the oscilloscope. These lost columns appear lost for good, they are still gone at room temperature and on our next cool down.

D. SIRTf detector delivery

We have received the first of the SIRTf optimized low-doped InSb array's, SCA 1, from SBRC. This array was chosen over SCA 2 because of its demonstrated low dark current, 4 atto amps at 6.5K. We plan to verify the dark current measurement and investigate the other properties, such as responsivity and noise, of this array soon. We are hoping to mount this detector soon, but first want to be sure there are no problems in our test set which could damage it. KPNO/NOAO has taken delivery on two similar arrays and finds they work quite well. The dark current is below 100 e^- /sec at 35- 40 K, the quantum efficiency is around 80% with 20% p-p uniformity and 10 bad pixels, and the read noise is around 400 e^- rms. One of the KPNO arrays also has one bad column, similar to our engineering array, so this appears to be a problem with the DRO's SBRC is using.

We have also received the Si:In photoconductive array mounted on the same type of 58x62 DRO. This will be tested after we have characterized the InSb array.

APPENDIX F

Penn State University Update

SIRTF Grant NAG2-317 Progress Report of D.W. Weedman

May 1, 1986 to March 1, 1987

Weedman has monitored results on extragalactic observations from IRAS in order to maintain and update a census of the extragalactic sky needed for modelling predictions of SIRTF scientific performance. This modelling uses luminosity functions of galaxies at various infrared wavelengths to predict source counts and redshift distributions for various observing flux limits. One example of the results is that 30μ observations will access a minimum of 55 galaxies/deg² to 5 mJy, or 1000 galaxies/deg² to 0.5 mJy.

SIRTF IRS performance was considered using a program written to produce synthetic spectra; this makes possible decisions for optimizing the technical parameters of the spectrograph toward successful extragalactic observations. It was found that a high priority requirement for detector testing is the determination of "flat-field" repeatability -- maintaining accurate knowledge of the relative pixel response during a given observation. This proves to be very important because the IRS is background limited at the fluxes and resolutions required for observations of distant galaxies.

The properties of infrared-bright galaxies as determined by IRAS were evaluated in comparison to their optical properties to learn how SIRTF scientific performance can be enhanced by supplementing with observations at other wavebands. For example, an important correlation was found between the 60μ luminosity and the ratio of this luminosity to the blue luminosity, giving a way of selecting SIRTF targets in favor of these galaxies at the greatest distance.

Progress Report 4

for

NASA-Ames Grant NAG2-317

The Infrared Spectrograph During the SIRTf Pre-Definition Phase

through September 30, 1987

January 31, 1987

TABLE OF CONTENTS

	Page
CORNELL ACTIVITIES REVIEW	
Technology Development	3
Management Activities	4
 APPENDIX A	
Cornell Technology Development (Hardware)	
 APPENDIX B	
Rockwell Bi-Monthly Progress Report No. 7	
Rockwell Bi-Monthly Progress Report No. 8	
Rockwell Bi-Monthly Progress Report No. 9	
Rockwell Bi-Monthly Progress Report No. 10	
Rockwell Bi-Monthly Progress Report No. 11	
 APPENDIX C	
Germanium blocked-impurity-band far-infrared detectors	

Technology Development

Cornell:

We describe below the progress in the Cornell Technology Development effort funded by NAG2-317 made since Progress Report 3 (March 1, 1987). The scope of this work is very narrow because, as of November 1, 1986, most of the Cornell Technology Development work has been performed under NASA contract NAS2-12524, Phase I (Definition and Conceptual Design) for the SIRTf Infrared Spectrograph.

From March 1, 1987 until the end of the grant, September 30, 1987, the only work performed under grant funding has been the design and construction of a preamplifier for the Cornell Si BIBIB test facility by Wallace Instruments and the remaining work being performed by Rockwell International under subcontract OSP 3867, Impurity Band Conduction Arrays for SIRTf.

The work performed by Wallace Instruments is reviewed in Appendix A; the Rockwell International work is covered in Appendix B.

Caltech:

In September Dan Watson completed a paper detailing preliminary test results on germanium blocked-impurity-band far-infrared detectors. The detectors were purchased with grant funds and this paper appears in Appendix C.

Rochester, Penn State, NASA-ARC:

All other co-investigating institutions had completed their grant-funded research by March 1, 1987.

Management Activities

During this time period the grant supported no management activities. All activities related to grant management - written reports, accounting, and progress monitoring - was provided at no charge to the grant.

APPENDIX A

Wallace Instruments Work

The services Wallace Instruments provided to Cornell for SIRTf grant activities during the period from March - October 1987 included completion of and revisions to the preamplifier used in testing the Rockwell Si BIBIB 10x50 hybrid array.

A schematic of the Cornell University Detector Evaluation Facility is shown in Figure 1. The system consists of a data acquisition computer (DAC) which downloads clocking instruction to a single-board computer (SBC). The SBC then provides the timing signals for running the array. These signals are passed into a conditioner, known as the clocking box, which sets the upper and lower levels of each clocking signal and provides filtering. The unit also supplies the DC levels necessary to run the array. The output signals from the array are filtered and amplified by the preamp, and data are taken for storage and analysis by the DAC. Schematics of individual cards for the clock box and the preamp are shown in figures 2 and 3 respectively. The clock box contains five cards designed in the manner shown in figure 2 while the preamp has 10 channels each with its own PC card.

Wallace instruments worked on filter selection for the DC lines running to the detector. Filter selection is based on the finding the necessary RC filtering to achieve isolation while allowing sufficient current to be drawn by the chip for proper operation. The problem of optimum filter selection for the DC lines will be revisited again under our SIRTf contract because of recent information provided by Rockwell on their noise and filtering tests.

Since the DAC utilizes a 12-bit A/D converter (see figure 1), the full dynamic range need for testing requires a selectable gain in the preamp. At the lowest noises gains of 400 to 1000 are required. Because the output of the Rockwell hybrid array has a slope associated with its output, that is, the offsets between the detectors on different sides of the array are several tens of millivolts, full gain can not be achieved on the detector signal without saturating the preamp and the A/D converter. Wallace instruments constructed a dynamic offset adjustment card which contains an 8-bit D/A converter that is clocked by the SBC array controller in sync with the output of the array. This dynamic offset adjustment compensates for the slope changes in the array to flatten the output signal and allow the full dynamic range to be achieved. Software automatically monitors the signal levels and adjusts the offset table which is clocked to the D/A converter to achieve a flat output signal. The input offset level is not changed while a given pixel is being accessed, but only when a new pixel is output. Tests indicate this offset adjustment introduces no extra noise into the system.

In addition to providing services related to the above projects Wallace instruments consulted on several issues regarding system noise and overall system performance and optimization.

CORNELL DETECTOR EVALUATION FACILITY

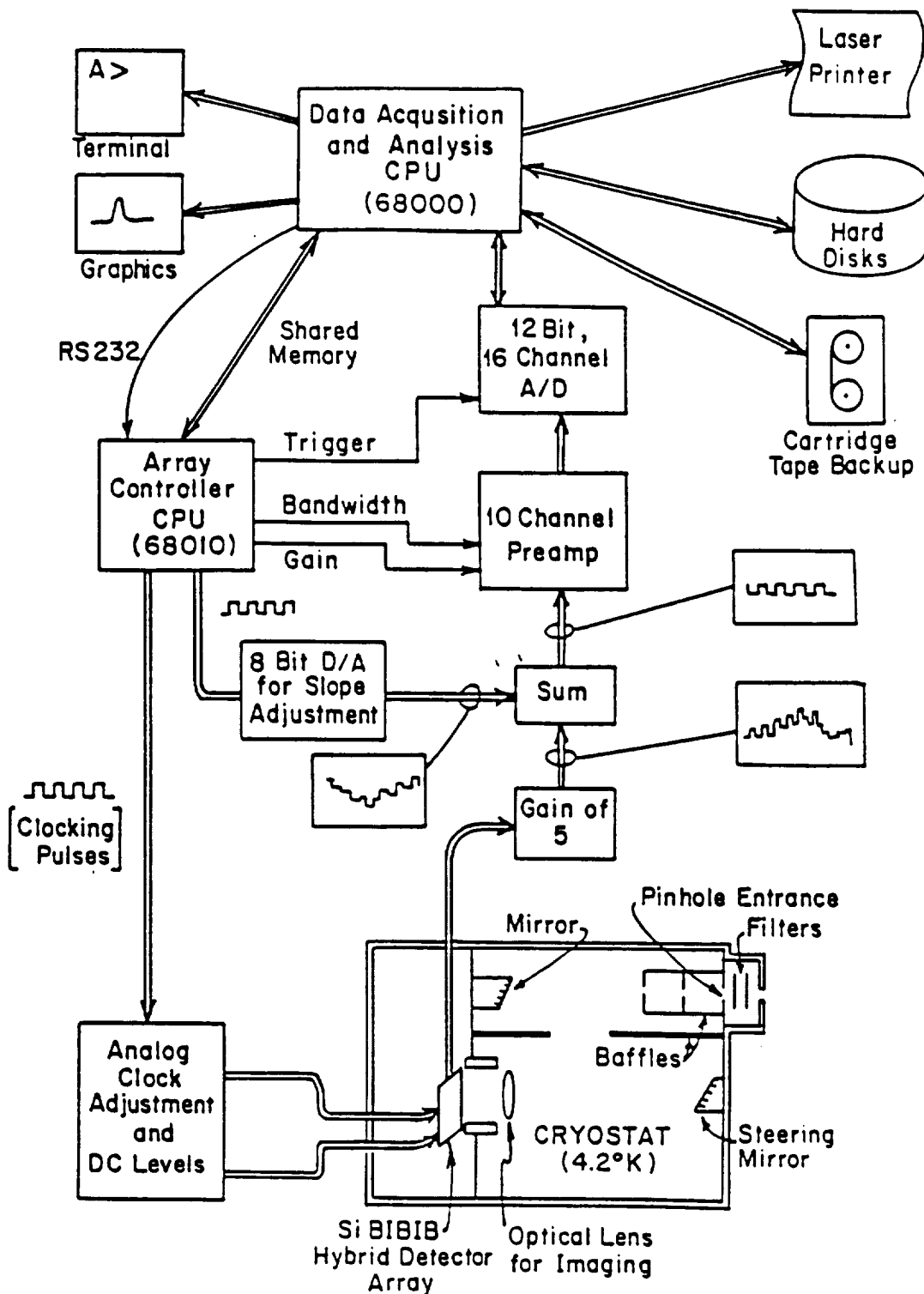


Figure 1 - Schematic diagram of the Cornell University Detector Evaluation Facility (CUDEF).

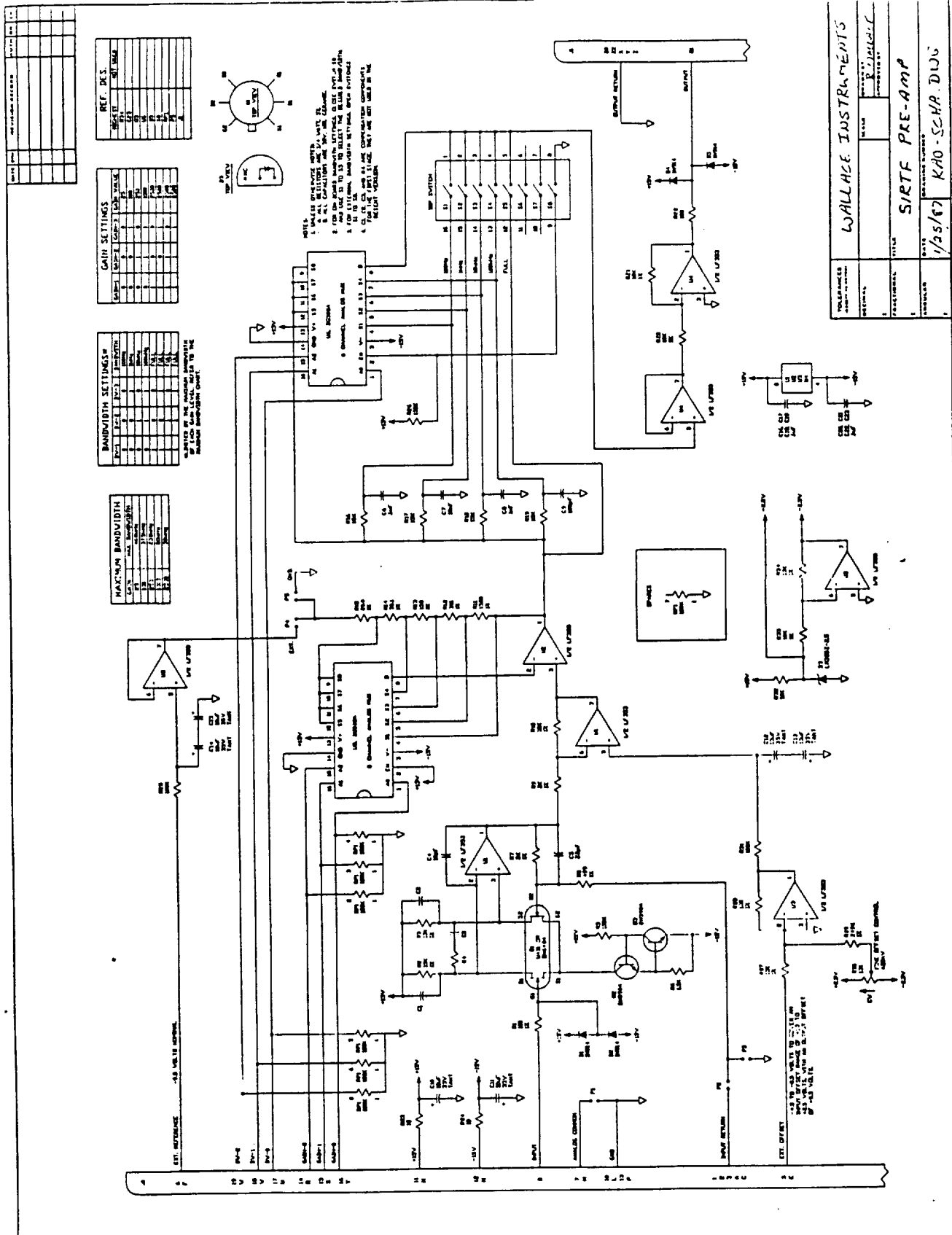


Figure 2. Schematic diagram of Cornell preamplifier card.

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX B

Science Center
Rockwell International Corporation
3370 Miraloma Avenue
P.O. Box 3105
Anaheim, California 92803-3105



Rockwell
International

July 21, 1987

In reply refer to SC87-384

Cornell University
Attn: Dr. James Houck, CRSR
220 Space Science Building
Ithaca, New York 14853-2801

Re: Bi-Monthly Progress Report No. 7
For Period 10/21/86 through 12/20/86
Sub-Contract No. OSP 3867
Document No. SC5452.BMR

In accordance with the above referenced contract, enclosed
please find subject report.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

D. H. Seib
Manager
Focal Plane Technology

cc: T. Herter
K. Duclos

IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRTf

1.0 GENERAL

Four of six newly fabricated 10 x 50 BIBIB/SWIFET hybrid focal plane arrays were found to function properly at room temperature. One was chosen for detailed characterization. Responsivity and detectivity measurements were made and a software method for implementing correlated triple sampling was developed and tested, with the preliminary result that this method gives a higher read noise than the conventional readout mode. Node capacitance was measured on the originally characterized hybrid and found to be identical to previous measurements.

2.0 HYBRID EVALUATION

Six new 10 x 50 BIBIB/SWIFET hybrid arrays (serial numbers 12 thru 17) were fabricated for the program and delivered for testing. Four of the devices satisfactorily passed room temperature screen testing; the other two had shift register failures similar to the failures experienced with the previous batch of hybrids. However, the problems previously experienced have been overcome and an adequate number of devices to complete hybrid characterization for the first phase of the program are now available. Device #13 was chosen for more extensive characterization in this reporting period. Measurements conducted included responsivity at different backgrounds and integration times, detectivity, study of the split in output response for the two different types of input cells on the multiplexer, and comparison of noise in double sampled and correlated triple sampled modes of operation. The results of these measurements are discussed in more detail below.

All 500 pixels of hybrid # 13 were operative and had low dark current. Figures 1 thru 4 show responsivity measurements made under different background flux, integration time and signal flux conditions. Table 1 tabulates the test conditions and the mean responsivity obtained. Additional test conditions are device temperature = 4.2 K and radiation wavelength = 10.6 microns. Mean responsivity differences in the various measurements is due to signal flux measurement uncertainty. As previously observed, when the integrated signal charge is relatively small there is a split in the responsivity histograms, for example Figs. 1 and 3, due to the fact that the input cells on output lines 1-5 have a design different than the input cells on output lines 6-10. In Fig. 2, even though the integrated charge is less than that for Fig. 3, the split is not resolved; however the non-uniformity is equivalent for the first

three figures (standard deviation over mean of 4.5-5 %). When the integrated charge is larger, as in Fig 4, the responsivity uniformity is excellent (0.8 %). While the reason for the split response is not understood in detail, these and other measurements on equivalent hybrids have indicated that the design used for the input cells of busses 1-5 is the preferred approach and should be used for future designs.

The detectivity (D^*) histogram at a background of 6.7×10^9 ph/cm²-s and integration time of 2 seconds is shown in Fig. 5. Standard deviation over the mean for 499 pixels is 6.7 %.

One thrust of the program was to implement a multiplexer design (the non-destructive read option) that was capable of being operated in a correlated triple sampled mode. Correlated triple sampling could theoretically remove kTC noise and also discriminate against MOSFET 1/f noise, and would be useful when the kTC noise dominated other noise sources. With correlated triple sampling, samples of a pixel output are taken at the integrated signal level, the reset level (reset pulse on), and immediately after the reset level (reset pulse off). The resulting outputs are then used to calculate the integrated output with kTC noise removed. Experiments were conducted to evaluate correlated triple sampling with hybrid #13 and existing test equipment. Limitations of the analog-to-digital converter used dictated that it be operated in a single ended mode to obtain the samples needed and these samples were differenced in a computer to obtain the final result. The normal double sampling mode of readout, which does not eliminate kTC noise, was also run for comparison. Read noise of the hybrid, i.e. the noise with detector bias = 0 V, was evaluated. The double sampled (conventional) mode gave an output referred noise value of 27 microvolts rms while the correlated triple sampled mode of operation gave a value of 37 microvolts rms. This increase may be due to a combination of bit noise and the fact that correlated triple sampling causes increased noise (by a factor of 1.4) if electronics noise dominates kTC noise (due to the increased number of samples required). Further work is needed to assess whether correlated triple sampling will be advantageous with the present devices.

Node capacitance measurements were made on hybrid #2. The values obtained were 0.41 pF at 4.2 K and 0.43 pF at 10K; these values are in excellent agreement with values previously obtained for equivalent BIBIB/SWIFET hybrids on other programs.

3.0 PLANS FOR NEXT PERIOD

A new proposal for continuation work will be prepared and submitted in order to obtain the next funding increment and continue work on the program.

TABLE 1

RESPONSIVITY TEST CONDITIONS AND RESULTS

Hybrid #13 T =4.2K wavelength = 10.6 μ m

FIGURE	BACKGROUND FLUX (ph/cm ² -s)	SIGNAL FLUX (ph/cm ² -s)	INTEGRATION TIME (msec)	RESPONSIVITY (A/W)
1	9 x 10 ⁹	2.7 x 10 ⁹	62	3.4
2	4.5 x 10 ¹¹	1.35 x 10 ¹¹	1.24	2.4
3	8.9 x 10 ⁹	2.7 x 10 ⁹	250	4.5
4	6.7 x 10 ⁹	2.0 x 10 ⁹	2000	3.3

1

ORIGINAL RESULTS OF POOR QUALITY

MEAN VALUE OF MAIN GROUP OF PIXELS IS 3.432E+00
STD OF MAIN GROUP OF PIXELS IS 1.730E-01
THE NUMBER OF GOOD PIXELS IS EQUAL TO 498

145487874703 S1RTF HYBRID Tint=62msec T=4.2K BKND=9.0E9 & 10.6microns

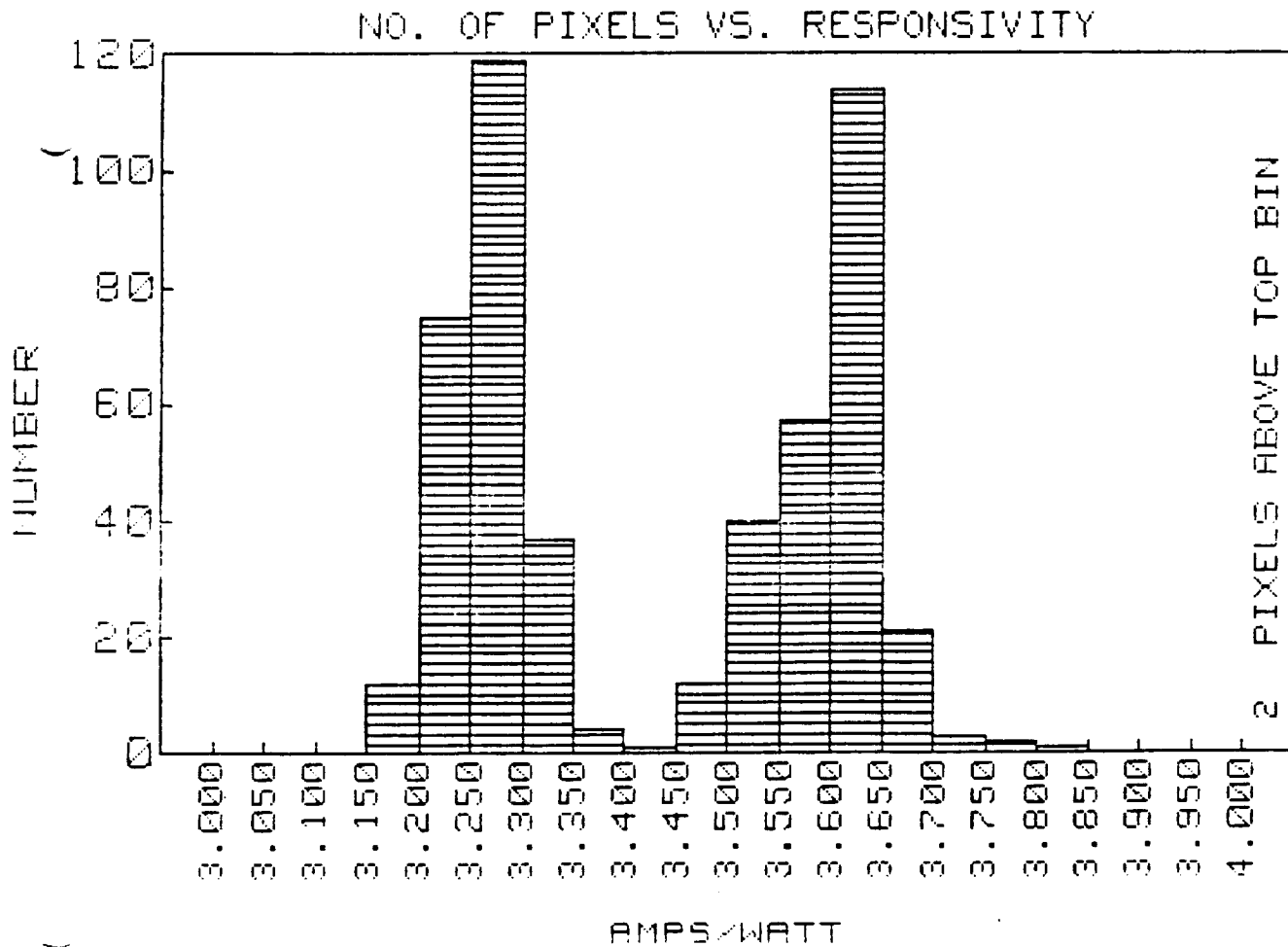


FIGURE 1

2

EXPERIMENTAL RESULTS
OF POOR QUALITY

MEAN VALUE OF MAIN GROUP OF PIXELS IS 2.409E+00
STD OF MAIN GROUP OF PIXELS IS 1.076E-01
THE NUMBER OF GOOD PIXELS IS EQUAL TO 500

14546/8/4/03 SIRTIF HYBRID Tint=1.24msec T=4.2K BRND=4.5E11 @ 10.6microns

NO. OF PIXELS VS. RESPONSIVITY

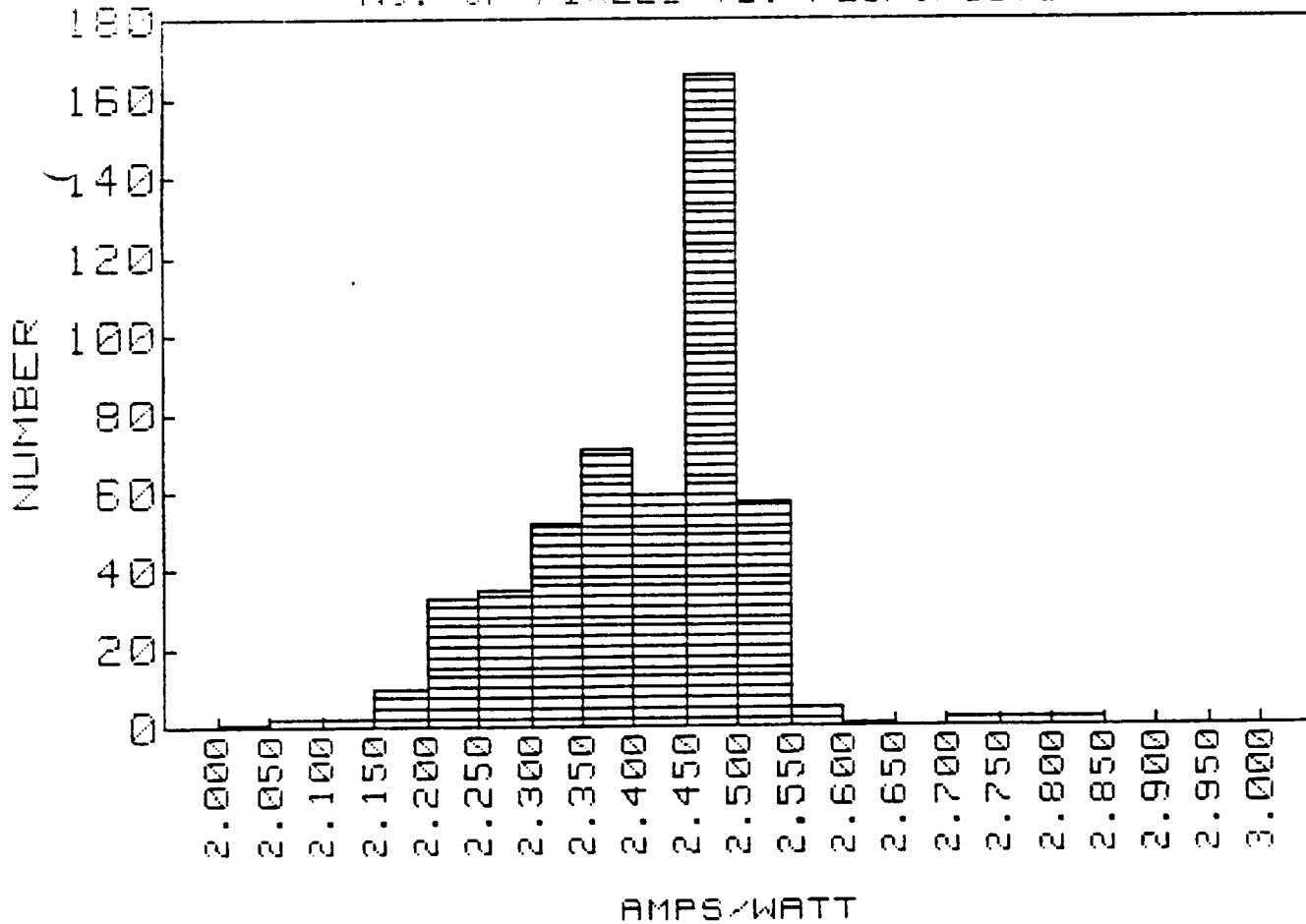


FIGURE 2.

3

MEAN VALUE OF MAIN GROUP OF PIXELS IS 4.499E+00
STD OF MAIN GROUP OF PIXELS IS 2.166E-01
THE NUMBER OF GOOD PIXELS IS EQUAL TO 500

14546/8/4/03 SIRTIF HYBRID Tint=250msec T=4.2K BKND=8.9E9 @ 10.6microns

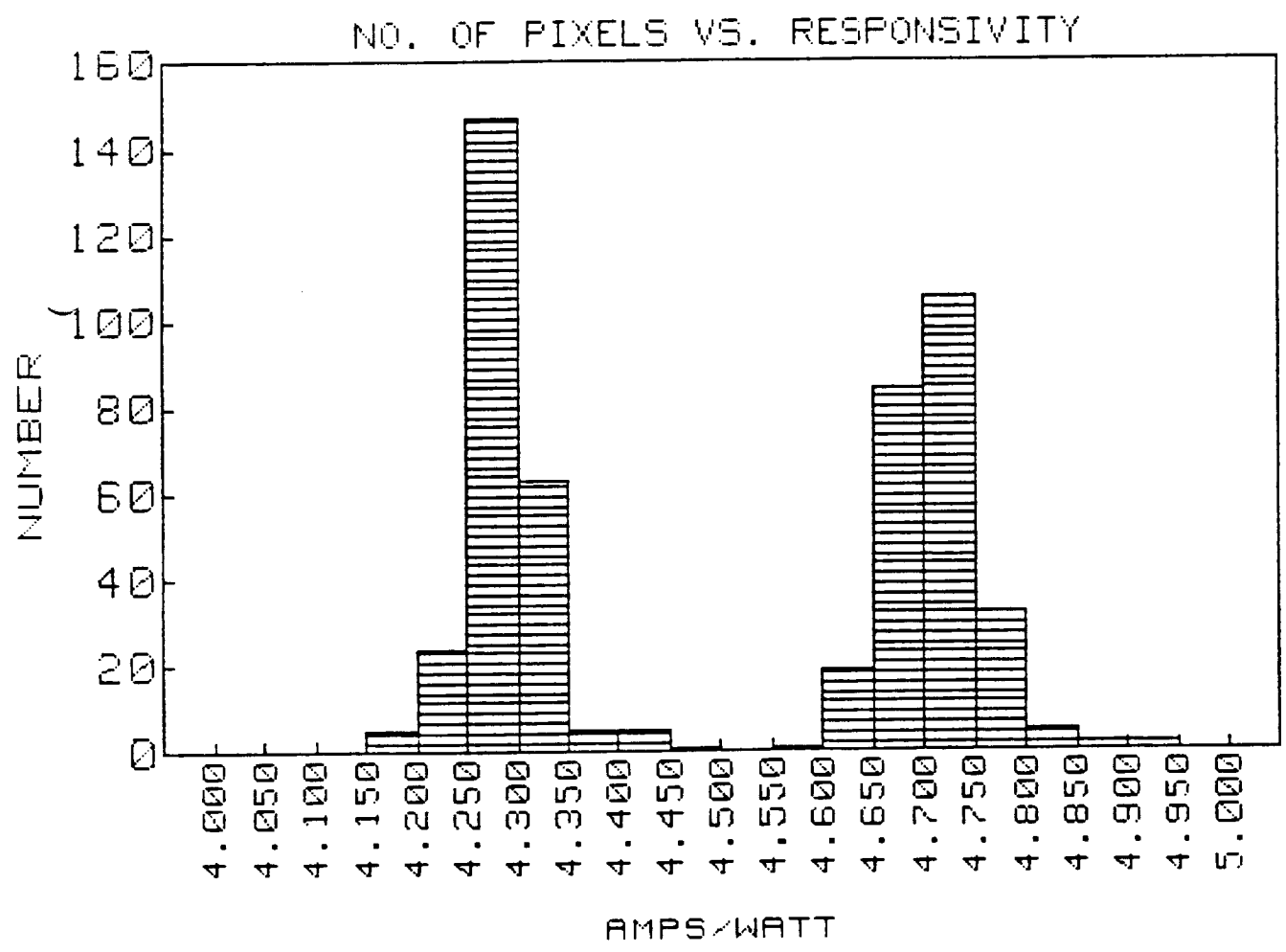


FIGURE 3.

4

MEAN VALUE OF MAIN GROUP OF PIXELS IS 3.288E+00
STD OF MAIN GROUP OF PIXELS IS 2.688E-02
THE NUMBER OF GOOD PIXELS IS EQUAL TO 500

14548/008/4/03 SIRTIF HYBRID Tint=2 sec T=4.2K BKND=6.7E9 @ 10.6 microns

NO. OF PIXELS VS. RESPONSIVITY

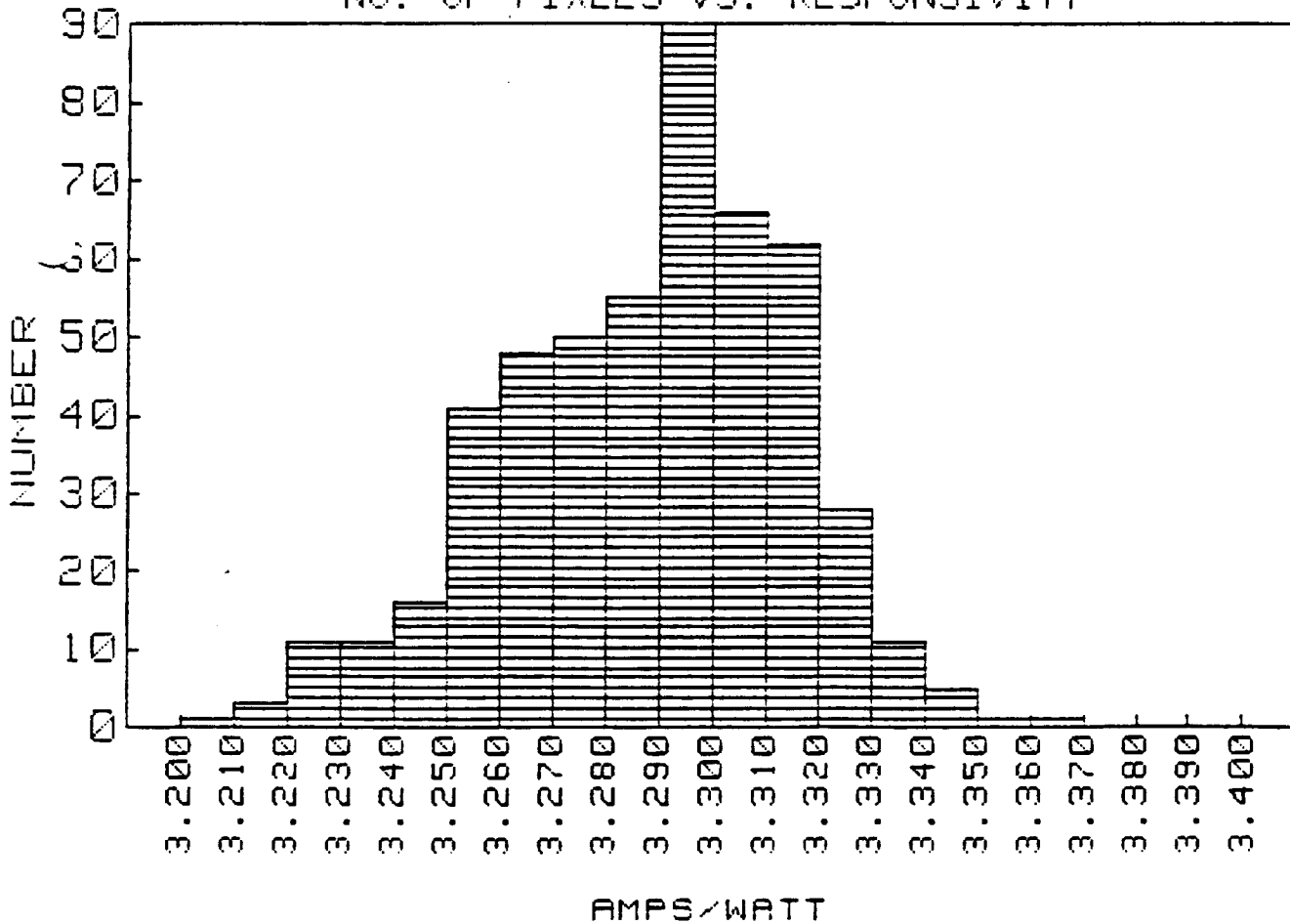


FIGURE 4.

5

MEAN VALUE OF MAIN GROUP OF PIXELS IS 2.322E+14
STD OF MAIN GROUP OF PIXELS IS 1.551E+13
THE NUMBER OF GOOD PIXELS IS EQUAL TO 499

14546/008/4/03 SIRTf HYBRID Tint=2 sec T=4.2K BKND=6.7E9 @ 10.6 microns

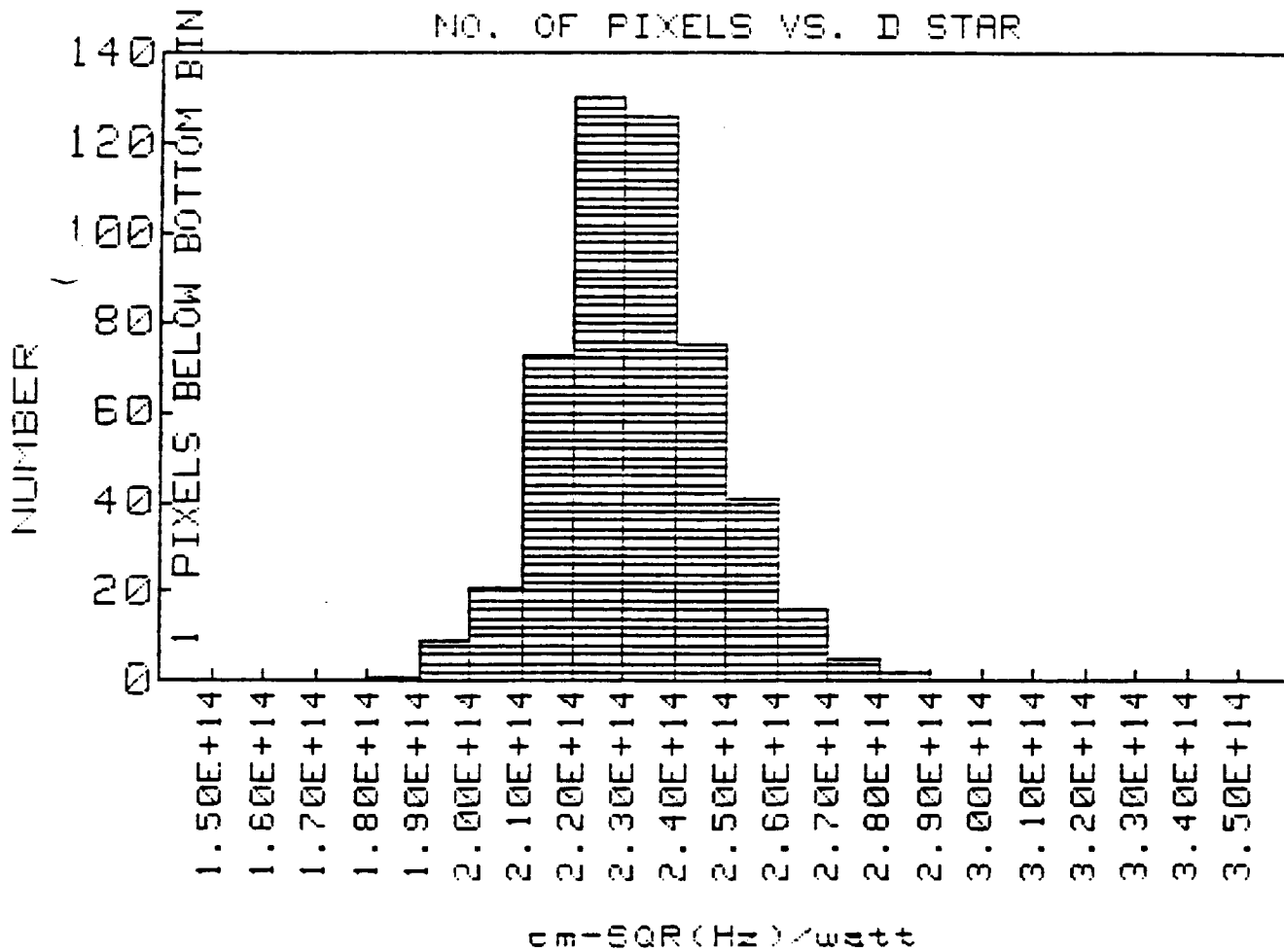


FIGURE 5.

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Rockwell
International

May 19, 1987

In reply refer to SC87-380

Cornell University
Attn: Dr. James Houck, CRSR
220 Space Science Building
Ithaca, NY 14853-2801

Re: Bi-Monthly Progress Report No. 8
For Period 12/21/86 through 02/20/87
Sub-Contract No. OSP 3867
Document No. SC5452.BMR

No work was performed on the above referenced contract during this period since the second funding increment was not in place.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

D. H. Seib
Manager
Focal Plane Technology

cc: K. Duclos
T. Herter

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Rockwell
International

In reply refer to SC87-381

Cornell University
Attn: Dr. James Houck, CRSR
220 Space Science Building
Ithaca, NY 14853-2801

Re: Bi-Monthly Progress Report No. 9
For Period 02/21/86 through 04/20/87
Sub-Contract No. OSP 3867
Document No. SC5452.BMR

No work was performed on the above referenced contract during this period since the second funding increment was not in place.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

A handwritten signature in cursive script, appearing to read "D. H. Seib".

D. H. Seib
Manager
Focal Plane Technology

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Rockwell International Corporation
3370 Miraloma Avenue
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Anaheim, California 92803-3105



**Rockwell
International**

August 13, 1987

In reply refer to SC87-385

Cornell University
Attn: Dr. James Houck, CRSR
220 Space Science Building
Ithaca, New York 14853-2801

Re: Bi-Monthly Progress Report No. 10
For Period 04/21/87 through 06/20/87
Sub-Contract No. OSP 3867
Document No. SC5452.BMR

In accordance with the above referenced contract, enclosed please find subject report.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

D. H. Seib
Manager
Focal Plane Technology

IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRTF

1.0 GENERAL

Program activity was re-initiated with Rockwell International interim funding. Parameters for a new lot of BIBIB detectors with increased short wavelength response were defined and a new series of epitaxial runs was initiated.

2.0 DETECTOR FABRICATION

A goal for the remainder of the program is to develop 10 x 50 BIBIB/SWIFET hybrid focal plane arrays with increased short wavelength (<10 μ m) response (compared to the first arrays developed and characterized for the program). Increased short wavelength response is achieved by increasing the infrared active layer thickness, decreasing the acceptor concentration so that the active layer can be depleted, and possibly increasing the active layer arsenic concentration. The availability of a Rockwell Science Center in-house, state-of-the-art epitaxial reactor for impurity band conduction detector materials allows fabrication of the layers and structures required with a small parameter variation matrix.

Table 1 lists the parameter matrix to be grown. Group #1 is a standard BIBIB deposition intended to serve as a performance baseline. Groups #2 and #3 increase the infrared-active (doped) layer thickness to 30 microns and 50 microns, respectively. Assuming such layers can be adequately depleted, these variations should result in factors of two and three improvements in the short-wavelength quantum efficiency. Groups #4 and #5 will be used to further investigate the effect of doping concentration on the dark current. Data obtained on other programs indicate a strong influence of doping concentration on the dark current. Finally, Group #6 will attempt to use a graded donor profile to minimize dark current while maintaining high quantum efficiency. Dark current is preferentially generated in the high electric field regions of the device (near the blocking layer). The profile will reduce the number of dark current generating centers near the blocking layer.

1972-1973
1974-1975

Table 1. Parameter Variation Matrix.

GROUP	N_D (cm^{-3})	ACTIVE LAYER
		THICKNESS (microns)
#1	5×10^{17}	15
#2	5×10^{17}	30
#3	5×10^{17}	50
#4	8×10^{17}	30
#5	3×10^{17}	30
#6	$8 - 3 \times 10^{17}$	30

Substrate wafers for the epitaxial runs needed to fabricate the above BIBIB detector devices were prepared and sent for the transparent contact implant. The epitaxial growth lot follower was written to include the six groups of Table 1. The epitaxial growths will commence in the next period

3.0 PLANS FOR NEXT PERIOD

Epitaxial layer growth of the materials of Table 1 will be continued and completed. Detector lot fabrication will then begin.

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September 23, 1987

In reply refer to SC87-389

Cornell University
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Ithaca, New York 14853-2801

Re: Bi-Monthly Progress Report No. 11
For Period 06/21/87 through 08/20/87
Sub-Contract No. OSP 3867
Document No. SC5452.BMR

In accordance with the above referenced contract, enclosed
please find subject report.

ROCKWELL INTERNATIONAL CORPORATION
Science Center

D. H. Seib
Manager
Focal Plane Technology

cc: T. Herter
K. Duclos

IMPURITY BAND CONDUCTION HYBRID ARRAYS FOR SIRTF

1.0 GENERAL

The capability to deposit epitaxial layers in our reactor with the sharp doping profile necessary for BIBIB detectors was lost during this period, therefore no layers were grown for the program. The problem has been rectified and layer growth will begin at the end of September. The contract for the second phase of the program was approved and signed by Rockwell International, after having been modified by mutual consent, and was returned to Cornell for approval.

APPENDIX C

Germanium blocked-impurity-band far-infrared detectors

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Ge:Ga blocked-impurity-band (BIB) detectors having long-wavelength thresholds of 190 μm and peak quantum efficiencies of 4% have been fabricated. This performance approaches that of state-of-the-art discrete Ge:Ga photoconductors, with the additional benefit of good response at wavelengths longer than that obtained with unstressed photoconductors.

Astronomical spectrographs and photometers require detectors with sensitivity approaching the fundamental limits. At far-infrared wavelengths the limit is usually imposed by photon noise from the background radiation emitted thermally by the optics and material along the optical path. The present state of the art in far-infrared detection is achieved by extrinsic Ge photoconductors (PCs), which have sufficiently high responsivity and low enough intrinsic noise to reach this criterion^{1,2,3}. Ge:Ga is the most highly-developed of these PCs; its threshold wavelength is 120 μm without stress and about 220 μm with large uniaxial stresses. High-performance Ge:Ga has Ga densities around 10^{14} cm^{-3} , leading to a photon absorption length of about 1 cm^3 . The rather large detector volume makes them extremely vulnerable to saturation and long-lasting responsivity variations from cosmic-ray particle encounters, a very serious problem in the orbital environment. In addition, the long distance between electrodes would lead to prohibitively large crosstalk in monolithic array formats. Finally, for response at the longest wavelengths, the necessity of mechanical stress adds an additional complexity to focal plane arrays.

Many of the shortcomings of extrinsic Ge PCs are shared by the extrinsic Si PCs used at shorter infrared wavelengths. Recently, it has been shown that extrinsic Si blocked-impurity-band (BIB) detectors are free of essentially all of these problems, offering good monolithic array performance and high radiation hardness^{4,5,6}. In an initial effort to apply the BIB concept in longer-wavelength detectors, we have constructed discrete, front-illuminated Ge:Ga BIBs and evaluated their performance at $\lambda > 50 \mu\text{m}$.

The theory of BIB detectors is discussed in detail in a series of papers by Petroff and Stapelbroek^{4,5,6}; here we include only a brief description of the operation of these devices. One way of achieving radiation hardness and low array crosstalk without sacrifice of quantum efficiency is to use thin extrinsic Si or Ge with doping concentrations 100-1000 times higher than in conventional extrinsic PCs. At these high impurity concentrations impurity bands⁷ are formed, and if the material alone were used as a detector, it would exhibit a very large dark current and associated shot noise, because of impurity-band conduction. In BIBs this is prevented by including a thin layer of high-purity *intrinsic* material (hereafter referred to as the *blocking layer*) between the heavily-doped layer and one of the electrical contacts, so that carriers in the valence or conduction bands can complete the circuit, but those in the impurity band are "blocked."

This is illustrated in Figure 1. At low temperatures and with no electric fields applied, the doped portion of the detector has a density N_D of donors, all of which are ionized, an equal number of ionized acceptors, and a much larger density of neutral acceptors. With a DC bias voltage applied such that the blocking layer's electrode has negative polarity, the electrons in the acceptor impurity band are swept away from this layer, leaving behind a region devoid of ionized acceptors. This A^- depletion region is the active part of the detector. Photoionization of an acceptor in the A^- depletion region leads to a hole in the Ge valence band and an electron in the Ga impurity band which are swept in opposite directions by the electric field, resulting in photoconductive gain $g \equiv 1$. In many respects, this behaviour resembles that of a reverse-biased photodiode.

The width of the A^- depletion region is determined by the bias voltage and the concentration of donors. Poisson's equation can be used to derive the following expressions for the peak electric field strength E_{BL} , the device capacitance C and the A^- depletion region width w :

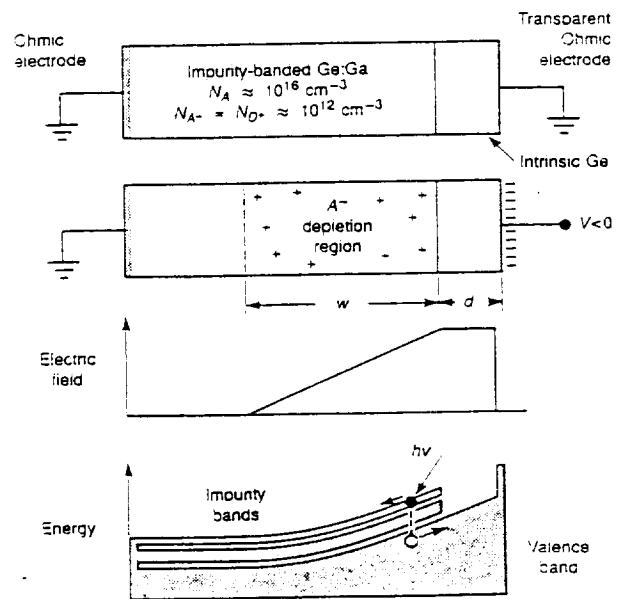


FIG. 1. Structure of a Ge:Ga BIB (not drawn to scale). (a) Schematic diagram of the detector configuration, where N_A is the density of neutral acceptors, N_{A-} is the ionized acceptor density and N_{D+} is the density of ionized donors. (b) Charge distribution for negative bias. (c) Electric field distribution for negative bias. (d) Energy level diagram for negative bias, illustrating the photodetection process.

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$$E_{BL} = N_D e w / \epsilon \epsilon_0 \quad (1)$$

$$C = 2\epsilon \epsilon_0 A / (2d + w) \quad (2)$$

$$w = \sqrt{2\epsilon \epsilon_0 V / N_D e + d^2} - d \quad (3)$$

where A is the detector area, d is the blocking layer thickness, V is the bias voltage, and $\epsilon = 15.4$ is the dielectric constant of Ge. From the dependence of w on V and N_D , we see that the quantum efficiency is made largest with high values of V and N_A and low values of N_D . Measurements of capacitance at finite bias voltage provide a way to determine w and therefore the donor concentration N_D .

One feature of BIB detectors which is especially important in the far-infrared is the fact that they respond at longer wavelengths than the corresponding extrinsic photoconductor, because the edge of the lower impurity band is closer in energy to the valence or conduction band than the lower hydrogenic states. A rough estimate of the threshold extension can be made by use of the calculations of impurity-band widths by Bhatt and Rice⁸; in Ge:Ga, a threshold wavelength of approximately 200 μm would be obtained with a gallium density of $1 \times 10^{16} \text{ cm}^{-3}$.

Simple detectors were fabricated by growing a high-purity intrinsic Ge epilayer (blocking layer) on a suitably-doped Ge substrate. The Ge:Ga substrate material (Eagle-Pitcher, Quapaw, OK) was made into 0.4 mm wafers with polish-etched (100) faces. The Ga density was chosen to be $3 \times 10^{16} \text{ cm}^{-3}$. The undoped Ge epilayers were grown by chemical vapor deposition (CVD) in a RF-heated, horizontal-flow reactor operating at atmospheric pressure. Ultrahigh-purity GeCl_4 was used as the Ge precursor with purified H_2 as the carrier gas. Surface defect densities (stacking faults and point defects) were typically below 100 cm^{-2} . Spreading resistance analysis (SRA) was used to determine the layer thickness; all of the devices tested here had 3.5 μm thick blocking layers. Due to the high intrinsic carrier concentration of Ge at room temperature (about $2 \times 10^{13} \text{ cm}^{-3}$), SRA is of limited use in estimating the purity of the epilayers, but all of the layers prepared had room temperature carrier concentrations consistent with the intrinsic value. Ohmic electrodes which are transparent at far-infrared wavelengths^{9,10} were created on each side of the detector wafer by boron-ion implantation, using an energy of 25 keV and a fluence of $5 \times 10^{12} \text{ cm}^{-2}$, followed by a two-step anneal (1 hour at 330 C, 12 hours at 150 C). A diamond wire saw was used to cut the wafers into individual 2 mm \times 2 mm detectors which were indium-soldered into integrated-circuit flat packs.

Five Ge:Ga BIBs were tested to evaluate detector performance and to determine the width of the A^- depletion region, the electric field distribution and the donor concentration. These detectors turned out to be very similar in all of their properties. A high-performance unstressed Ge:Ga photoconductor^{1,2} in a cylindrical integrating cavity was put through the same detector tests for the purpose of comparison. The detectors were operated in a liquid helium dewar at temperatures from 1.7 K to 4.2 K. Absolute current responsivities at $\lambda = 101.6 \mu\text{m}$ were measured by use of a system of calibrated, liquid-helium cooled 1% bandwidth filters¹¹ and the radiation from 300 K and 80 K blackbodies. A Fourier-transform spectrometer (FTS) was used to

determine the spectral response. The FTS efficiency was corrected for by dividing the observed spectra by that of a bolometer, and the corrected spectra were normalized to give the same responsivity at $\lambda = 101.6 \mu\text{m}$ as was obtained in the absolute responsivity measurements.

Figure 2 shows the current responsivity spectrum for a typical Ge:Ga BIB at $T = 1.7 \text{ K}$, compared to that of the Ge:Ga PC at $T = 4.2 \text{ K}$. A longer threshold wavelength for the BIB detector is clearly evident. The spectrum and magnitude of the current responsivity of the BIBs were constant for all chopping frequencies in the range used (3-100 Hz), and increased by a factor of approximately a factor of 50 as the detector temperature decreased from 4.2 K to 1.7 K. Peak current responsivities of $\mathcal{R} = 5 \text{ A W}^{-1}$ are obtained near 140 μm , and the threshold wavelength is approximately 190 μm . With unit photoconductive gain, we obtain a peak quantum efficiency of $\eta = h\nu\mathcal{R}/ge = 0.04$ for the Ge:Ga BIB. The responsivity spectrum is broadly consistent with that observed before on a similar Ge BIB device¹², but the responsivity of the present Ge:Ga BIBs is more than three orders of magnitude higher.

The DC current, capacitance, current responsivity at 101.6 μm and threshold wavelength as functions of bias voltage for a typical Ge:Ga BIB are shown in Figure 3. The responsivity drops off, and the DC current and noise increase dramatically, at voltages higher than about 40 mV, due to impurity impact-ionization breakdown. The device capacitance was obtained by application of a 1 mV amplitude, 4 Hz sine-wave AC bias in addition to the DC bias, and measurement of the amplitude and phase of the detector current. From the resulting complex impedance, the detector resistance and capacitance were derived, using a circuit model in which these two elements are in parallel and their combination is in series with the undepleted part of the substrate, assumed to be a resistance equal to that derived from the DC current-voltage characteristics at bias voltages above breakdown (Figure 3a). At zero DC bias, the measured capacitance agrees well with that expected for the blocking layer. As DC bias voltage increases, the capacitance decreases gradually as the A^- depletion region extends further into the substrate, and drops abruptly to zero at breakdown. The latter feature indicates the collapse of the A^- depletion region, and therefore breakdown of the blocking layer. From equations 1-3 and the measured values of capacitance at finite bias, the A^- depletion region width is calculated to

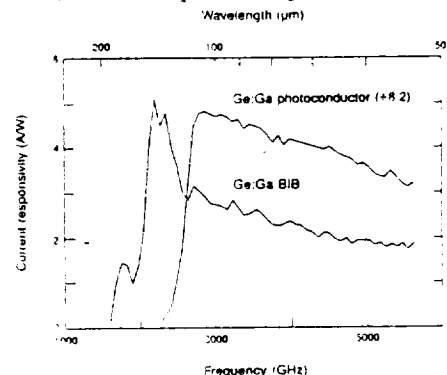


FIG. 2. Current responsivity as a function of wavelength for a typical Ge:Ga BIB (with 40 mV bias) and an unstressed Ge:Ga photoconductor in an integrating cavity (with 200 mV bias).

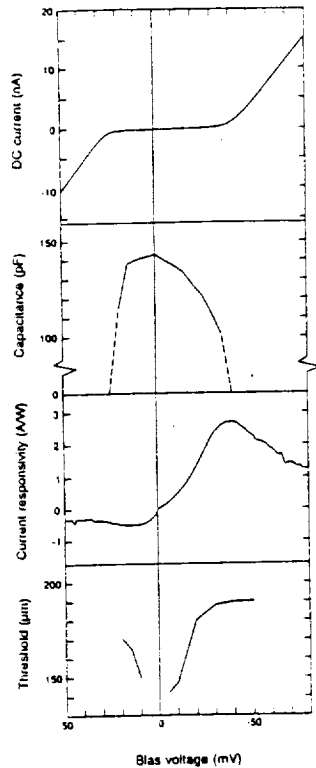


FIG. 3. DC current, capacitance, current responsivity and threshold wavelength as functions of bias voltage for a typical Ge:Ga BIB.

be $w = 3 \mu\text{m}$ for bias voltages just below breakdown (roughly consistent with the derived quantum efficiency), with a derived donor concentration of $N_D = 2.1 \pm 0.2 \times 10^{12} \text{ cm}^{-3}$. The electric field in the blocking layer just before breakdown is approximately 65 V cm^{-1} . Also shown in Figure 3 is the bias dependence of the long-wavelength threshold, which changes from $140 \mu\text{m}$ at 5 mV bias to $190 \mu\text{m}$ with the bias near breakdown.

Measurements of the signal-to-noise ratio were carried out for one Ge:Ga BIB and for the standard Ge:Ga photoconductor, using the narrow-band filters mentioned above. Here, the background is high enough to expect background photon-noise limited sensitivity, which depends upon quantum efficiency and not on photoconductive gain¹³. For the BIB, a quantum efficiency of $\eta = 2.1 \%$ was obtained in this manner, consistent with the value of $\eta = 3\%$ derived at this wavelength from the current responsivity and the assumption of unit photoconductive gain. The signal-to-noise ratio for the PC suggests background-limited performance with $\eta = 16 \%$, in good agreement with previous determinations for similar detectors^{3,11}.

It is evident that the photoresponse of our new detectors represents genuine BIB behaviour. The detector capacitance and its variation with bias voltage demonstrates the formation of a region depleted of ionized acceptors, and the extension of the threshold to longer wavelengths indicates that the states from which the photoexcited carriers arise lie in a broadened impurity band. Table 1 is a summary of the properties of the Ge:Ga BIBs and the Ge:Ga PC used for

TABLE 1. Summary of Detector Characteristics.

	Ge:Ga BIB	Unstressed Ge:Ga photoconductor
Gallium density (cm^{-3})	3×10^{16}	2×10^{14}
Donor density (cm^{-3})	2×10^{12}	$< 10^{12}$
Highest bias voltage (mV)	40	200
Threshold wavelength (μm)	192	120
Peak current responsivity (A W^{-1})	5	39
Peak quantum efficiency	4%	16%
Photoconductive gain	1	3

comparison. The peak current responsivity, and possibly the lowest background-limited sensitivity, are about the same as those of commercially-available Ge:Ga PCs and are surpassed only by the best PCs made^{1,2,3}. Finally, the threshold is extended to longer wavelengths without the necessity of mechanical stress. The prospects of achieving good performance in arrays of extrinsic Ge BIBs are therefore quite good.

Further details related to the high-purity Ge epitaxial growth and characterization, and to the long-wavelength response and ultimate sensitivity of Ge BIB detectors, will be presented in a forthcoming paper.

We are indebted to C.A. Beichman, J.R. Houck, M.D. Petroff, B.T. Soifer and M.G. Stapelbroek for many fruitful discussions, and to M.J. Wengler and J.B. Keene for their FTS software. This work was supported in part by NASA through the instrument development program for SIRTf.

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- We use the term "impurity band" loosely; at the impurity densities considered here it is likely that the impurity states are localized, although there is a continuum of states in the range of energy which comprises the band. The nature of impurity bands is discussed by N.F. Mott and E.A. Davis, *Electronic Processes in Non-Crystalline Materials* (Oxford: Clarendon Press)(1979) and by B.I. Shklovskii and A.L. Efros, *Electronic Properties of Doped Semiconductors* (Berlin: Springer-Verlag)(1984).
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- See, for example, R.H. Kingston, *Detection of Optical and Infrared Radiation* (Berlin: Springer-Verlag)(1978).